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Plant-water relationship of indica rice in Malaysia

Katsuo SUGIMOTO

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FOREWORD

The Tropical Agriculture Research Center, established in June 1970, has been publishing two periodicals in English: the Japan Agricultural Research Quarterly (JARQ) and Tropical Agriculture Research Series, in addition to several publications in Japanese. The JARQ is a publication designed to inform the oversea scientists of the latest research findings and practical experiences obtained in Japan in the field of agricultural technology, while the Tropical Agriculture Research Series is the proceedings of international symposia held annually by the Center on various topics of tropical agriculture.

The Center has now reached a stage to initiate a publication of a new series of Technical Bulletin. The Technical Bulletin will contain rather complete original scientific reports on research works done by the staff members of the Center or comprehensive reviews of the literatures on particular subjects of common interest in tropical agriculture.

On the occasion of the first publication of the Technical Bulletin, I would like to emphasize that articles to be presented in the Bulletin is not only a crystal of enthusiasm and endeavor of research workers but also a fruit of international co-operations in research between oversea scientists and the Center.

The Center sincerely hopes that the Technical Bulletin, along with other publications stated above, will contribute, even in a small measure, to the promotion of tropical agriculture research in the world.

1 March, 1971

Noboru YAMADA

Director

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Explanation of Technical Terms Used in This Paper

Water requirement (WR) in depth	:	Total evaporation from paddy field (E)+Transpiration (T)+Percolation (downward seepage (P_1)+ plot border seepage (P_2)) for a whole growth period unless otherwise indicated
Pan evaporation (Em)	:	Amount of water lost by evaporation from free water surface
Evaporation ratio	:	E/Em ratio
Transpiration ratio	:	T/Em ratio
Evapo-transpiration ratio	:	ET/Em ratio
Ground water level	:	A distance from the surface of soil to the head of ground water
Transpiration coefficient	:	A quantity of water (gram) transpired to produce one gram of plant dry matter excluding roots
Growth duration (growth period)	:	Number of days from sowing to harvest
Soil moisture ratio	:	$\frac{\text{Water contained in soil}}{\text{Dry soil weight}} \times 100$
Heading stage	:	About a half of total number of panicles emerged from sheaths of flag leaves

INTRODUCTION

In West Malaysia, there are 2.6 million ha (6 million acres) of agricultural land of which about 402,000 ha (992,000 acres) are used for wet and dry paddy cultivation[5,47] (1969, Appendix 1). The livelihood of more than 60% of the people in this country depends on agriculture. Of the agricultural products, rubber is the most important. The export of rubber occupies almost half of the total export value. On the other hand, imports of essential foodstuffs and agricultural products have constituted about one-third of the total import value.

In 1969, the rice production in West Malaysia amounted to about 1,354,000 metric tons of paddy or 881,000 ton of milled rice.[5] This amount could feed 70—80% of the population of 8 million. Accordingly, this country had to import rice from foreign countries such as Thailand and China. The yearly import of rice in recent years, has amounted to about 250,000—300,000 ton.

In order to achieve as near self-sufficiency of foods as is economically feasible and desirable, the Ministry of Agriculture and Co-operatives has adopted a policy to increase the quantity and improve the quality of essential foods.[4,46] Among these, rice has been given top priority. Since independence in 1957, double cropping of paddy has been encouraged as one of the major means to achieve self-sufficiency in rice and also to increase the farmers' income. With the provision and improvement of irrigation facilities in many of the paddy growing areas, the acreage under double-cropping of paddy is expanding rapidly.[2,5] In 1969, the areas under double cropping occupied more than 93,000 ha (230,000 acres), that was about 25% of the total wet paddy land. Its production was nearly 22% of the total including that of dry paddy.[5]

The Kedah Coastal Plain which is known as the rice bowl of Malaysia, occupies 40% of the total wet paddy land and has been left under traditional single cropping.[2,5] In order to increase paddy production, a major irrigation scheme called the Muda River Irrigation Project was started in 1966[3] (Appendixes 2 and 3). Upon completion in 1973, its aim is to supply irrigation water from two reservoirs particularly during off season (March to July) to irrigate 105,000 ha (260,000 acres) of paddy land in the Kedah Coastal Plain (Plates 1 and 2). Increase in paddy production due to double cropping in these areas will be around 400,000 ton with an average yield of 3.8 ton per ha (600 gantangs per acre).[3,5]

With this in view, the author who was assigned to work in the Kedah Coastal Plain of West Malaysia under the Tropical Agricultural Research Program of Japan for two years (April 1967 to July 1969) had carried out a series of studies and experiments on water requirement of rice at Telok Chengai Padi Experiment Station (Plate 3), Bukit Merah Padi Experiment Station, Sala Kanan Padi Test Station and in several double cropping Pilot Project areas[34] (Plate 20). This was the author's second assignment to West Malaysia to conduct experiments as he had previously worked at the Bukit Merah Padi Experiment Station in the State of Province Wellesley from March 1962 to March 1964 under the Colombo Plan[32,33] (Appendix 3).

At the Telok Chengai Padi Experiment Station in the suburbs of Alor Star, the author's work was directed towards conducting investigations on water requirement in paddy fields, measurements of transpiration coefficient for suitable double cropping varieties and in finding out the critical stages of plants for water deficiency.

Emphasis was also placed on the following lines of investigations:— (a) to study the relation between different depths of water and fertilizer application methods, (b) to evaluate the farm practice of mid-season drainage on growth and yield of rice.

Acknowledgement

The author wishes to express his deep feeling of gratitude and sincere appreciation to Tan Sri Mohamad bin Jamil (Director of Agriculture, West Malaysia), Messrs. Chew Hong Jung (Deputy Director of Agriculture), Van Thean Kee (Assistant Director of Research), Mohamad Tamin bin Yeop (State Agricultural Officer, Kedah), Chee Sek Pan (Head, Rice Research Unit), Goh Khek Boon (Former Agronomist, Kedah) and Samy Selvaraj Joseph (Agronomist, Kedah). Thanks are due to the staff of Telok Chengai Padi Experiment Station and Department of Agriculture in Kuala Lumpur and Alor Star respectively for their generous support and assistance to make his work possible.

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Thanks are especially due to Dr. N. Yamada for his valuable suggestions in framing and preparation of this paper and for his critical discussion with the author.

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I. WATER REQUIREMENT

(1) Evapo-transpiration and Evapo-transpiration Ratio in Paddy Field

To estimate the amount of water required for paddy cultivation, in the designing of any irrigation project, it is necessary to know the water requirement of rice under field condition and factors affecting it.

The purpose of this investigation is to determine the consumption of water in the paddy field by evaporation, transpiration and percolation as compared with pan evaporation.

1. Methods and Materials

Apparatus:

A paddy field of 0.01—0.07 ha was used as an experiment plot.

Enamelled iron tank,[23, 38] 91 cm×91 cm and 61 cm high, was installed in an experimental plot 2.7 meters apart from the border for measurements of evapo-transpiration. This enamelled tank (ET tank) and the plot were planted with seedlings at a spacing of 30 cm×30 cm and at a rate of 3 seedlings per hill (Plates 7 and 9).

The enamelled iron evaporation tank[38] (E tank) was made up of two compartments which were connected by a 5 cm diameter pipe. The size of each compartment was 30 cm×137 cm and the height was 30 cm (Plate 8). This enamelled tank was settled on the surface of the soil 91 cm apart from the ET tank for the purpose of taking measurement of evaporation from the water surface of paddy field. Rice plants were planted closely around the E tank.

The loss of water in depth in two kinds of tank was measured every morning around 8.00 a.m. and the water requirement in depth in the plot was also measured with the use of a scale (mm unit). However during non-working days the measurement was carried out at every two or three day intervals. When there was an excess or shortage of water in both tanks and plot, water was drained out or irrigated after measurements in order to grow rice plants at optimum conditions (Fig. 1).

Readings obtained at days with heavy rainfall were omitted from ten-day period summation because heavy rain caused overflow both in the plot and tanks.

It was unable to measure the amount of water used for puddling operation because the experimental plot was placed in a rain-fed paddy field.

A 137 cm long vinyl pipe with a diameter of 5 cm was also installed into a vertical hole made on the levee of the plot for measurement of ground water level.[23] The measurement was carried out continuously every Tuesday morning throughout the year.

Meteorological observation of rainfall and pan evaporation (Em) was carried out throughout the year. For the measurement of evaporation, a round pan, 20 cm in diameter and 10 cm in height, was used at the station near the paddy field.

Variety used: Ria[12] (IR 8, growth duration 125 days) and Radin Ebos 33[34] (growth duration 170 days) for main season, 1967/68. Bahagia[12] (Sister line of IR 5, growth duration 140 days) for off season, 1968. Bahagia (growth duration 130 days) and R. Ebos 33 (growth duration 200 days) for main season, 1968/69 (Plates 10 and 11).

Investigation site: Telok Chengai Padi Experiment Station (for three seasons) and Sala Kanan Padi Test Station (for main season 1967/68 and only Ria was used).

Soil used: Parent material is recent slightly brackish alluvium. Soil series was named Talok Chengai and Kundor by McWalter respectively. Paddy field soils of both stations are low humic gley.[11, 20]

Transplanting:

Variety	Season	Period of nursery	Date of planting
R. E. 33	Main season, 1967/68	31 day	29/8/1967
Ria	〃 , 〃	25	20/9/1967
Ria (at Sala Kanan)	〃 , 〃	27	10/9/1967
Behagia	Off season, 1968	23	14/5/1968
Behagia	Main season, 1968/69	22	14/8/1968
R. E. 33	〃 , 〃	30	1/7/1968

Basal dressing:

N (Ammonium sulphate or Urea) 34 kg, P_2O_5 (Christmas Islands rock phosphate) 67 kg and K_2O (Potasium chloride) 34 kg per ha were applied for main season, 1967/68 and off season, 1968.

N (Urea) 17 kg, P_2O_5 (Christmas Islands rock phosphate) 67 kg and K_2O (Potasium chloride) 34 kg per ha were applied for main season, 1968/69.

Top - dressing:

N (Urea or Ammonium sulphate) 17—34 kg per ha was applied about 20 days before heading.

2. Results and Discussion

It is natural that transpiration and evaporation values fluctuate due to change of weather conditions, such as velocity of wind, air humidity, insolation amount, air temperature and staturation deficit.[8, 10, 25, 35, 39, 41] In order to eliminate such fluctuation caused by weather conditions, the ratios of evaporation (E), transpiration (T) and evapo-transpiration (ET) to the pan evaporation (Em), i.e. E/Em, T/Em and ET/Em, are generally used.

In this study, evaporation ratio, transpiration ratio and evapo-transpiration ratio per ten-day period were calculated throughout the growth period. These ratios are used mainly for discussion in this report.

1) Plant growth

The maximum tiller number was attained at about 40 to 50 days after transplanting. However, this stage appeared slightly earlier and more distinct in Ria and Bahagia than in R. Ebos 33 (Fig. 2 and 3).

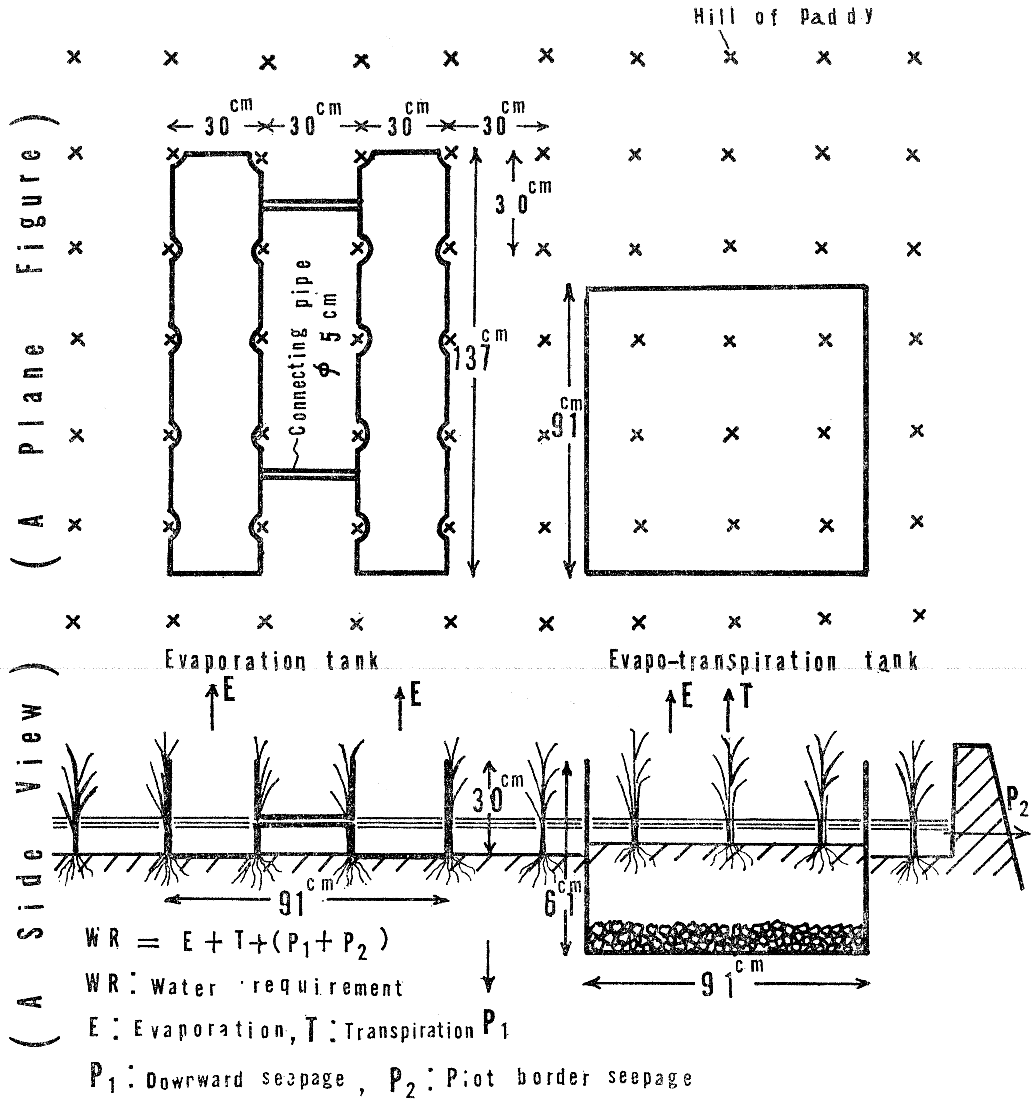


Fig. 1. Apparatus for measurement of water requirement in the field.

The trend of increase in dry weight became more evident at about 50—60 days before heading whereas in Ria, a short term variety, the trend commenced only 30 days before heading. Observations revealed that after heading, an increase of total dry matter still continued steadily except for R. Ebos 33 (Fig. 2 and 3).

2) Evaporation, transpiration and evapo-transpiration

The results obtained for each variety during the different seasons are shown in Tables 1 to 6 and Fig. 4 to 11.

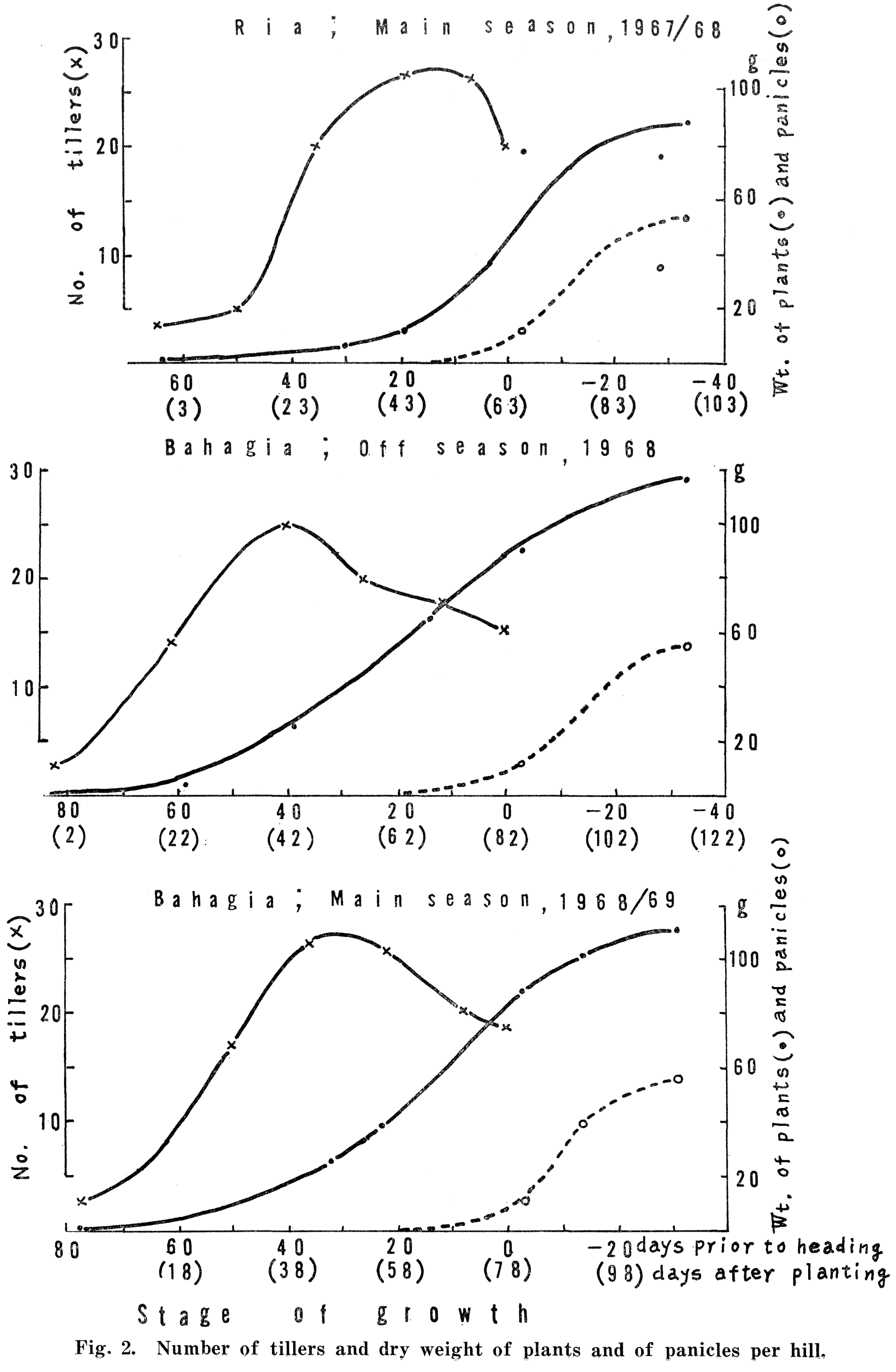


Fig. 2. Number of tillers and dry weight of plants and of panicles per hill.

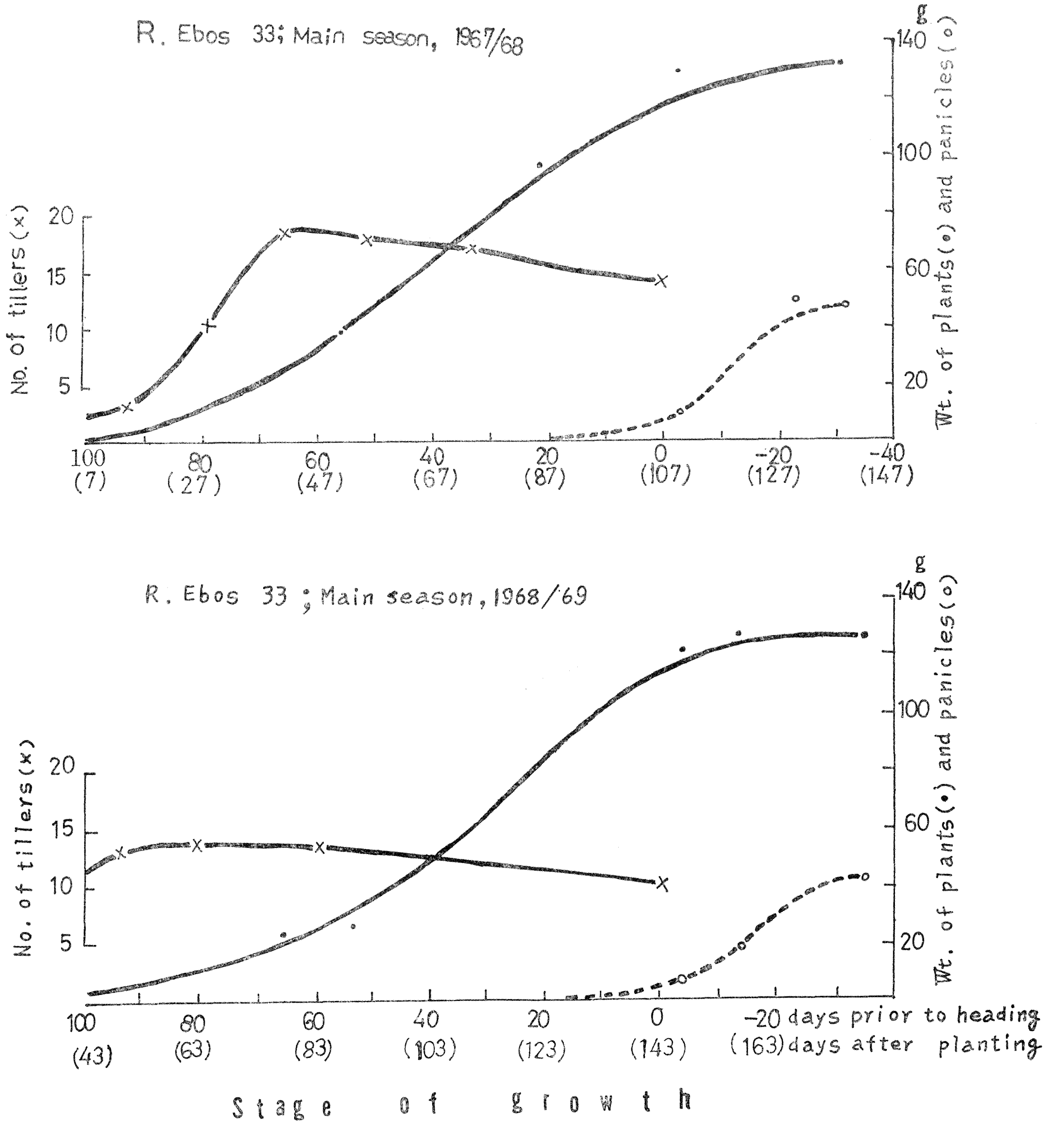


Fig. 3. Number of tillers and dry weight of plants and of panicles per hill.

The evaporation and evaporation ratio were greater during the early stage of growth but showed a gradual decrease with the growth of plants. The decrease in evaporation was largely due to the mutual shading of the plants caused by an increased leaf area, plant height and dry matter[8,10,25,34] (Fig. 2 and 3). There is a negative correlation ($r=-0.50^*$) between leaf area index and evaporation ratio (Fig. 8).

The value of evaporation ratio was 0.8—0.9 during the early stage of growth, 0.4—0.6 during the heading stage and 0.2—0.3 during the ripening stage. The average for a whole growth period was 0.63 (Fig. 4 to 7, 10 and 11).

Contrary to the evaporation ratio, the transpiration ratio and evapo-transpiration ratio

Table 1. Water requirement for Ria during the main season, 1967/68.

Date	Days before heading	Em Pan evapo-ration	ET Evapo-trans-pira-tion	ET/Em	E Evapo-ration	E/Em	T Trans-pira-tion	T/Em	WR Water require-ment	Ground water level	Rain-fall
		cm	cm	%	cm	%	cm	%	cm	cm	cm
20*/9–29	63– 54	5.09	5.08	100	4.41	87	0.67	13	6.47	−6.1	1.96
30– 9/10	53– 44	3.67	4.22	115	3.13	85	1.09	30	5.16	−3.6	18.75
10–19	43– 34	4.86	5.39	111	3.41	70	1.98	41	5.35	−0.8	1.60
20–29	33– 24	4.45	5.62	126	3.00	67	2.62	59	4.94	4.3	16.00
30– 8/11	23– 14	4.15	5.75	139	2.50	60	3.25	79	4.68	4.1	7.42
9–18	13– 4	4.49	4.68	104	2.25	50	2.43	54	5.22	11.7	10.62
19–28	3– − 6	3.81	5.16	135	2.44	64	2.72	71	5.51	14.0	2.08
29– 8/12	− 7– −16	4.26	6.19	145	2.23	52	3.96	93	6.40	17.0	4.88
9–18	−17– −26	4.89	6.70	137	1.86	38	4.84	99	8.40	23.9	0
19–25**	−27– −33	3.93	3.93	100	1.33	34	2.60	66	6.64	43.4	0.03
Total		43.60	52.72		26.56		26.16		58.77		63.34
Average/day		0.45 (0.18″)	0.54 (0.21″)	121	0.27 (0.11″)	61	0.27 (0.11″)	60	0.61 (0.24″)		0.65 (0.26″)

* 25 days after sowing.
** 121 days after sowing or 96 days after transplanting.

Table 2. Water requirement for Ria during the main season, 1967/68 at Sala Kanan P. T. Station.

Date	Days before heading	Em	ET	ET/Em	E	E/Em	T	T/Em	WR	Ground water level	Rain-fall
		cm	cm	%	cm	%	cm	%	cm	cm	cm
10*/9–19	63– 54	4.91	5.48	112	5.27	107	0.21	4	5.91	0.8	12.04
20–29	53– 44	5.02	5.80	116	4.61	92	1.19	24	5.83	−2.3	1.19
30– 9/10	43– 34	4.25	5.39	127	3.70	87	1.69	40	5.42	3.0	22.40
10–19	33– 24	4.17	6.30	151	3.20	77	3.10	74	6.51	10.7	2.29
20–29	23– 14	4.06	5.94	146	3.30	81	2.64	65	6.28	17.3	8.51
30– 8/11	13– 4	4.41	6.52	148	3.25	82	3.27	74	6.46	23.1	5.94
9–18	3– − 6	3.93	5.03	128	2.41	61	2.62	67	6.44	31.2	6.45
19–28	− 7– −16	3.76	6.33	168	2.50	66	3.83	102	5.66	38.4	4.14
29– 8/12	−17– −26	4.20	6.13	146	1.70	40	4.43	105	6.12	40.1	3.48
9–13**	−27– −31	2.55	3.18	125	1.05	41	2.13	84	3.18	50.3	0
Total		41.26	56.10		30.99		25.11		57.81		66.00
Average/day		0.43 (0.17″)	0.59 (0.23″)	136	0.33 (0.13″)	75	0.26 (0.10″)	61	0.61 (0.24″)		0.69 (0.27″)

* 27 days after sowing.
** 121 days after sowing or 94 days after transplanting.

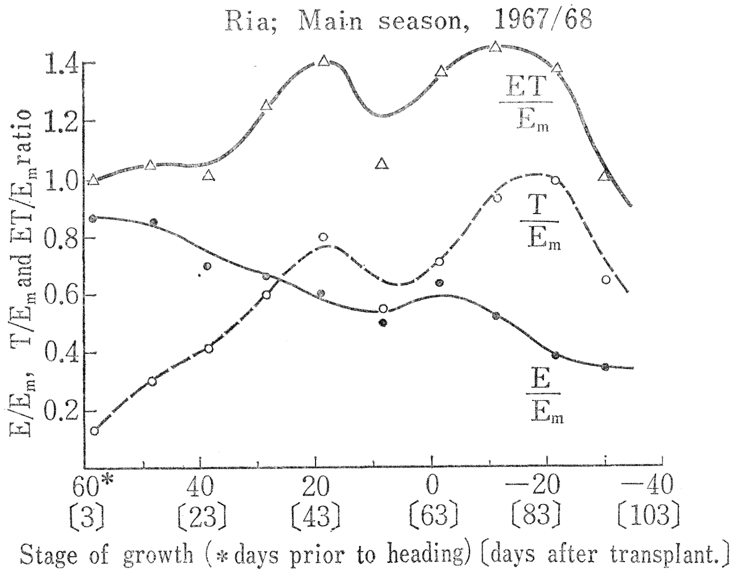
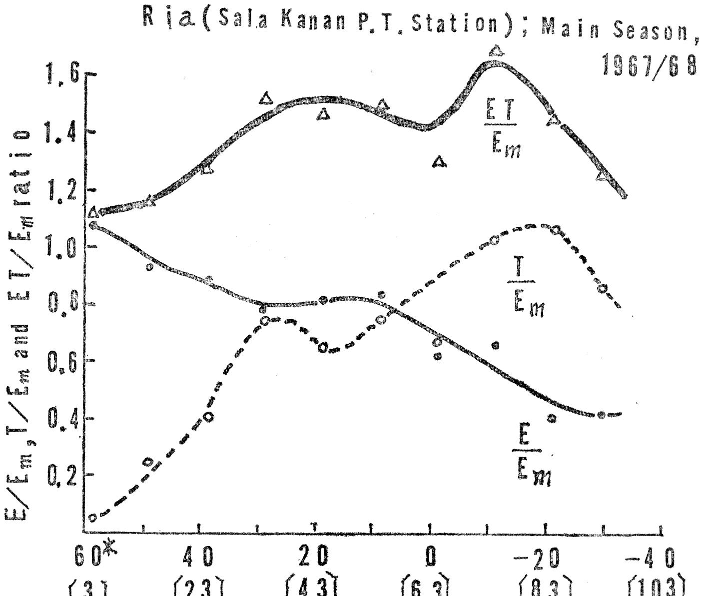


Fig. 4. Evaporation ratio, transpiration ratio and evapo-transpiration ratio at different stages of growth.



Stage of growth (*days prior to heading) [days after transplant.]

Fig. 5. Evaporation ratio, transpiration ratio and evapo-transpiration ratio at different stages of growth.

Table 3. Water requirement for Bahagia during the off season, 1968.

Date	Days before heading	Em	ET	ET/Em	E	E/Em	T	T/Em	WR	Ground water level	Rain-fall
		cm	cm	%	cm	%	cm	%	cm	cm	cm
14*/5-23	82- 73	5.56	5.93	107	4.90	88	1.03	19	5.72	− 1.0	18.14
24- 2/ 6	72- 63	6.33	5.56	88	4.34	69	1.22	19	3.43	− 3.3	17.73
3-12	62- 53	5.08	6.18	122	3.41	67	2.77	55	4.87	9.4	0.61
13-22	52- 43	5.91	7.36	125	4.41	75	2.95	50	7.23	14.7	10.19
23- 2/ 7	42- 33	5.08	6.61	130	2.98	59	3.63	71	6.73	− 1.3	8.15
3-12	32- 23	5.49	5.80	106	2.57	47	3.23	59	7.13	− 9.7	7.92
13-22	22- 13	4.69	6.26	133	3.10	66	3.16	67	6.37	−15.7	25.35
23- 1/ 8	12- 3	5.46	6.84	125	2.72	50	4.12	75	7.17	− 7.9	2.44
2-11	2- − 7	4.78	6.78	135	2.36	49	4.42	92	6.80	− 7.4	4.37
12-21	− 8- −17	6.40	8.07	126	2.64	41	5.43	85	8.36	− 8.1	5.31
22-31	−18- −27	5.31	5.85	110	2.10	40	3.75	71	5.00	− 7.4	9.25
1/9-6**	−28- −33	2.63	2.42	92	0.89	34	1.53	58	2.94	−15.0	2.77
Total		62.72	73.66		36.42		37.24		71.75		112.23
Average/day		0.54 (0.21″)	0.64 (0.25″)	117	0.31 (0.12″)	58	0.32 (0.13″)	59	0.62 (0.24″)		0.97 (0.38″)

* 23 days after sowing.
** 138 days after sowing or 115 days after transplanting.

Table 4. Water requirement for Bahagia during the main season, 1968/69.

Date	Days before heading	Em	ET	ET/Em	E	E/Em	T	T/Em	WR	Ground water level	Rain-fall
		cm	cm	%	cm	%	cm	%	cm	cm	cm
14*/8-23	78- 69	6.30	6.00	100	4.57	73	1.43	23	6.03	−4.3	2.39
24-2/ 9	68- 59	4.95	5.05	102	3.39	68	1.66	34	5.85	−5.3	11.86
3-12	58- 49	4.51	4.86	108	3.48	77	1.38	31	6.00	−7.6	8.08
13-22	48- 39	4.51	6.00	133	3.06	68	2.94	65	5.31	−6.6	5.92
23- 2/10	38- 29	4.38	5.61	128	3.20	73	2.41	55	5.93	−5.6	11.73
3-12	28- 19	5.06	7.10	140	3.60	71	3.50	69	6.00	−6.9	8.00
13-22	18- 9	4.33	6.53	151	3.50	81	3.03	70	7.30	−6.9	10.59
23- 1/11	8- − 1	4.15	5.81	140	2.53	61	3.28	79	8.22	−6.1	8.74
2-11	− 2- −11	5.52	6.31	114	2.33	42	3.98	72	7.16	−2.8	5.13
12-21	−12- −21	5.10	6.52	128	2.30	50	4.22	83	7.23	−1.0	3.76
22- 1/12**	−22- −31	5.04	5.06	100	1.67	33	3.39	67	5.50	6.1	0
Total		53.85	64.85		33.63		31.22		70.53		76.20
Average/day		0.49 (0.19″)	0.59 (0.23″)	120	0.31 (0.12″)	62	0.28 (0.11″)	58	0.64 (0.25″)		0.69 (0.27″)

* 22 days after sowing.
** 131 days after sowing or 109 days after transplanting.

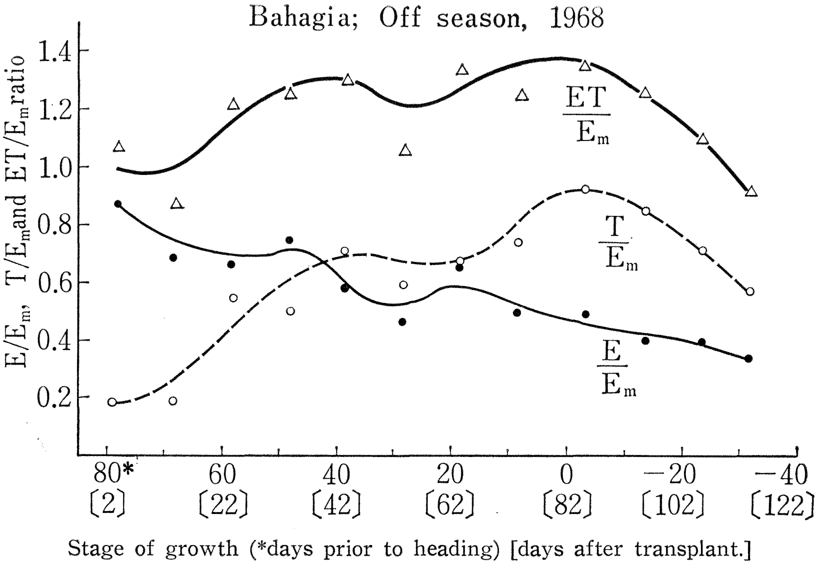


Fig. 6. Evaporation ratio, transpiration ratio and evapo-transpiration ratio at different stages of growth.

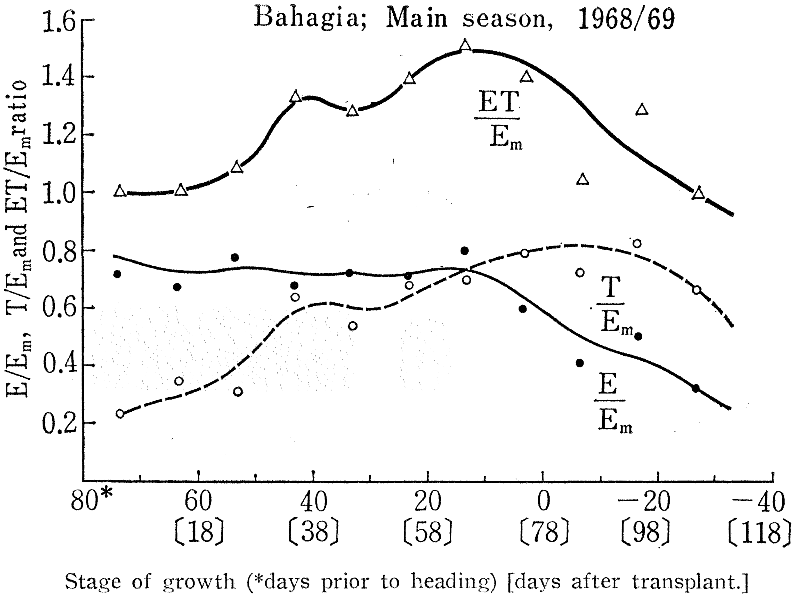


Fig. 7. Evaporation ratio, transpiration ratio and evapo-transpiration ratio at different stages of growth.

were small during the early stage of growth but they became greater gradually. In both, the peak was reached around the stage of maximum tiller number and the heading stage. There was however a slight decrease in the value between the two stages. The former peak was lower than the latter one.[10, 26, 40] There was a sharp decrease in value during the ripening stage due to the dying of leaves.

The increase in transpiration was caused by an increase in plant size, particularly by an increasing leaf area up to a certain extent of leaf area index (Fig. 8). Thus, when the

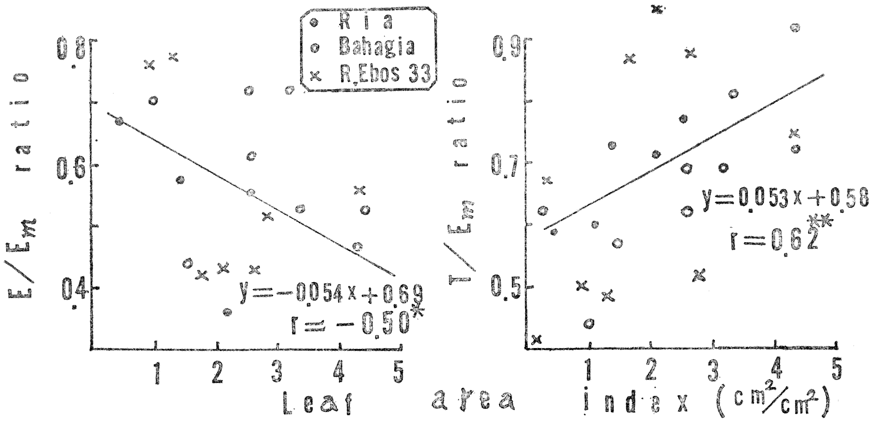


Fig. 8. Relationship of evaporation ratio and transpiration ratio to LAI.

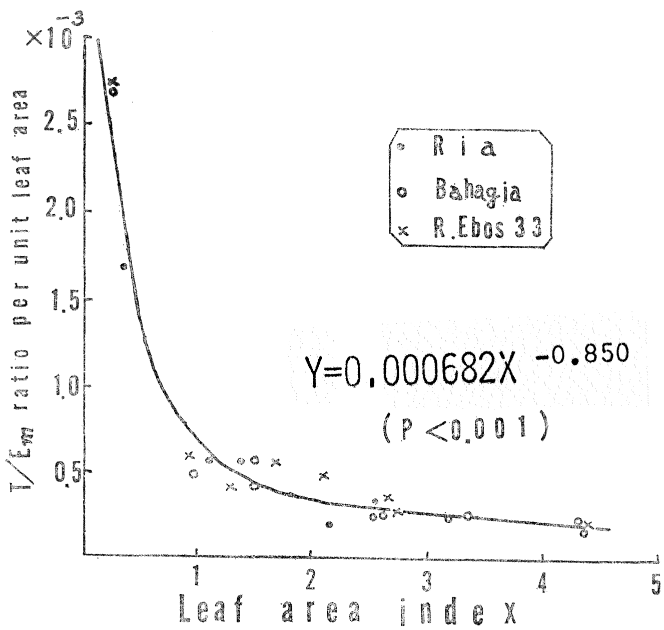


Fig. 9. Relationship between transpiration ratio per unit leaf area (mm/mm·cm²) and LAI.

LAI was small, the transpiration was parallel to the plant growth, although transpiration ratio per unit leaf area was decreased with the increase of leaf area.[10,25,35] A negative logarithmic correlation was found between transpiration ratio per unit leaf area and leaf area index (Fig. 9).

When the leaf area index became larger than 3.5, the transpiration ratio per unit leaf area became almost constant. The LAI at which such condition begins to occur in this study was found to be lower than that reported so far with japonica rice plants in Japan.[10,25]

The value of transpiration ratio was 0.2—0.4 during the early stage of growth, 0.6—0.7 during the maximum tiller number stage and 0.8—0.9 just after the heading stage, with an average of 0.68 throughout a growth duration. The value of evapo-transpiration ratio was 1.0—1.2 during the early stage of growth, 1.2—1.3 during the maximum tiller number stage and 1.4 around the heading stage with an average of 1.2 throughout a growth duration.

The average of total evapo-transpiration was 54 cm (21.4 inches) with Ria, 69 cm (27.2 inches) with Bahagia and 88 cm (33.3 inches) with R. Ebos 33. The total amounts of evaporation, transpiration and evapo-transpiration were correlated mainly with growth duration and weather conditions (Fig. 12). The total amount of evaporation was almost equal to that of transpiration,[13,17,35,40] and the consumption of water per day which was the total of the two did not vary among the 3 varieties (Tables 1 to 6).

Consumption of water, i.e. evapo-transpiration as measured each ten-day period was

Table 5. Water requirement for Radin Ebos 33 during the main season, 1967/68.

Date	Days before heading	Em	ET	ET/Em	E	E/Em	T	T/Em	WR	Ground water level	Rain-fall
		cm	cm	%	cm	%	cm	%	cm	cm	cm
29*/8-30	107- 106	0.80	0.70	88	0.70	88	0	0	1.00		0
31- 9/ 9	105- 96	5.16	5.16	100	4.31	84	0.85	16	5.67	−11.4	12.83
10-19	95- 86	4.63	4.75	103	4.08	88	0.67	14	7.20	− 8.6	19.56
20-29	85- 76	5.09	5.11	100	3.50	69	1.61	32	6.70	− 6.1	1.96
30- 9/10	75- 66	3.67	4.84	132	2.56	70	2.28	62	4.78	− 3.6	18.69
10-19	65- 56	4.86	5.58	115	2.53	52	3.05	63	6.33	− 0.8	1.60
20-29	55- 46	4.45	5.09	114	2.02	45	3.07	69	3.28	4.3	16.00
30- 8/11	45- 36	4.15	5.06	122	1.60	39	3.46	83	4.25	4.1	7.42
9-18	35- 26	4.49	4.98	111	1.92	43	3.06	68	4.65	11.7	10.62
19-28	25- 16	3.81	4.32	113	2.28	60	2.04	54	5.36	14.0	2.08
29- 8/12	15- 6	4.26	5.64	132	2.78	65	2.86	67	5.67	17.0	4.88
9-18	5- − 4	4.89	6.00	123	1.50	31	4.50	92	10.09	23.9	0
19-28	− 5- −14	5.74	7.27	127	2.38	41	4.89	85	11.00	43.4	0.03
29- 7/ 1	−15- −24	6.05	5.69	94	1.42	23	4.27	71	11.29	54.6	0
8-14**	−25- −31	5.04	3.22	63	1.12	22	2.10	41	8.68	67.3	0
Total		67.09	73.41		34.70		38.71		93.53		95.67
Average/day		0.48 (0.19″)	0.53 (0.21″)	109	0.25 (0.10″)	52	0.28 (0.11″)	58	0.67 (0.26″)		0.69 (0.27″)

* 31 days after sowing.

** 169 days after sowing or 138 days after transplanting.

Table 6. Water requirement for Radin Ebos 33 during the main season, 1968/69.

Date	Days before heading	Em	ET	ET/Em	E	E/Em	T	T/Em	WR	Ground water level	Rain-fall
		cm	cm	%	cm	%	cm	%	cm	cm	cm
11*/7-20	143- 134	4.88	4.67	96	4.41	90	0.26	5	5.23	− 6.4	29.64
21-30	133- 124	5.86	6.15	105	4.97	85	1.18	20	6.34	− 5.8	4.09
31- 9/ 8	123- 114	5.35	5.29	99	4.24	79	1.05	20	5.85	− 5.3	4.37
10-19	113- 104	6.53	6.48	99	5.85	90	0.63	10	7.81	− 5.1	5.31
20-29	103- 94	5.23	5.82	111	3.87	74	1.95	37	7.19	− 3.0	4.52
30- 8/ 9	93- 84	4.53	5.23	115	3.04	67	2.19	48	5.51	− 8.9	9.14
9-18	83- 74	4.15	5.70	137	3.65	88	2.05	49	5.99	− 6.6	11.99
19-28	73- 64	4.54	5.71	126	3.36	74	2.35	52	5.86	− 3.3	10.49
29- 8/10	63- 54	4.45	5.31	119	3.36	76	1.95	44	6.84	− 7.9	6.25
9-18	53- 44	4.76	5.70	120	3.88	82	1.82	38	6.31	− 6.9	7.72
19-28	43- 34	3.60	5.25	139	3.00	83	2.25	63	6.83	− 6.9	14.61
29- 7/11	33- 24	4.91	7.19	146	3.46	70	3.73	76	8.10	− 4.3	5.83
8-17	23- 14	5.07	6.91	136	1.97	39	4.94	97	7.69	1.5	3.76
18-27	13- 4	5.40	6.50	120	1.53	28	4.97	92	7.10	3.3	0
28- 7/12	3- − 6	4.63	6.22	134	1.90	47	4.32	93	7.29	17.3	1.63
8-17	− 7- −16	4.11	5.53	135	1.91	46	3.62	88	7.21	15.5	2.41
18-27	−17- −26	4.78	5.04	105	1.83	38	3.21	67	9.50	11.9	0.58
28-5**/1	−27- −35	3.56	3.52	99	1.21	34	2.31	65	5.93	52.8	5.18
Total		86.34	102.22		57.44		44.78		122.58		127.03
Average/day		0.48 (0.19″)	0.57 (0.22″)	118	0.32 (0.13″)	67	0.25 (0.10″)	52	0.68 (0.27″)		0.71 (0.28″)

* 30 days after sowing.
** 208 days after sowing or 178 days after transplanting.

within the range of 4.2—6.7 mm/day for Ria, 5.6—7.1 mm/day for Bahagia and 4.3—7.3 mm/day for R. Ebos 33.

3) Transpiration coefficient of rice varieties

The growth and yield of rice plants and transpiration coefficient are shown in Table 7. Assuming the moisture percentage of the air-dried harvested plant to be 14,[22, 34)] the transpiration coefficient of a given variety, for example Ria at the main season 1967/68, can be calculated as follows:—

$$\frac{\text{Total transpiration in depth} \times \text{area per hill}}{\text{Harvested air-dried plant} \times \text{its dry matter percentage}} = \frac{26.16\ \text{cm} \times 929\ \text{cm}^2}{89.29\ \text{g} \times 0.86} = 316$$

A positive correlation was found between the transpiration coefficient and growth duration[18, 22, 34, 35)] (Fig. 12).

However, among the total evaporation, transpiration, evapo-transpiration and transpiration coefficient, total evapo-transpiration was highly correlated to the growth duration.

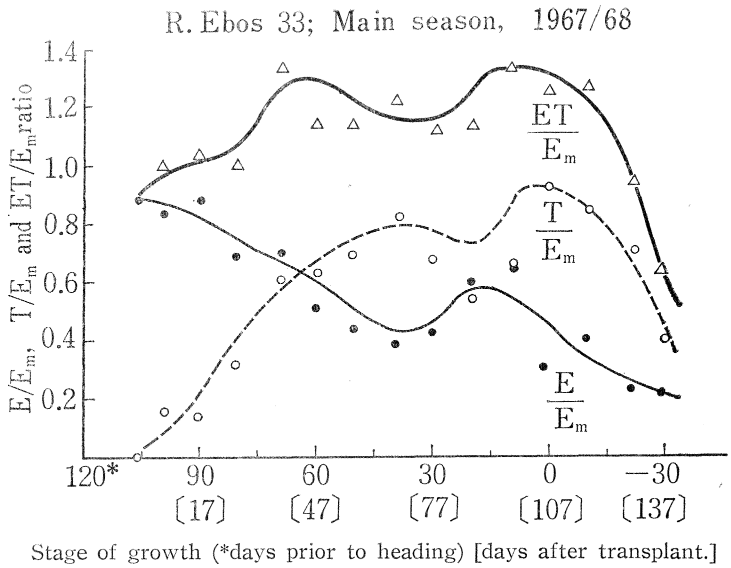


Fig. 10. Evaporation ratio, transpiration ratio and evapo-transpiration ratio at different stages of growth.

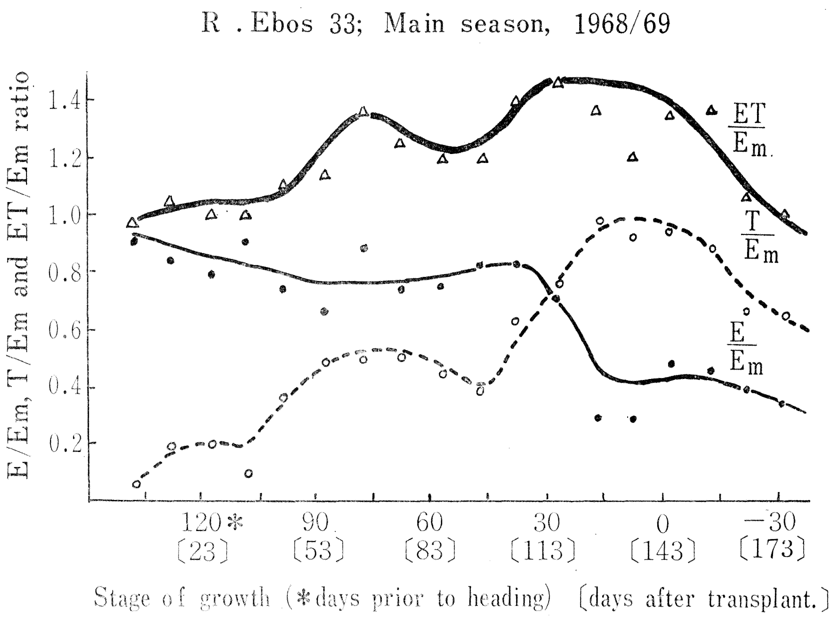


Fig. 11. Evaporation ratio, transpiration ratio and evapo-transpiration ratio at different stages of growth.

Table 7. Growth and yield of rice plants (per hill) in relation to transpiration coefficient (Telock Chengai P. E. Staion).

Variety	Season	Max. tiller no.	Culm ht.	No. of panicles	Wt. of total air-dried plant	Wt. of straw	Wt. of panicle	% of ripened grains	Grain yield per hill	Grain yield per ac.	Grain yield per ha	Transpiration coeffi.
			cm		g	g	g	%	g	lb	t	
Ria	Main season 1967/68	26.4	70	20.0	89.29	38.4	53.7	76	45.56	4,375	4.9	316
Ria*	Main season 〃	24.6	76	20.4	103.54	52.0	52.3	68	44.25	4,249	4.8	262
Bahagia	Off/season 1968	24.8	108	15.5	116.90	64.4	55.9	73	46.70	4,485	5.0	344
Bahagia	Main season 1968/69	26.5	108	18.8	110.22	54.7	55.5	78	49.90	4,792	5.4	306
R.E. 33	Main season 1967/68	18.3	149	13.8	130.12	87.4	45.6	70	37.61	3,612	4.1	321
R.E. 33	Main season 1968/69	13.9	155	10.1	125.46	85.6	42.7	70	35.00	3,361	3.8	386

* Sala Kanan Padi Test Station.

4) Relationship between weather conditions and evapo-transpiration

As seen in Table 8, the amount of pan evaporation was correlated with sunshine hour, relative humidity and mean air temperature, and also with field evaporation, transpiration and evapo-transpiration respectively.

In general sunshine hour and relative humidity were more closely correlated with evaporation, transpiration and evapo-transpiration than that mean air temperature was.[10, 34] However, an increase in transpiration and evapo-transpiration per day observed during the off season was due to a rise of air temperature and low relative humidity[22, 26, 34] (Appendixes 4 and 5).

Evaporation during the early stage of growth and transpiration during the middle and late stages of growth were fairly correlated to the weather conditions with the respective varieties, suggesting that weather conditions influenced more on the evaporation than on the transpiration before the stage of maximum tiller number and after that stage they influenced on the transpiration rather than on the evaporation.[10, 34]

5) Water requirement in depth and percolation

Percolation consists of two factors—downward seepage and plot border seepage.[23] However, as the percolation was calculated indirectly from water requirement in depth and evapo-transpiration, these two factors were not separated in this study.

Moreover, both the fields in Telok Chengai and Sala Kanan, used for study, were located in the coastal area of the Kedah Plain, with almost negligible percolation (Appendix 3). Therefore most of the water requirement in depth indicates a consumption by evapo-transpiration (Tables 1 to 6). The average water requirement in depth per day was 6.1—6.2 mm for Ria, 6.2—6.4 mm for Bahagia and 6.7—6.8 mm for R. Ebos 33.

The average figures of percolation were 0.5—1.4 mm/day for main season in Telok Chengai, −0.2 mm/day for off season in Telok Chengai and 0.2 mm/day for main season in Sala Kanan. These figures were somewhat related to the fluctuation of ground water

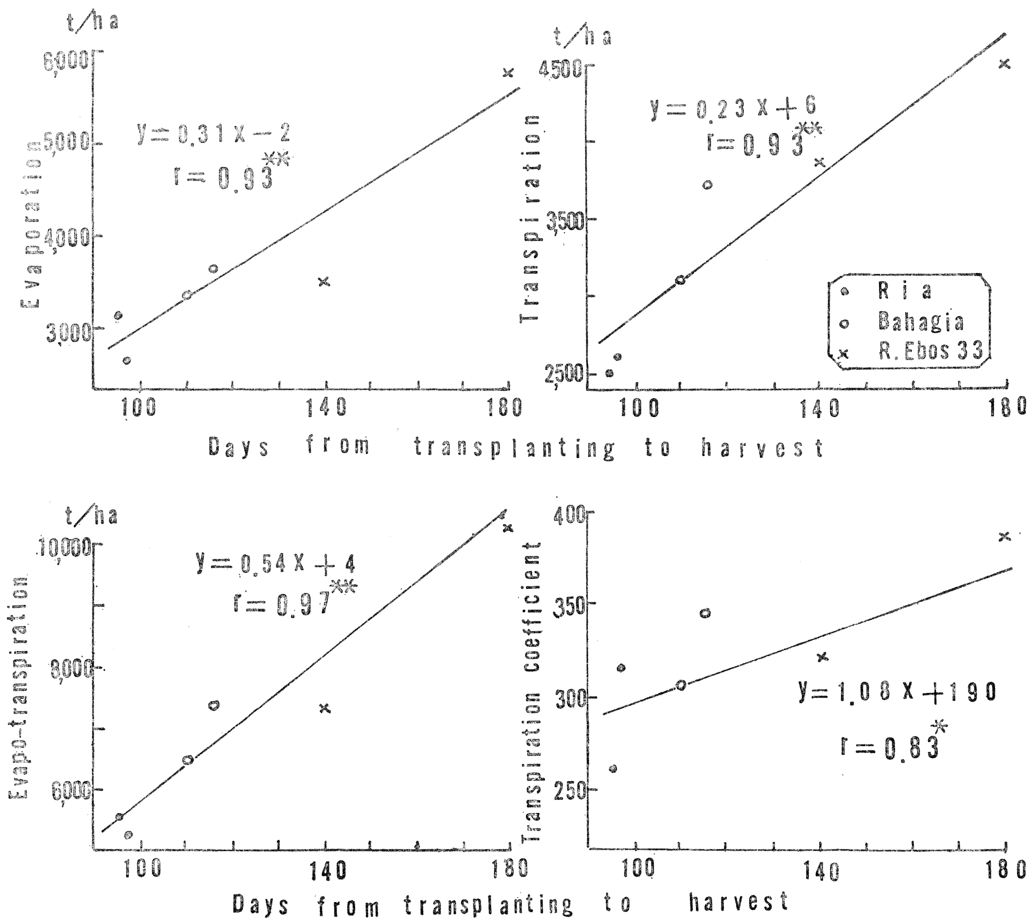


Fig. 12. Relationship of evapo-transpiration and transpiration coefficient to growth duration.

level[24,34] and the surrounding condition of the paddy fields under test. It was therefore presumed that the horizontal seepage tended to exceed the vertical seepage.

Generally, the seepage shows such a wide variation as 0—100 mm/day depending on the topography, soil, irrigation system, method of cultivation and other conditions.[23,44] It can be said, therefore, that the seepage is a main variable factor which determines the amount of total water consumption in paddy fields.

However, in case of small percolation below 10 mm/day, the evapo-transpiration becomes a dominant factor which determines water requirement in depth.[23,34] The peak of water requirement was found at the maximum tiller number stage (about 50 days after transplanting) or heading stage.

6) Ground water level and puddling water

The fields with constantly high ground water level except during the dry period from January to March,[34] such as heavy alluvial and peat soil fields in the lower stream of the Kedah Plain where water wells up at times, might have little seepage[24] (Tables 1 to 6 and

Table 8. **Correlation coefficient of weather conditions to pan evaporation and to evapo-transpiration.**

Variety Season	Item	Pan evapo-ration	Evapo-trans-piration	Evapora-tion early stage[1] of growth	Transpira-tion middle and late stages of growth
Ria	Sunshine hour	0.79*	0.72*	0.84	0.85*
	Relative humidity	−0.70*	−0.58	−0.87	−0.68
Main season 1967/68	Air temperature	0.56	0.52	0.57	−0.85**
	Pan evaporation		0.57	0.69	0.63
	Sunshine hour	0.63	0.63	0.67	0.86**
Bahagia	Relative humidity	−0.64*	−0.25	−0.56	−0.40
	Air temperature	0.86**	0.22	0.32	0.39
Off season 1968	Pan evaporation		0.59	0.70	0.66
	Sunshine hour	0.93***	0.76*	0.93*	0.90**
	Relative humidity	−0.64	−0.71	−0.76	−0.93**
Main season 1968/69	Air temperature	0.82**	0.25	0.72	0.72
	Pan evaporation		0.34	0.95	0.77
R. Ebos 33	Sunshine hour	0.72**	0.50	0.96*	0.79*
	Relative humidity	−0.90***	−0.75**	−0.73	−0.92**
Main season 1967/68	Air temperature	0.69*	0.01	0.96*	0.52
	Pan evaporation		0.74*	0.76	0.84
	Sunshine hour	0.63*	0.62*	0.85	0.85
Main season 1968/69	Relative humidity	−0.51	−0.65*	−0.71	−0.90***
	Air temperature	0,75**	0.77**	0.92*	0.56
	Pan evaporation		0.56*	0.90*	0.64

1) Duration from transplanting to the stage of maximum tiller number.
The data were calculated each other in respect of each ten day average.

Appendixes 3 to 5). But during the initial stage of off season, the ground water level is extremely low.[24] Thus it is necessary to supply huge amounts of water for filling the cracks of the soil profile and to raise the ground water level (Plate 12). It is said that a main aim of the Muda and Pedu Dams is to provide an enough water during the initial stage of off season from March to April[3,4] (Plate 1). Because the field used for the study was rain-fed, it was not possible to measure the amount of puddling water. Further investigation is needed to determine the puddling water in several parts of the Kedah Plain.[6,19,26,43]

According to Murakami,[22] 170 mm of water in depth is required for puddling and levelling and to maintain field at saturated moisture condition for a period of 2 days in Ceylon. Matsushima[19] estimated 178 mm of water in depth for puddling. His data ranged from 107 mm in case of 45% of soil moisture ratio and 20 cm of ground water level, to 263 mm in case of 24% of soil moisture ratio and 65 cm of ground water level in the field of Tanjong Karang Research Station. Van de Goor and Zijlstra made a recommendation on water requirement for irrigating double cropping rice in Malaya in 1963.[2,6,43] They pointed out that a greater amount of presaturation water is needed in off season than in main season; 381 mm (15 inches)/month (12.7 mm/day) for off season and 330 mm (13 inches)/month (11.0 mm/day) for main season during 40 days period of presaturation. van't Woudt[41] reported that on the basis of general experience in Asia, some 12 to 18 centimeters of water are needed for land preparation over a period of 20 to 30 days.

It is necessary to determine the extent of contribution of rainfall as a supplementary irrigation water, but no technique for measuring an effective rainfall is available, because such variables as plant height, height of border, depth of water, and overflow systems are involved.[44] In Japan, the effective rainfall is generally estimated to be from 3—5 mm to 20—30 mm per day or 70—80% of the total rainfall during paddy season according to rainfall intensity and rainfall excess.[23] However no data were obtained in the present study.

7) Estimation of water consumption by rice plants

The total quantity of water to be consumed by plants with 130—140 days of growth duration is estimated based on the results obtained[19, 34, 43] in the present field experiments and given in Table 9 (Appendixes 4 to 6). This estimation was made on the assumption that standing water was maintained in the field up to harvest time. The amount of 9.5 mm/day of water was required during the off season and 7.4 mm/day during the main season.

The greater value for the off season is attributed to:—(a) greater evapo-transpiration during the off season,[26, 34] and (b) longer growth duration in the off season.[12, 26, 32, 34] Bahagia in case of the off season crop took 142 days to mature as compared to 132 days for the main season crop.[12, 26, 34] If Ria with a short growth period of 120—125 days was used,[12, 34] its water consumption would approximately be 1,200 mm (9.6 mm/day) in the off season and 930 mm (7.4 mm/day) in the main season respectively. Thus, 10% and 5%

Table 9. An estimation of the water consumption in the cultivation of Bahagia by providing with standing water from sowing to harvest.

Period	Item	Off season (Mar. 15 to Aug. 4)	Main season (Sep. 1 to Jan. 11)
From sowing to transplanting	Evapo-transpiration (Em/day)×(No. of days)	mm mm* 8.3×25=208	mm mm* 5.1×25=128
Prior to transplanting	Water required for puddling and levelling, and maintaining field at saturated moisture condition for 5 days	mm 190	mm 150
From transplanting to harvest	Evaporation (Em/day)×(No. of days)×(E/Em)	mm mm 5.9×117×0.55=380	mm mm 4.6×107×0.55=271
	Transpiration (Em/day)×(No. of days)×(T/Em)	mm mm 5.9×117×0.65=449	mm mm 4.6×107×0.65=320
	Percolation (Perc./day)×(No. of days)	mm mm 1×117=117	mm mm 1×107=107
From sowing to harvest	Total (Growth duration)	mm inches 1,344=53 (142 days)	mm inches 976=38 (132 days)

* Water requirement for nursery which is about 1/30 area of paddy field.

water could be saved by growing a short-period variety, Ria, in the off season and main season respectively.

Field must be drained at the time of harvest. The drainage should be started at about 20 to 25 days after heading.[14, 23, 26, 30, 34] By doing this 10 days could be saved from the irrigation period. To design the water duty, the drainage at harvest time, soil water remaining in the fields after harvest, effective rainfalls and conveyance loss should be taken into consideration.[14, 23, 34, 44]

(2) Transpiration Coefficient with Reference to Varietal Differences

This experiment was undertaken to determine varietal differences in transpiration and transpiration coefficient which are factors affecting water requirement of rice plants, by using varieties of different growth duration (Plates 13 and 14).

It is also necessary to determine the values of transpiration and transpiration coefficient at different stages of growth, in order to establish an economical water management practice.

1. Material and Method

Varieties: Ria[12] (IR 8) (120—125 days growth duration).
Mahsuri[12] (130—140 days growth duration).
Peta×Tangkai Rotan line or Bahagia[12] (sister line of IR 5) (130—140 days growth duration).
Subang Intan 16[34] (160—180 days growth duration).
Radin Ebos 33[34] (160—180 days growth duration).

Spacing: 1 hill per pot, using 3 seedlings per hill. Surface area of pot was 1/22 sq. meter.

Layout:

	Variety	Number of pots: For measuring ET	Number of pots: For sampling	Total
Main season, 1968/69	Ria	2(2)	0(12)	2(14)
	Mahsuri	2(2)	0(0)	2(2)
	P×T. R. line (Bahagia)	2(2)	16(0)	18(2)
	S. I. 16	2(2)	0(0)	2(2)
	R. E. 33	2(2)	20(18)	22(20)
	No planting (Control) for measuring E	2(2)	—	2(2)
				48(42)
Off season, 1968	Ria	2	16	18
	Mahsuri	2	0	2
	P×T. Rotan line	2	16	18
	No planting (Control) for measuring E	2	—	2
				40

Figres in parentheses show main season, 1967/68.

Measurement: The pots with plants were placed under polyethylene sheets to eliminate the effects of rain. The levels of water in the pots were measured by means of a ruler at an interval of 2 to 7 days according to the recession of the water level. Two control pots with wooden cylinder in the center were used to assess the evaporation loss. After the recording, water was added up to a certain mark and the water depth was once again recorded.

2. Pot Culture

Transplanting: Main season, 1967/68—22/8/1967 (24 days seedling).
Off season, 1968 —20/4/1968 (24 days seedling).
Main season, 1968/69—22/8/1968 (25 days seedling).

Manuring: (Basal dressing)
Main season, 1967/68—1.43 g Ammonium sulphate, 1.37 g Christmas Islands rock phosphate and 0.42 g Potasium chloride per pot.
Off season, 1968 and
Main season, 1968/69—0.65 g Urea, 1.37 g Christmas Islands rock phosphate and 0.42 g Potasium chloride per pot.
(Top - dressing)
1.43 g Ammonium sulphate or 0.65 g Urea per pot were applied around the young panicle formation stage.

3. Results and Discussion

Data on growth, dry matter production, transpiration and transpiration coefficient at different stages of growth with all varieties used are given in Tables 10 to 17 and Fig. 13 to 22.

1) Transpiration and transpiration coefficient at different growth stages

Dry matter increase per day was small during the early stage of growth, then it increased gradually and reaching the maximum during the heading stage, and then decreased (Fig. 13, 14 and 15). In R. Ebos 33, the maximum point was observed either at the stage

Table 10. Growth and dry weight of plant per hill (Main season, 1967/68).

	Days after transplanting	21	42	64	82	92	103	116	147
Ria	Dry wt. of plant	3.55 g	18.90	36.00	32.62	28.33			
	Dry wt. of panicle			11.50 g	36.87	48.85			
	Plant height	58 cm	69	80	78	(55)			
	No. of tillers	15.7	28.3	21.3	21.0	(19.7)			
R. E. 33	Dry wt. of plant	3.99 g	22.50	47.00	67.00		88.50	87.00	70.37
	Dry wt. of panicle							12.50 g	53.03
	Plant height	80 cm	97	105	115		122	149	(104)
	No. of tillers	13.3	25.0	22.7	16.7		13.7	19.0	(15.0)

Table 11. Transpiration and transpiration coefficient (Main season, 1967/68).

1) Ria

Days after transplanting	0	21	42	64	82	92	Total or average
Days before heading	60	39	18	-4	-22	-32	
Transpiration per hill	kg 0.11	4.60	6.95	5.44	2.39		19.50
Ratio	0.6	23.6	35.7	27.9	12.3		100
Transpiration per day	g 5	219	316	302	239		212
Increas of dry matter per hill	g 3.20	15.35	28.60	21.99	7.69		76.83
Increas of dry matter per day	g 0.15	0.73	1.30	1.22	0.77		0.84
Transpiration coefficient	34	300	243	247	311		254

2) R. Ebos 33

Days after transplanting	0	21	42	64	82	103	116	147	Total or average
Days before heading	114	93	72	50	32	11	-2	-33	
Transpiration per hill	kg 0.17	5.48	7.39	4.50	7.61	7.32	15.92		48.38
Ratio	0.3	11.3	15.3	9.3	15.7	15.1	32.9		100
Transpiration per day	g 8	261	336	250	362	563	514		329
Increas of dry matter per hill	g 3.59	18.51	24.50	20.00	21.50	11.00	23.90		123.00
Increas of dry matter per day	g 0.17	0.88	1.11	1.11	1.02	0.85	0.77		0.84
Transpiration coefficient	47	296	302	225	354	665	666		393

Table 12. Transpiration and transiration coefficient (Main season, 1967/68).

Item	Mahsuri	P×T. Rotan	S. I. 16
Transpiration per hill	kg 27.15	28.73	52.31
Transpiration per day	g 254	261	356
Increase of dry matter per hill	g 109.43	104.72	121.25
Increase of dry matter per day	g 1.02	0.95	0.82
Transpiration coefficient	248	274	431

of reduction division or young panicle differentiation. As seen in Fig. 13, 14 and 15, transpiration showed its peak around the heading stage with the smallest value at the initial growth stage. The peak of transpiration per day in Ria and Bahagia was observed around the reduction division stage.

As shown in Fig. 16, a distinct correlation was obtained between the dry matter increase per day and transpiration per day in relation to growth stage. From the data of dry matter increase per day and the transpiration per day at each stage of growth, the transpiration coefficient for dry matter increase per day was obtained.

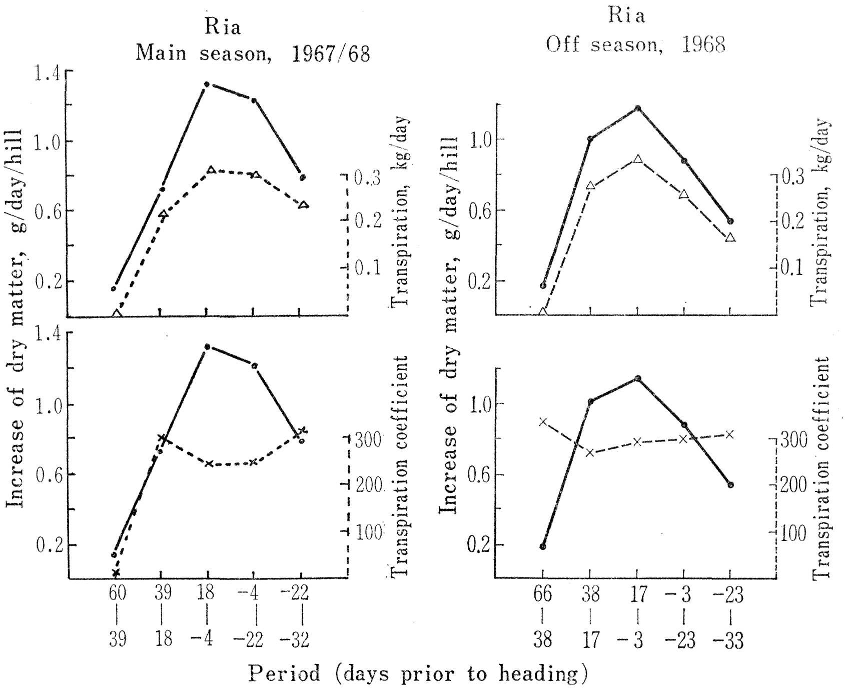


Fig. 13. Increase of dry weight, transpiration and transpiration coefficient (Ria).

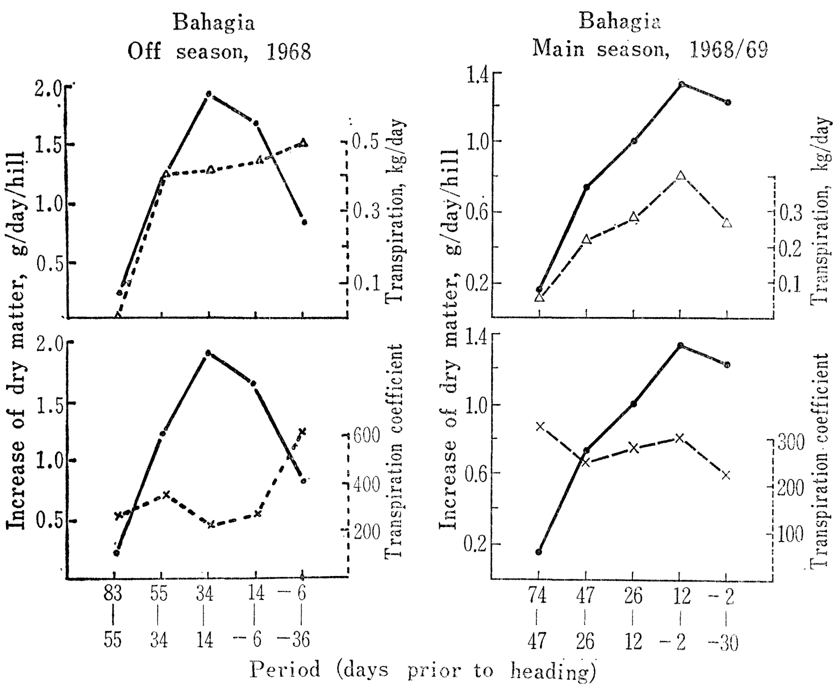


Fig. 14. Increase of dry weight, transpiration and transpiration coefficient (Bahagia).

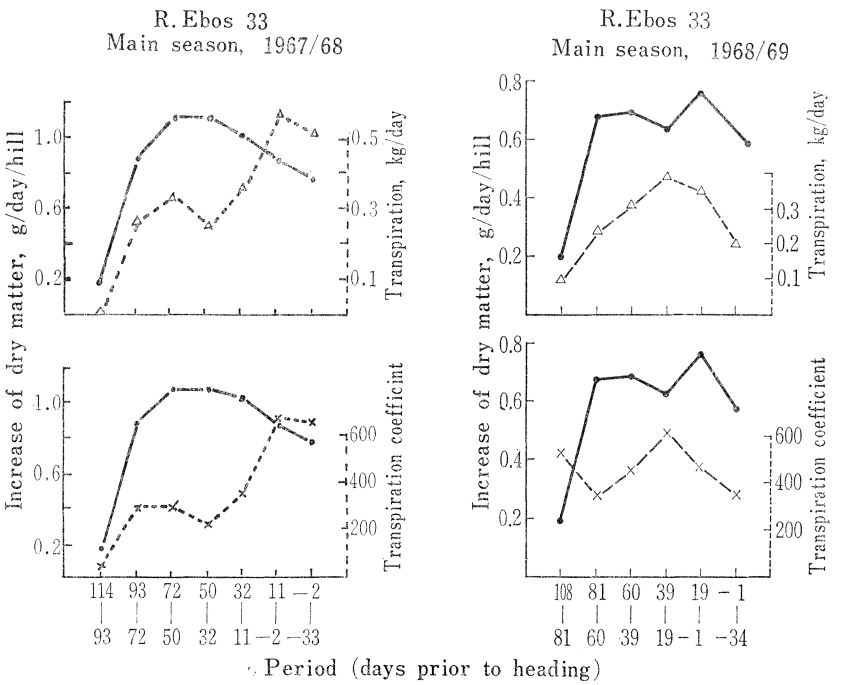


Fig. 15. Increase of dry weight, transpiration and transpiration coefficient (R. Ebos 33).

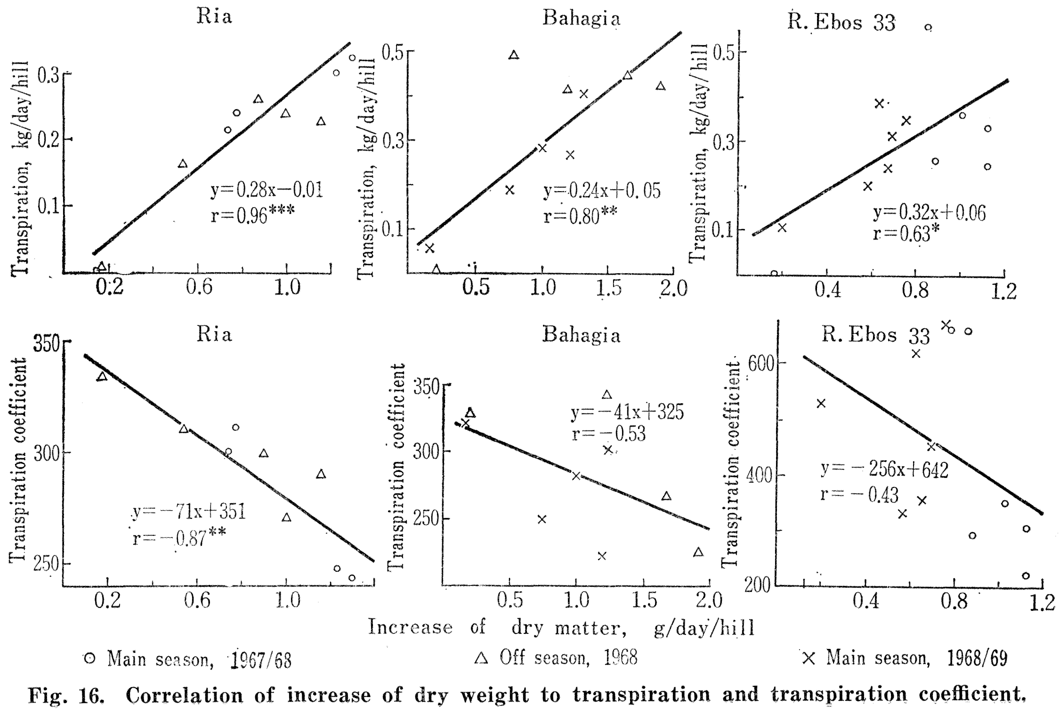


Fig. 16. Correlation of increase of dry weight to transpiration and transpiration coefficient.

In general, transpiration coefficient for dry matter increase per day was comperatively high during the early growth stage, lowest in the mid-growth stage and highest during the ripening stage[22,34] (Fig. 13 to 15). Although, in some cases a rather low transpiration coefficient at the early growth stage was observed, there exists a negative correlation between transpiration coefficient and increase in dry matter per day throughout the growth period. It is particularly clear with Ria (Fig. 16).

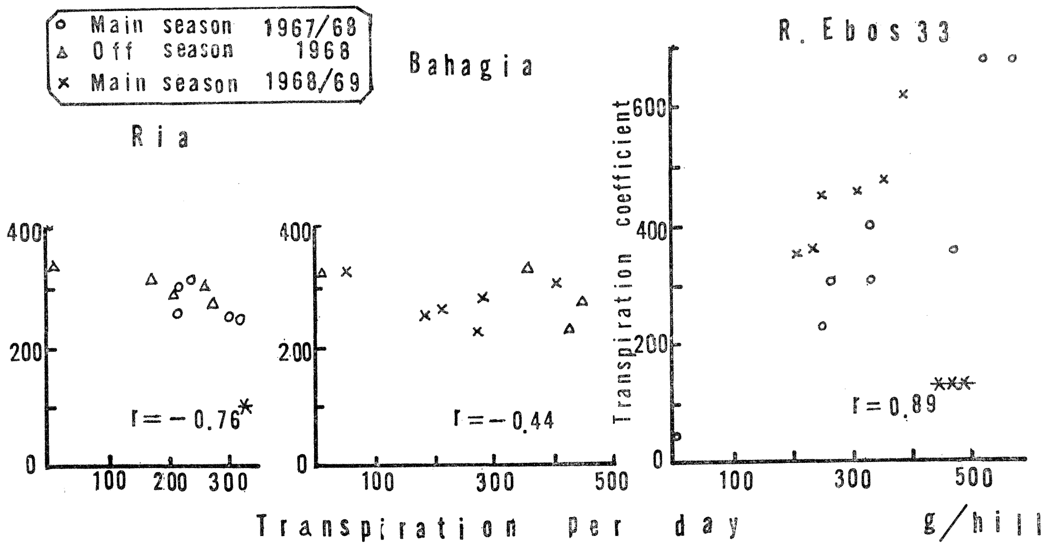


Fig. 17. Correlation between transpiration per day and transpiration coefficient at each stage of growth.

Table 13. Growth and dry weight of plant per hill (Off season, 1968).

	Days after transplanting	28	49	69	89	Final
Ria	Dry wt. of plant	g 4.77	26.00	36.50	33.00	(99) 31.97
	Dry wt. of panicle			g 12.50	33.50	39.86
	Plant height	cm 53	86	97	95	(58)
	No. of tillers	15.6	30.1	25.2	17.4	(18.5)
P×T. Rotan	Dry wt. of plant	g 6.02	31.60	69.50	93.50	(120) 81.04
	Dry wt. of panicle				g 9.00	45.28
	Plant height	cm 54	89	106	117	(80)
	No. of tillers	18.5	37.7	30.3	25.5	(25.0)
Mahsuri	Plant height	cm 67	109	125	133	(105)
	No. of tillers	15.0	37.0	33.0	27.0	(27.0)

Table 14. Transpiration and transpiration coefficient (Off season, 1968).

1) Ria

Days after transplanting	0		28		49		69		89		99	Total or average
Days before heading	66		38		17		-3		-23		-33	
Transpiration per hill		kg 1.54		5.75		6.68		5.21		1.65		20.83
Ratio		7.4		27.6		32.1		25.0		7.9		100
Transpiration per day		g 6		274		334		260		165		210
Increase of dry matter per hill		g 4.62		21.23		23.00		17.50		5.33		71.68
Increase of dry matter per day		g 0.17		1.01		1.15		0.88		0.53		0.72
Transpiration coefficient		334		271		290		298		310		291

2) P×T. Rotan

Days after transplanting	0		28		49		69		89		119	Total or average
Days before heading	83		55		34		14		-6		-36	
Transpiration per hill		kg 1.90		8.74		8.46		8.84		14.70		42.64
Ratio		4.5		20.5		19.8		20.7		34.5		100
Transpiration per day		g 7		416		423		442		490		358
Increase of dry matter per hill		5.80		25.58		37.90		33.00		23.82		126.10
Increase of dry matter per day		g 0.21		1.22		1.90		1.65		0.79		1.06
Transpiration coefficient		328		342		223		268		617		338

3) Mahsuri

Days before heading	87		59		38		18		-2		-32	Total or average
Transpiration per hill		kg 1.82		7.94		9.73		8.72		15.62		43.84
Ratio		4.2		18.1		22.2		19.9		35.6		100
Transpiration per day		g 6		378		487		436		521		368
Increase of dry matter per hill												g 137.45
Transpiration coefficient												319

Between transpiration coefficient at each stage of growth and transpiration per day, there exists a negative correlation in case of short term varieties (Fig. 17). These relations signify that the plants utilized water most efficiently when the plants grew most actively.[22,35] With R. Ebos 33, a variety with long growth duration, even a positive correlation was found between the transpiration coefficient at different stages of growth and transpiration per day; i.e. absolute amount of transpiration per day was small at the stage when transpiration coefficient was small.

2) Varietal difference in transpiration and transpiration coefficient

All varieties were transplanted at the age of 24 to 25 days, although varieties of different growth duration were used in this investigation.

Transpiration coefficients determined in three seasons are shown as below:—

Variety	Main season, 1967/68	Off season, 1968	Main season, 1968/69
Ria	254 (92 days*)	291 (99 days*)	257 (91 days*)
Mahsuri	248 (107)	319 (119)	274 (104)
P×T. R. line or Bahagia	274 (110)	338 (119)	259 (104)
S. Intan 16	393 (147)	—	444 (142)
R. Ebos 33	431 (147)	—	483 (137)

* Number of days indicates growth duration from transplanting to harvest.

The values of three varieties in off season (dry season) were higher than those in main season (wet season) due mainly to difference in weather conditions.[22, 34, 35, 45] Transpiration and transpiration coefficient were higher in case of off season than in main season. Based on these figures, transpiration in a given paddy field can be calculated, if the growth duration and dry matter production of the variety planted are known.[18, 22, 35]

The relation between the growth period, as expressed by number of days from transplanting to harvest, and an increase in dry weight or transpiration coefficient for the main season of 1967/68 and 1968/69 are shown in Fig. 18 and 19 respectively. Transpiration coefficient as directly proportional to the growth duration of the varieties.

The following equations indicate the relation between growth duration of varieties and transpiration coefficient for main season of 1967/68 and 1968/69 respectively.

$$y=3.27x-75 \quad (r=0.96^{**}) \qquad (1)$$

$$y=4.71x-201 \quad (r=0.96^{**}) \qquad (2)$$

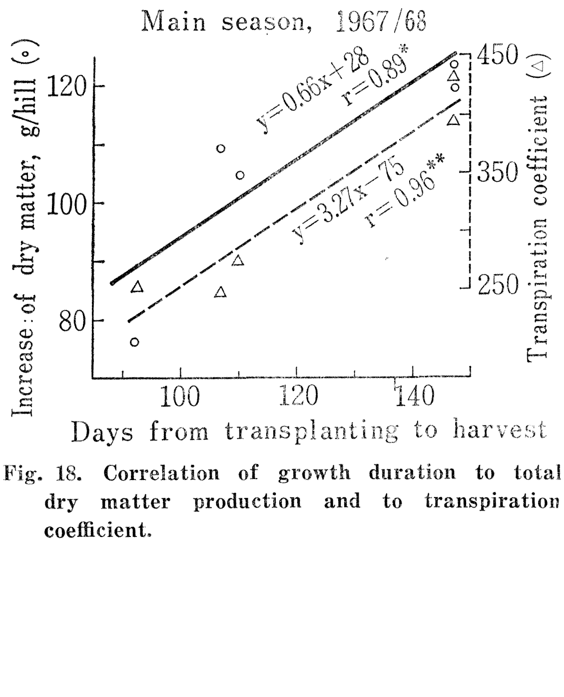


Fig. 18. Correlation of growth duration to total dry matter production and to transpiration coefficient.

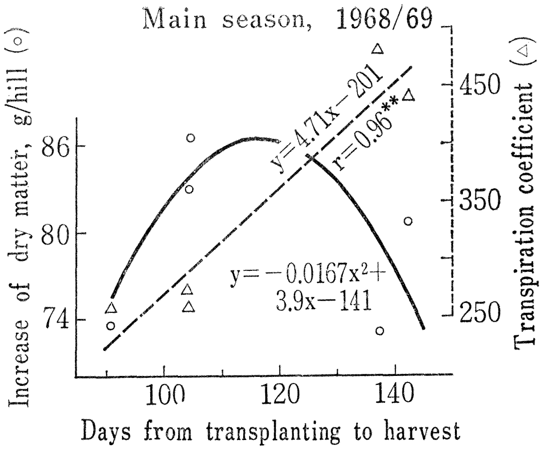


Fig. 19. Correlation of growth duration to total dry matter production and to transpiration coefficient.

Where x=period from transplanting to harvest (days) and y=transpiration coefficient. There existed a surprisingly high correlation between transpiration coefficient and growth duration.

Thus transpiration coefficient can be calculated when the growth duration of a given variety is known, by using the above equation (1) and (2) for main season. The calculated figures are shown below in comparison with the actually determined figures.

Table 15. Growth and dry weight of plant per hill (Main season, 1968/69).

	Days after transplant.	27	48	62	69	76	89	104	109	142
Bahngia	Dry wt. of plant	4.95 g	20.50	34.50		47.71		40.00		
	Dry wt. of panicle					5.29 g		47.12		
	Plant height	57 cm	81	93		117		(76)		
	No. of tillers	14.3	21.0	19.8		21.9		(20.0)		
	No. of leaves	13.1	16.2	18.1	18.7	19.2		19.3		
R. E. 33	Dry wt. of plant	5.86 g	20.00		34.50		47.00		57.02	55.13
	Dry wt. of panicle								4.99 g	25.94
	Plant height	69 cm	95	105	112	120	127		136	(119)
	No. of tillers	11.0	13.4	14.8	14.7	13.0	11.6		11.8	(11.3)
	No. of leaves	13.2	16.2	17.6	18.2	18.7	19.9		21.3	21.3

Table 16. Transpiration and transpiration coefficient (Main season, 1968/69).

	Days after transplanting	0	27	48	62	76	104	Total or average
	Days before heading	74	47	26	12	-2	-30	
Bahagia	Transpiration per hill	1.44 kg	3.86	3.94	5.65	7.57		22.46
	Ratio	6.4	17.2	17.5	25.2	33.7		100
	Transpiration per day	53 g	184	281	404	270		216
	Increase of dry matter per hill	4.47 g	15.55	14.00	18.50	34.12		86.64
	Increase of dry matter per day	0.16 g	0.74	1.00	1.32	1.22		0.83
	Transpiration coefficient	322	248	281	305	222		259

Variety	No. of days after transplanting to harvest	Transpiration coefficient calculated	Actually measured
Ria	92 days	227 g	256 g
Mahsuri	104—107	275—289	248—274
Bahagia	104—110	285—289	259—274
S. Intan 16	137—147	406—444	431—483
R. Ebos 33	142—147	406—468	393—444

From the above figures, it is apparent that the longest term variety needs two times as much water required for the shortest term variety for the production of one gram of dry matter. It means that varieties of short growth duration utilize water more efficiently in producing dry matter than varieties of longer growth duration.[18, 22, 34, 45)]

The dry matter production was not directly proportional to the growth duration of the variety during main season 1968/69. This could be attributed to the decrease of dry matter production in the two long term varieties, inspite of the longer growth duration (Tables 16, 17 and Fig. 19 and 22).

The relation of total transpiration to total dry weight and to weight of panicles is shown in Fig. 20 and 21. The following equations were obtained for the relation between total transpiration (x) and total dry weight (y), in main season 1967/68 and 1968/69 respectively.

Table 17. Transpiration and transpiration coefficient (Main season, 1968/69).

Item	Ria	Mahsuri	S. Intan 16
Transpiration per hill	18.88 kg	22.76	34.85
Transpiration per day	207 g	219	254
Increase of dry matter per hill	73.38 g	83.14	72.16
Increase of dry matter per day	0.81 g	0.80	0.53
Transpiration coefficient	257	274	483

$$y = 1.07x + 70 \quad (r = 0.84)$$

$$y = -0.187x^2 + 10.3x - 53$$

As the weight of panicles decreased with the increase in total transpiration or growth duration, a quadratic curve was obtained for the relation between total transpiration and weight of panicles in both seasons[22,34] (Tables 10, 12, 15 and 17 and Fig. 20 to 22).

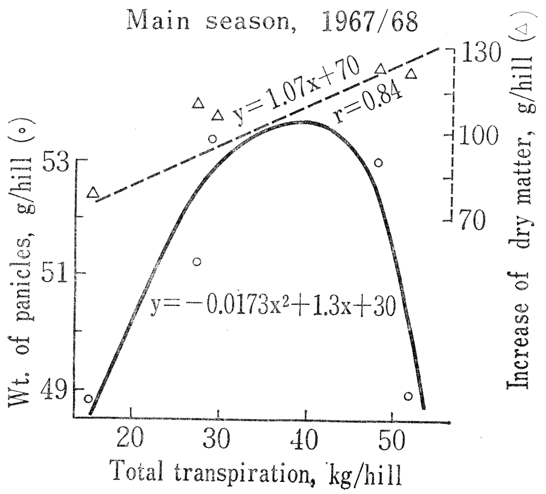


Fig. 20. Correlation of total transpiration to weight of panicles and to total dry matter.

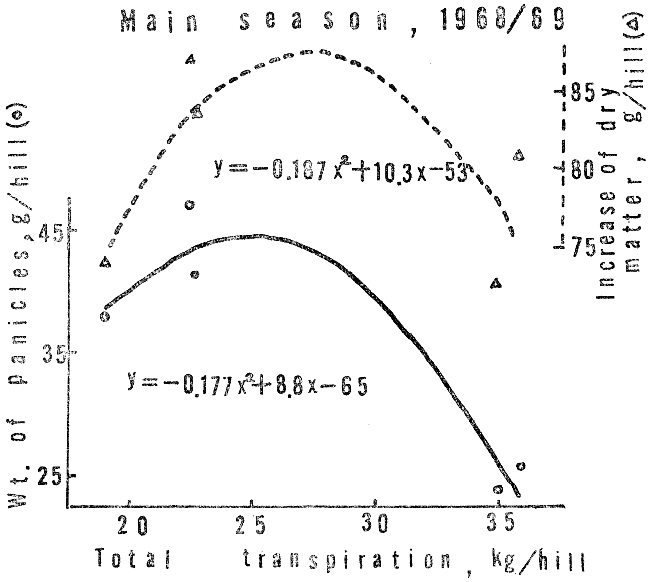


Fig. 21. Correlation of total transpiration to weight of panicles and to total dry matter.

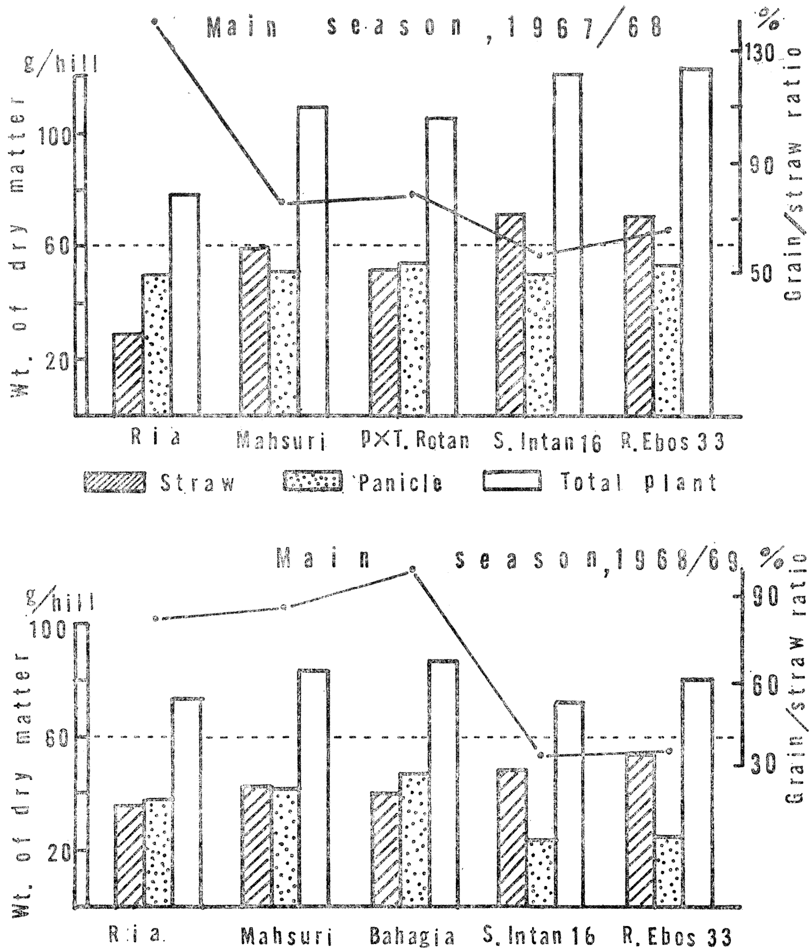


Fig. 22. Varietal differences of dry matter production and grain/straw ratio.

The same amount of fertilizer was used in this investigation, inspite of the differences in growth duration of the varieties tested. This could be the cause for the poor dry matter production in the long term varieties. The grain production was also poor in the long term variety as compared with the short term ones[34, 35] (Fig. 22). It is concluded therefore that the use of longer growth duration varieties is inadvisable as the grain yield does not commensurate with the water consumption.

Matsushima[18] pointed out that there was no seasonal difference in the transpiration coefficient and 5 grams of transpiration coefficient/growth duration, existed in many of the Malayan varieties, it was noted that there was in fact a slight difference in transpiration coefficient between main season and off season (Table 47). Furthermore lesser figure in transpiration coefficient was obtained in this investigation.[34, 35] These trends are rather similar to the investigations carried out by Murakami[22] in Ceylon. This inconsistency might have been caused by the differences in measuring method, apparatus and varieties tested. Therefore, further investigation is necessary to study the above stated inconsistency with improved method and apparatus.

II. WATER DEPTH

(3) Depth of Water in Relation to Fertilizer Application Method

A priliminary experiment carried out at Bukit Merah Padi Experiment Station (Appendix 3) showed that the grain yield was decreased almost proportionally to the increase of water depth under non-fertilized condition but the yield reduction was small under fertilized condition particularly with a medium term variety.[32, 33] There was also a small difference in yield between basal dressing plot and top-dressing plot.

A large number of places, everywhere in the Kedah Plain, was submerged under deep water during the rainy season, July to November, due to the poor drainage.[3, 4, 26, 34] The water depth in some cases was more than 30 centimeters. It is assumed that short term varieties for double cropping have little tolerance to the deep water as compared with local varieties. Therefore the following experiment was conducted to study effects of different water depth on plant growth and grain yield of rice with different fertilizer application. For an experimental control of water depth for a whole growth period, large frames were used to grow plants (Plate 15).

1. Material and Method

Variety: Ria (120 days of growth duration)—Main season, 1967/68.
Bahagia (130 days of growth duration)—Main season, 1968/69.

Layout: 9 randomized plots, with 3 replications, 27 plots in all.

Frame Size: 91 cm×91 cm×38 cm (1/1.2 sq. meter).

Spacing: 30 cm×30 cm, 9 hills per frame (3 seedlings per hill).

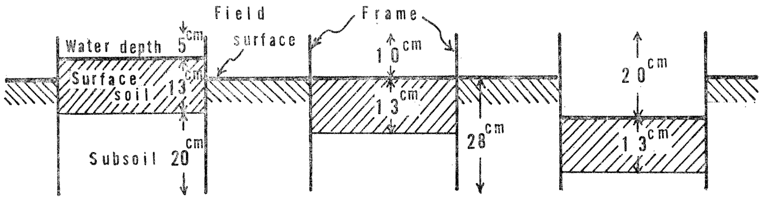
Treatments:

	Treatment	Water depth	N Basal dressing	N Top-dressing	
				30–35 days after planting	Young panicle formation stage
		cm	kg/ha (lb/ac)	kg/ha (lb/ac)	kg/ha (lb/ac)
1.	Non Fertilizer	5 (2″)	0	0	0
2.	Basal Dressing	5 (2)	67 (60)	0	0
3.	Top Dressing	5 (2)	0	34 (30)	34 (30)
4.	Non Fertilizer	10 (4)	0	0	0
5.	Basal Dressing	10 (4)	67 (60)	0	0
6.	Top Dressing	10 (4)	0	34 (30)	34 (30)
7.	Non Fertilizer	20 (8)	0	0	0
8.	Basal Dressing	20 (8)	67 (60)	0	0
9.	Top Dressing	20 (8)	0	34 (30)	34 (30)

67 kg/ha of P_2O_5 as Christmas Islands rock phosphate and 45 kg/ha of K_2O as Potasium chroride were applied as basal dressing except treatment nos. 1, 4 and 7. Nitrogen fertilizer used was Ammonium sulphate for main season, 1967/68 and Urea for main season, 1968/69.

Preparation of frames:

Galvanized iron bottomless frames were set into the field soil. The soil was dug up to the depth of 30 centimeters to receive the frames and the soil was put back inside the frames as indicated below.[32]



Transplanting: 20/9/1967 (25 days seedling)—Main season, 1967/68.
15/8/1967 (23 days seedling)—Main season, 1968/69.

2. Results and Discussion

The records of growth, yield, chemical analysis of rice plant and water and soil temperature are shown in Tables 18 to 26 and Fig. 23 to 25.

Table 18. Record of plant growth (Ria, Average of 3 rps.).

Treatment		cm	11/10(21) No. of tillers	25/10(35) Plant ht. (cm)	25/10(35) No. of tillers	8/11(49) Plant ht. (cm)	8/11(49) No. of tillers	15/11(56) Plant ht. (cm)	15/11(56) No. of tillers	23/12 Culm ht. (cm)	23/12 Panicle length (cm)	23/12 No. of panicles
1.	N.F.	5	7.9	49	23.0	67	23.8	69	23.3	62	22.7	19.1
2.	B.D.	5	8.8	53	25.6	65	25.3	71	24.9	62	22.6	17.8
3.	T.D.	5	6.8	49	21.8	68	27.4	76	29.0	66	23.8	25.3
4.	N.F.	10	7.0	51	19.5	65	19.6	73	19.5	64	23.4	15.7
5.	B.D.	10	6.7	51	19.5	66	21.2	75	21.0	63	22.8	18.1
6.	T.D.	10	5.8	48	16.6	66	22.0	76	25.2	64	24.1	22.9
7.	N.F.	20	5.0	54	11.5	71	13.7	79	14.0	66	23.5	13.4
8.	B.D.	20	5.0	54	12.5	71	14.1	79	15.1	64	23.7	14.2
9.	T.D.	20	5.4	57	14.0	76	17.6	84	18.0	70	24.7	18.3

Figures in parentheses show number of days after transplanting.

Table 19. Record of plant growth (Bahagia, Average of 3 rps.).

Treatment	12/9(28)		26/9(42)		10/10(56)		24/10(70)	18/11		
	Plant ht.	No. of tillers	Plant ht.	No. of tillers	Plant ht.	No. of tillers	Plant ht.	Culm ht.	Panicle length	No. of panicles
cm	cm		cm		cm		cm	cm	cm	
1. N.F. 5	48	20.5	68	30.9	87	30.8	105	102	25.0	22.3
2. B.D. 5	53	28.9	77	39.5	100	35.9	117	108	24.8	27.5
3. T.D. 5	48	20.0	74	37.9	95	39.9	117	106	27.1	28.2
4. N.F. 10	48	19.2	70	29.4	88	29.6	106	101	25.2	22.3
5. B.D. 10	53	26.5	78	38.0	101	36.2	119	109	25.2	26.4
6. T.D. 10	48	20.5	76	36.2	99	37.2	123	109	27.4	27.2
7. N.F. 20	57	18.0	78	26.1	99	26.5	116	108	25.9	19.5
8. B.D. 20	61	23.2	88	32.3	109	30.8	128	117	26.0	23.6
9. T.D. 20	56	17.3	82	32.6	103	33.1	126	111	28.6	24.1

Table 20. Records of water and soil temperature (Main season, 1967/68).

Treatment \ Item / Time	Water temperature		Soil temperature at 5 cm depth	
	7.30	14.30	7.30	14.30
cm	°C	°C	°C	°C
3. T.D. 5	25.0 (20.5–27.5)	31.2 (26.0–33.5)	24.8 (20.6–27.5)	30.6 (26.0–37.0)
6. T.D. 10	24.8 (20.5–27.0)	30.5 (25.5–32.5)	25.2 (20.5–27.5)	30.8 (26.0–37.5)
9. T.D. 20	25.8 (20.5–28.0)	30.1 (25.5–32.5)	26.1 (20.6–29.0)	30.3 (26.0–32.0)

Average of 13 readings. Measurement was made on every Tuesday.
Figures in parentheses show the range of temperature.

Table 21. Records of water and soil temperature (Main season, 1968/69).

Treatment \ Item / Time	Water temperature		Soil temperature at 5 cm depth	
	7.30	14.30	7.30	14.30
cm	°C	°C	°C	°C
3. T.D. 5	25.6 (24.0–27.5)	32.3 (28.5–37.0)	26.3 (25.0–28.0)	30.9 (28.0–34.5)
6. T.D. 10	25.9 (24.0–27.5)	31.7 (28.5–36.0)	26.8 (25.5–28.5)	29.8 (27.5–33.0)
9. T.D. 20	26.4 (24.5–28.5)	30.9 (27.5–36.5)	27.1 (25.0–29.5)	29.8 (27.0–32.5)

Average of 16 readings. Measurement was made on every Wednesday.

1) Plant growth

In general deep water treatment induced an increased plant height and markedly reduced number of tillers. However there was not much difference in growth between the groups of 5 and 10 cm of water depth in case of Bahagia.

Fertilizer application was effective to increase number of tillers even at deep water condition. Top-dressing of nitrogen was more effective than basal dressing in increasing tillers and consequently number of panicles with Ria, but not such a clear difference was found with Bahagia.

Table 22. Grain yield and yield components (Ria, Average of 3 rps.).

Treatment	Heading date	Wt. of straw	No. of spikelets per panicle	No. of spikelets per hill	% of ripened grains	Wt. of 1,000 grains	Grain/straw ratio	Yield per frame	Index	Index
cm		g			%	g	%	g	%	%
1. N.F. 5	22/11	269	92	1,772	72	28.1	120	321	**100**	**100**
2. B.D. 5	23/11	286	99	1,760	75	28.3	120	337	105	105
3. T.D. 5	21/11	349	101	2,580	68	28.8	133	451	141	141
4. N.F. 10	21/11	225	97	1,529	76	28.2	135	293	**100**	91
5. B.D. 10	21/11	262	92	1,653	74	27.7	121	303	104	94
6. T.D. 10	21/11	307	96	2,189	74	28.6	139	417	143	130
7. N.F. 20	21/11	186	102	1,383	78	27.9	144	271	**100**	84
8. B.D. 20	18/11	219	98	1,389	78	28.4	125	276	102	86
9. T.D. 20	19/11	278	108	1,967	80	29.1	149	410	151	128

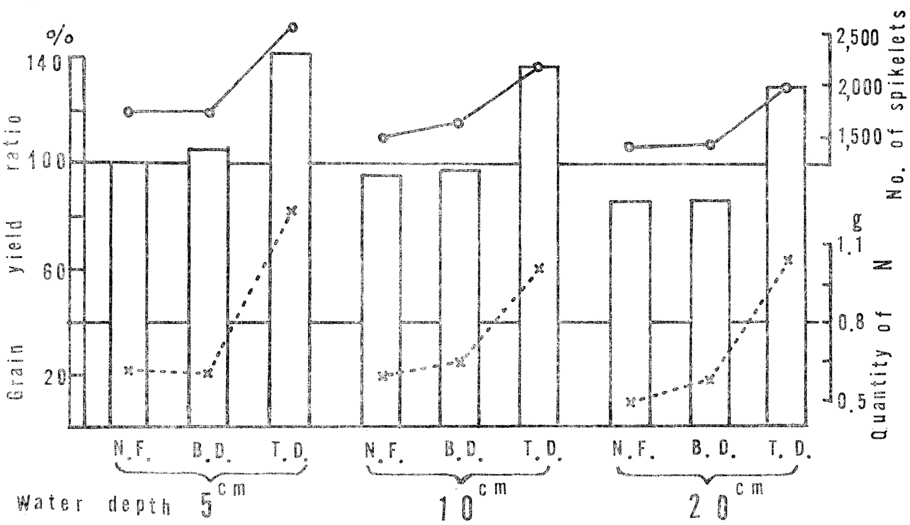


Fig. 23. Relationship of grain yield to number of spikelets and to quantity of nitrogen in total plant per hill (Ria).

2) Water temperature and soil temperature

Water and soil temperature at 7.30 a.m. and 2.30 p.m. can be regarded roughly indicating minimum and maximum temperature respectively. According to Tables 20 and 21, water temperature was slightly lower at the minimum and slightly higher at the maximum than soil temperature. It was observed that the deeper the water depth, the higher was the minimum and the lower was the maximum temperature for both water and soil temperatures. This means that a range of daily fluctuation of temperature was reduced by deep water.[18] However, all these differences in temperature were very small, and can not be a significant factor causing differences in plant growth.

3) Grain yield and its components

The highest yield was obtained with 5 cm water depth plots (Tables 22 to 25).

The difference in yield was significant at 10% level between 5 cm and 20 cm water depth groups with Bahagia, but not significant with Ria.

Table 23. Statistical analysis of yield (Ria).

Source	d.f.	S.S.	M.S.	F
Total	26	203529.9		
Block	2	6564.3	3282.2	0.59 N.S.
Treatment	8	108203.9	13525.5	2.44
N.F.—B.D.	1	501.3	501.3	0.09 N.S.
N.F.—T.D.	1	77618.0	77618.0	13.99**
B.D.—T.D.	1	65642.7	65642.7	11.83**
5 cm—10 cm	1	4672.2	4672.2	0.84 N.S.
5 cm—20 cm	1	11653.6	11653.6	2.10 N.S.
Error	16	88763.6	5547.6	

L.S.D.: 5% 129 g, 1% 178 g/frame.

Table 24. Grain yield and yield components (Bahagia, Average of 3 rps.).

Treatment	Heading date	Angle of lodg-ing	Wt. of straw	No. of spike-lets per panic-le	No. of spike-lets per hill	% of ripened grains	Wt. of 1,000 grains	Yield per fram	Index	Index
cm										
1. N.F. 5	31/10	32°	510 g	121	2,690	82 %	26.4 g	528 g	**100** %	**100** %
2. B.D. 5	1/11	33	676	113	3,114	84	.3	629	119	119
3. T.D. 5	2/11	23	703	132	3,716	83	.0	723	137	137
4. N.F. 10	2/11	30	501	117	2,625	83	.4	517	**100**	98
5. B.D. 10	30/10	38	673	128	3,104	83	.8	623	121	118
6. T.D. 10	1/11	37	589	134	3,632	80	.4	688	133	130
7. N.F. 20	31/10	33	488	126	2,458	87	.2	506	**100**	96
8. B.D. 20	1/11	42	640	129	3,033	82	.5	595	118	113
9. T.D. 20	1/11	33	732	141	3,391	78	.8	637	126	121

Table 25. Statistical analysis of yield (Bahagia).

Source	d.f.	S.S.	M.S.	F
Total	26	178150		
Block	2	5628.2	2814.1	1.31 N.S.
Treatment	8	138230.7	17278.8	8.06***
5 cm—10 cm	1	1352	1352	0.63 N.S.
10 cm—20 cm	1	4140.5	4140.5	1.93 N.S.
5 cm—20 cm	1	9464	9464	4.42
2, 3—8, 9	1	10800	10800	5.04*
N.F.—B.D.	1	43316	43316	20.21***
B.D.—T.D.	1	20267.6	20267.6	9.46**
Error	16	34291.1	2143.2	

L.S.D.: 5% 80 g, 1% 110 g, 0.1% 152 g/frame.

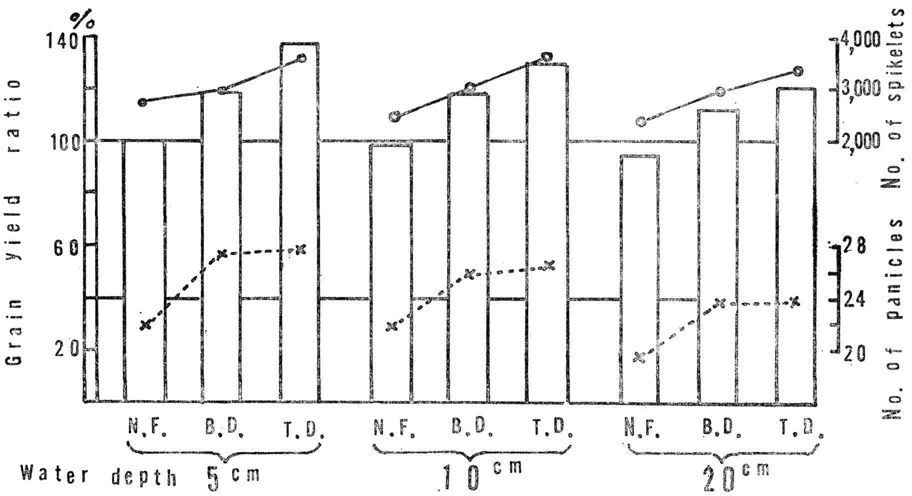


Fig. 24. Relationship of grain yield to number of panicles and to number of spikelets per hill (Bahagia).

Yields of non-fertilized plots were distinctly lower than that of fertilized plots particularly with Ria. Statistical significance was at 1% level with Ria and 0.1% level with Bahagia (Fig. 23 and 24). Top-dressing of nitrogen was more effective in preventing the reduction of yield caused by deep water submergence particularly with Ria.

Both Ria and Bahagia showed decreased yields with increasing water depth, but the rate of yield decrease was smaller with Bahagia than Ria, indicating that Bahagia is more tolerant than Ria to an adverse condition like deep water submergence.

It was observed that among yield components, number of spikelets and number of panicles per hill were highly correlated to yield with all experimental plots of each variety (Fig. 23 to 25). Number of spikelets per hill was more highly correlated to yield as compared with number of panicles in both varieties.[26,34,35] It also revealed that high yield in the top-dressing group was mainly attributed to an increase in number of spikelets per hill. In case of Ria, an increase in weight of 1,000 grains also contributed to an increase of yield in top-dressing group (Table 22).

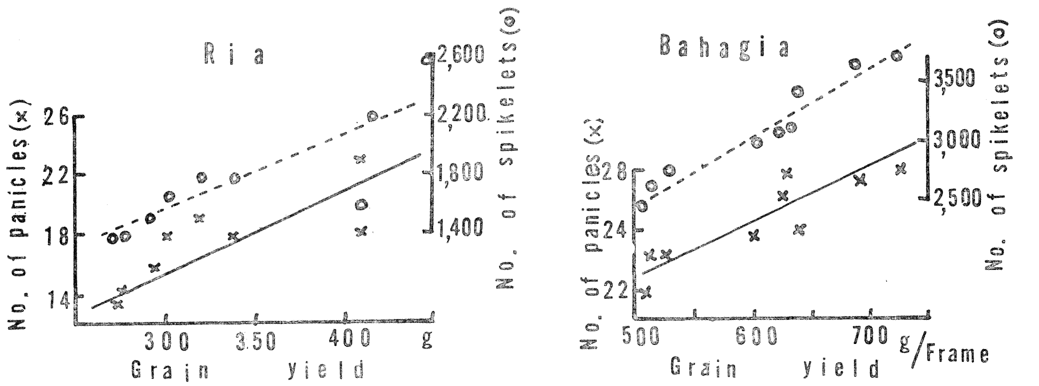


Fig. 25. Correlation of grain yield to number of panicles and to number of spikelets per hill.

4) Chemical analysis

Harvested panicles and straw were analyzed for N, P and K. This chemical analysis was carried out in the laboratory of the Soils and Water Research Division, Department of Agriculture.

According to Table 26 and Fig. 23, the total quantity of nutrients absorbed, particularly N, was highly correlated to grain yield. Top-dressing of N resulted in an increase in the total N absorbed by plants and percentage content of N in plants, thus causing high grain yield. Though total quantity of P and K increased in top-dressing group, the percentage of P and K content tended to decrease as compared with other groups.

It was also noticed that top-dressing gave the highest yield among the three groups but the yield/N ratio was lowest among them. However no significant difference in yield/P and yield/K ratio was found among them. N and K utilization ratio in top-dressing group also increased remarkably as compared with that of basal dressing group.

It can thus be concluded that top-dressing is most effective to increase the ratio of N utilization, and it is directly connected to the increase in grain production.

Table 26. Plant nutrient content per hill (Ria).

Treatment		Per cent content of N	Quantity of N	Y/N* ratio	N** utiliza. ratio	Per cent content of P	Quantity of P	Per cent content of K	Quantity of K	Y/K* ratio	K** utiliza. ratio
		%	g		%	%	g	%	g		%
1.	S	.52	.136			.057	.016	1.98	.519		
	P	1.09	.482			.25	.110	.36	.159		
	T		.618	58	—		.126		.678	53	—
2.	S	.54	.153			.050	.014	2.20	.618		
	P	1.01	.458			.26	.118	.34	.157		
	T		.611	61	0		.132		.775	48	23
3.	S	.75	.264			.054	.019	2.14	.750		
	P	1.55	.961			.19	.117	.28	.172		
	T		1.225	41	97		.136		.922	54	58
4.	S	.48	.102			.057	.012	2.01	.430		
	P	.99	.392			.25	.102	.31	.125		
	T		.499	65	—		.114		.555	59	—
5.	S	.50	.127			.044	.011	2.36	.600		
	P	1.03	.428			.25	.103	.31	.129		
	T		.555	61	9		.114		.629	54	18
6.	S	.78	.238			.050	.015	2.26	.687		
	P	1.40	.776			.18	.101	.27	.152		
	T		1.014	46	92		.116		.839	55	68
7.	S	.48	.082			.044	.007	2.35	.399		
	P	1.13	.419			.22	.082	.30	.111		
	T		.501	60	—		.089		.510	59	—
8.	S	.61	.125			.063	.013	2.37	.491		
	P	1.22	.454			.21	.078	.27	.099		
	T		.579	53	12		.091		.590	52	19
9.	S	.77	.209			.044	.012	2.28	.619		
	P	1.53	.821			.18	.097	.28	.149		
	T		1.030	44	85		.109		·768	59	64

$* \ \dfrac{\text{Grain yield (g)}}{\text{Total quantity of N or K (g)}}$

$** \ \dfrac{\text{(Quantity of N or K contained fertilized plant)} - \text{(N or K contained non-fertilized plant)}}{\text{Amount of applied N or K}} \times 100$

S……Straw, P……Panicle, T……Total plant.

III. DROUGHT AND WATER SAVING

(4) Drought at Different Stages of Growth

It is necessary, as a basis of field water management technology, to identify plant growth stages which are tolerant or less tolerant to water shortage and to find out the critical stage of plant growth for drought.

A series of pot culture experiment was carried out to know the effect of water shortage given at different stages of growth on growth and yield of rice (Plates 16 to 18).

1. Material and Method

Location: Bukit Merah Padi Experiment Station (Appendix 3)—off season, 1967 and main season, 1967/68.
Telok Chengai Padi Experiment Station—main season, 1968/69.

Soil used: Bumbong Lima Rice Research Center paddy field soil (Recent levee deposit and heavy clay[11, 20])—off season, 1967 and main season, 1967/68.
Telok Chengai Padi Experiment Station paddy field soil (Slightly brackish alluvium and heavy clay[11, 20])—main season, 1968/69.

Layout: Randomized with 4 replications.

Pot size: 1/12 sq. meter (Diameter 33 cm and depth 36 cm).

Procedure:

Drought treatment was given as belows:—

(a) Surface water was removed and no water was supplied during the period of treatment. However, plants grown in off season 1967 and main season 1967/68 were exposed to rainfall, although rain water was removed immediately after the rain. In the main season 1968/69, plants were placed under a vinyl sheet roofing to avoid rainfall.

(b) In the main season 1968/69, plot nos. 7 and 8 received the intermittent irrigation. During the period before young panicle formation stage, 3.4 l (40 mm) of water was applied at the interval of 7 days in plot no. 7 and 12 days in no. 8. The amount of water was increased to 5.1 l (60 mm) after the reduction division stage.

Transplanting: 2/6/1967 (26 days seedling)—Ria; off season, 1967.
25/11/1967 (26 days seedling)—P×T. Rotan line; main season, 1967/68.
22/9/1968 (27 days seedling)—Bahagia; main season, 1968/69.

Basal dressing: N (Ammonium sulphate or Urea) 1 g, P_2O_5 (Christmas Islands rock phosphate) 1 g and K_2O (Potasium chroride) 0.5 g per pot were applied.

Top - dressing: N (Ammonium sulphate or Urea) 1 g per pot was applied around the stage of young panicle formation.

2. Results

The records of growth, yield, rainfall and soil pH and Eh are shown in Tables 27 to 39.

Table 27. Record of plant growth (B. Merah; Off season, 1967. Aver. of 4 rps.).

Stage of drain	3/7(−47)		24/7(−26)		3/8(−16)		5/9(+17)		
	Plant ht.	No. of tillers	Plant ht.	No. of tillers	Plant ht.	No. of tillers	Culm ht.	Panicle length	No. of panicles
	cm		cm		cm		cm	cm	
1. Control	38	9.8	63	25.8	75	33.3	57	24	34.8
2. Tillering −71 to −42	47	10.5	63	29.8	74	34.0	61	24	33.5
3. Invalid tiller. −56 to −42	42	9.8	66	28.3	73	36.3	60	26	35.8
4. Rachis-branch differentiat. −40 to −26	**40**	**10.3**	60	22.3	74	36.5	57	26	36.0
5. Spikelet difierentiat. −25 to −14	45	11.5	**66**	**27.8**	74	31.3	60	25	34.3
6. 4 & 5 −40 to −14	**42**	**10.0**	61	25.0	63	25.5	54	24	30.5
7. Heading −1 to +8	41	9.3	64	24.8	**71**	**37.0**	55	24	36.3

Minus figures show number of days before heading of control.
Black letters are the figures before the treatment.

1) Plant growth

Ria (Off season, 1967)

Although the effects of treatments on plant growth was not apparent in this experiment, but it was clearly shown that the treatment no. 6 caused a considerable decrease in culm length and number of panicles, as shown in Table 27.

Peta×T. Rotan line (Main season, 1967/68)

Treatment no. 2, in which plants were exposed to water shortage during the tillering stage, caused a remarkable reduction in tillering and resulted in a decreased number of panicles. Similar effect, but to a less extent, was observed with the treatment no. 3 (Table 28).

Number of panicles was increased by treatments nos. 5, 6 and 7, but this was due to an increase of very poor panicles.

Table 28. Record of plant growth (B. Merah ; Main season, 1967/68. Aver. of 4 rps.).

Stage of drain	30/12(−40)		13/1(−26)		27/1(−12)		10/2(+2)	1/3(+21)		
	Plant ht.	No. of tillers	Plant ht.	No. of tillers	Plant ht.	No. of tillers	No. of tillers	Culm ht.	No. of panic-les	Index
	cm		cm		cm			cm		%
1. Control	57	28.5	70	36.5	77	37.5	36.3	69	36.5	**100**
2. Tillering −66 to −26	51	15.0	51	16.0	75	24.5	33.8	74	32.8	90
3. Invalid tiller. −47 to −26	**55**	**25.0**	59	30.0	76	34.8	33.5	73	34.0	93
4. Spikelet dif-ferentiat. −23 to −9	59	25.0	**68**	**33.8**	78	33.3	34.0	69	38.0	104
5. Heading −7 to +3	59	27.8	71	39.3	**83**	**40.3**	40.3	72	39.5	108
6. 4 & 5 −23 to +3	57	26.0	**68**	**34.5**	74	34.5	34.0	67	39.5	108
7. Most active ripening +7 to +18	57	28.8	68	39.8	77	39.3	**39.3**	69	39.5	108

Black letters are the figures before the treatment or at the beginning stage of treatment.

Bahagia (Main season, 1968/69)

Seven days after drying of soil, the soil was completely dried up and cracks were observed on surface soil of pot. Plants showed temporary wilting during daytime, causing the dying off of the tips of leaves particularly in treatment nos. 5, 7 and 8.

Table 29. Record of plant growth (T. Chengai ; Main season, 1968/69. Aver. of 4 rps.).

Stage of drain	20/10(−44)		3/11(−30)		17/11(−16)		1/12(−2)	Culm ht.	Panicle length	No. of panicles
	Plant ht.	No. of tillers	Plant ht.	No. of tillers	Plant ht.	No. of tillers	No. of tillers			
	cm		cm		cm			cm	cm	
1. Control	60	36.2	82	50.5	93	47.7	43.8	80	28.6	42.3
2. Invalid tiller. −52 to −37	59	32.6	81	56.4	86	54.3	45.9	83	27.8	45.3
3. Rachis-branch differentiat. −37 to −22	**58**	**34.3**	77	50.9	83	51.5	46.3	75	27.5	44.0
4. Spikelet differ-entiation −22 to −12	56	33.0	**78**	**49.1**	90	48.2	42.5	86	28.1	40.0
5. Booting −10 to 0	56	33.6	81	49.0	**90**	**49.4**	41.5	76	28.1	41.5
6. Initial ripening +1 to 11	62	35.1	79	51.2	89	51.6	**43.4**	79	27.5	39.3
7. Intermittent 7 days interval	56	35.0	76	47.2	84	46.2	41.5	68	24.6	40.0
8. Intermittent 12 days interval	58	32.9	81	52.1	83	50.3	47.2	55	21.9	39.5

Black letters are the figures indicate before the treatment.

Table 30. Amount of rainfall during treatment (B. Merah ; Off season, 1967).

Stage of drain	Period of drying	Days before heading	No. of rainy days	Rainfall	
	days	days	days	//	mm
2. Tillering	29 (9/6- 7/7)	71- 42	13	5.44	138.2
3. Invalid tillering	14 (24/6- 7/7)	56- 42	4	3.93	99.8
4. Rachis-branch differentiation	14 (10/7-23/7)	40- 26	2	0.13	3.1
5. Spikelet differentiation	11 (25/7- 4/8)	25- 14	1	0.67	17.0
6. 4 & 5	26 (10/7- 4/8)	40- 14	3	0.80	20.3
7. Heading	10 (18/8-27/8)	1--8	5	5.91	150.1

Effect of treatment on plant growth was not apparent in this experiment, except treatment nos. 7 and 8. These treatments are intermittent watering, and which caused reduced culm length and reduced number of panicles with distinctly short panicle length (Table 29).

Rainfall data for off season 1967 and main season 1967/68 are shown in Tables 30 and 31, because during that season experimental plants were exposed to rainfall, although rain water was drained after rain. The reason why the treatment at tillering stage caused a reduction in number of panicles in main season 1967/68 but not in off season 1967 can be attributed to the rainfall more than 100 mm during that treatment period in the latter season. Thus it can be concluded that water shortage at the tillering stage affects plant height and panicle number, but water shortage occuring middle and later stages of growth is less effective to plant growth.

Table 31. Amount of rainfall during treatment (B. Merah; Main season, 1967/68).

Stage of drain	Period of drying	Days before heading	No. of rainy days	Rainfall	
	days	days	days	//	mm
2. Tillering	40 (4/12-12/1)	66- 26	3	1.25	31.8
3. Invalid tillering	21 (23/12-12/1)	47- 26	2	0.58	14.7
4. Spikelet differentiation	14 (16/ 1-29/1)	23- 9	2	0.52	13.2
5. Heading	11 (1/ 2-11/2)	7- −3	2	1.59	40.4
6. 4 & 5	27 (16/ 1-11/2)	23- −3	2	1.40	35.6
7. Most active ripening	11 (15/ 2-25/2)	−7-−18	6	2.65	67.3

2) Changes of pH and Eh in the soil

Data are shown in Tables 32 and 33. Soil samples were taken from 3 to 7 cm below surface.

With both of B. Lima soil and T. Chengai soil, it was observed that no-watering treatments induced an oxidized condition of soils during the period of treatment, but with the start of re-watering after the end of treatments Eh value went down to the level of control pot which was submerged continuously throughout the growth period. Soil pH value was also changed by the treatments. When soils became oxidized condition, pH value decreased, whereas pH value increased when Eh value went down.[32] The change of pH was in a range of 4.5 to 6.3 with B. Lima soil and 4.4 to 6.4 with T. Chengai soil.

Table 32. pH and Eh of soil (B. Merah ; Off season, 1967).

Stage of drain	10/6		6/7		13/7		20/7		27/7		10/8	
	pH	Eh_6	pH	Eh_6	pH	Eh_6	pH	Eh_6	pH	Eh_6	pH	Eh_6
		mV		mV		mV		mV		mV		mV
1. Control	6.3	21	6.5	89	5.5	−36	6.1	17	6.4	−2	5.8	33
2. Tillering			6.1 (0)	106	5.5 (6)	−77	5.8 (13)	92	5.8 (20)	91	5.9 (34)	−17
3. Invalid tillering			5.9 (0)	115								
6. 4 & 5					6.0 (0)	14	5.6 (0)	72	4.4 (0)	289	4.5 (6)	212

Figures in parentheses show number of days after completion of treatment.

Table 33. pH, Eh and moisture ratio of soil (T. Chengai ; Main season, 1968/69. Aver. of 4 rps.).

Stage of drain	9/10 After trans-palnting		4/11 Initial genera-tive stage		9/12 Booting stage		24/12 Late ripening stage		
	pH	Eh_6	pH	Eh_6	pH	Eh_6	pH	Eh_6	Mois-ture
		mV		mV		mV		mV	%
1. Control	6.4	−56	5.5	− 19	6.3	−12	5.8	3	
2. Invalid tillering			5.1 (8)	−103					
3. Rachis-branch differ.			4.8 (0)	− 23	6.0 (28 days)	−12	6.3 (43 days)	16	
5. Booting					4.7 (6)	99	5.3 (21)	4	
6. Initial ripening					5.5 (0)	−16	5.1 (10)	56	
7. Intermittent 7 days interval			4.9 (0)	22	4.3 (0)	284	4.6 (0)	143	23.0
8. Intermitetnt 12 days interval			4.3 (0)	59	4.3 (0)	312	4.4 (0)	347	16.8

Figures in parentheses show number of days after completion of treatment.

Intermittent watering caused an extremely dry condition of soil. Soil moisture ratio was 17 to 23% and high Eh values with 350 mV at the highest. In addition to the water shortage, a serious nitrogen deficiency might have occurred due to a drastic nitrogen loss.[18] This can account for the very poor growth obtained in the intermittent watering pots.

3) Grain yield and yield components

Ria (Off season, 1967)

In a treatment no. 6 pot, heading delayed by 7 days. This might be caused by a wilting of plants during the treatment.

Grain yields were remarkably decreased by the treatment nos. 2, 5 and 6. Reduced yield in no. 2 pot, was attributed to a reduced number of panicles which resulted in a decreased number of spikelets per pot. On the contrary reduced yields in nos. 5 and 6 were caused mainly by a decrease in number of spikelets per panicle, because plants at the stage of spikelet formation was exposed to water shortage (Tables 34 and 35).

Table 34. Grain yield and yield components (B. Merah ; Off season, 1976. Aver. of 4 rps.).

Stage of drain	Date of heading	Wt. of straw	No. of spikelets per panicle	No. of spikelets per pot	% of ripened grains	Wt. of 1,000 grains	Grain/straw ratio	Yield	Index
		g			%	g	%	g	%
1. Control	19/8	65	123	4,234	68	29.1	129	83.8	**100**
2. Tillering −71 to −42	19/8	64	119	3,912	68	29.1	123	77.7	93
3. Invalid tillering −56 to −42	16/8	62	121	4,379	69	28.0	137	86.2	103
4. Rachis-branch differentiation −40 to −26	19/8	65	108	3,892	76	29.9	137	87.8	105
5. Spikelet differentiation −25 to −14	16/8	61	88	3,880	64	28.9	120	73.4	88
6. 4 & 5 −40 to −14	26/8	54	99	3,029	69	28.0	109	58.7	70
7. Heading −1 to +8	19/8	67	121	4,365	70	27.9	130	87.4	104

Table 35. Statistical analysis of yield (B. Merah; Off season, 1967).

Source	d.f.	S.S.	M.S.	F
Total	27	1345407.4		
Block	3	113433.7	37811.2	0.70 N.S.
Treatment	6	265689.4	44281.6	0.82 N.S.
1—6	1	125250.2	125250.2	2.33 N.S.
4—6	1	198780.5	198780.5	3.70
3,4—5,6	1	175351.5	175351.5	3.27
Error	18	966284.3	53682.5	

L.S.D.: 10% 28.4g, 5% 34.4g/pot.

It was found that treatment no. 7, no watering for 10 days during heading, showed a slight increase in yield as compared with those of the control. But this result should be discarded, because during the treatment there was rainfall of as much as 150 mm.

Peta×T. Rotan line (Main season, 1967/68)

All the treatments given at and after the stage of panicle formation resulted in a marked decrease in number of spikelets per panicle and in weight of 1,000 grains. In plots of treatment nos. 6 and 7, decrease in percentage of ripened grains and in number of perfect grains was also apparently observed. Thus, the grain yields of treatment nos. 4, 6 and 7 were markedly lower than the control. However, why only the treatment no. 5 gave a yield comparable to the control is not known (Tables 36 and 37).

Table 36. Grain yield and yield components (B. Merah; Main season, 1967/68. Aver. of 4 rps.).

Stage of drain	Heading date	Wt. of straw	No. of spikelets per panicle	No. of spikelets per pot	% of ripened grains	No. of perfect grains	Wt. of 1,000 grains	Yield	Index
		g			%		g	g	%
1. Control	8/2	76	102	3,731	71	2,636	26.9	70.8	**100**
2. Tillering −66 to −26	3/3	81	120	3,915	63	2,474	28.1	69.5	98
3. Invalid tillering −47 to −26	16/2	80	118	4,024	73	2,944	27.7	81.5	115
4. Spikelets differentiation −23 to −9	13/2	94	99	3,751	66	2,494	25.6	62.8	89
5. Heading −7 to +3	8/2	88	99	3,928	78	3,064	26.6	81.5	115
6. 4 & 5 −23 to +3	25/2	72	86	3,394	57	1,928	25.3	48.9	69
7. Max. ripening +7 to +18	7/2	76	97	3,839	53	2,033	25.2	51.3	72

Table 37. Statistical analysis of yield (B. Merah; Main season, 1967/68).

Source	d.f.	S.S.	M.S.	F
Total	27	5881.0		
Block	3	363.9	121.3	1.65 N.S.
Treatment	6	4193.8	699.0	9.51***
1—3	1	220.5	220.5	3.00 N.S.
1—4	1	136.2	136.2	1.85 N.S.
1—6	1	1012.5	1012.5	13.78**
1—7	1	780.2	780.2	10.61**
Error	18	1323.3	73.5	

L.S.D.: 5% 12.7g, 1% 17.4g/pot.

Bahagia (Main season, 1968/69)

(a) Treatment nos. 1 to 6.

It was observed that no-watering treatments given at and after the stage of panicle formation caused a decrease in number of spikelets per pot, although a rate of the decrease differed with different treatments. This decrease in number of spikelets was not caused by the decrease in number of spikelets produced per panicle, but due to the reduced number of panicles. A decrease in percentage of ripened grains was also observed in treatment no. 5, and decrease in weight of 1,000 grains in treatment nos. 3, 5 and 6. Thus these treatments resulted in lower yields than the control.

Table 38. **Grain yield and yield components (T. Chengai ; Main season, 1968/69. Aver. of 4 rps.).**

Stage of drain	Heading date	Wt. of straw	No. of spikelets per panicle	No. of spikelets per pot	% of ripened grains	Wt. of 1,000 grains	Grain/straw ratio	Yield	Index
		g			%	g	%	g	%
1. Control	3/12	95	139	5,858	60	25.0	95	88.0	**100**
2. Invalid tillering −52 to −37	5/12	104	129	5,995	62	24.7	88	90.9	103
3. Rachis-branch differ. −37 to −22	6/12	91	125	5,439	65	23.8	93	83.4	95
4. Spikelet differentiat. −22 to −12	3/12	88	130	5,100	64	25.4	94	82.3	94
5. Booting −10 to 0	5/12	102	134	5,551	56	22.4	67	68.2	78
6. Initial ripening +1 to 11	2/12	92	143	5,622	65	23.6	94	86.0	98
7. Intermittent 7 days interval	9/12	83	88	3,466	50	21.8	46	37.3	42
8. Intermittent 12 days interval	27/12	78	52	2,033	9	17.0	6	3.2	4

Table 39. Statistical analysis of yield (T. Chengai ; Main season, 1968/69).

Source	d.f.	S.S.	M.S.	F
Total	31	29375.5		
Block	3	209.3	69.8	0.83 N.S.
Treatment	7	27409.5	3915.6	46.73***
1—4	1	66.2	66.2	0.79 N.S.
1—5	1	780.2	780.2	9.32**
2,3,4,6—5	1	466.1	466.1	5.57*
5—7	1	1922.0	1922.0	22.96***
Error	21	1756.7	83.7	

L.S.D.: 5% 13.5g, 1% 18.3g, 0.1% 24.7g/pot.

(b) Treatment nos. 7 and 8.

Intermittent watering in these treatments resulted in drastic decreases in number of panicles, number of spikelets per panicle, percentage of ripened grains, and weight of 1,000 grains, thus giving very poor yields. Date of flowering was also very much delayed by these treatments, 6 days and 24 days delay in treatment nos. 7 and 8 respectively.

3. Discussion

It was found that the drying of soil was effective in preventing the heavily reduced condition of the soil during the treatment and also to a certain extent after the end of the

Table 40. Process in determination of grain yield, critical stages of plant growth for water deficiency and degree of necessity of water at different stages of growth (An example of Bahagia in off season).

Days afte sowing	30	40	50	60	70	80	90	100	110	120	130	140
Days after planting	0	10	20	30	40	50	60	70	80	90	100	110
Days before heading	80	70	60	50	40	30	20	10	0	−10	−20	−30

	Just after transplanting	Valid tillering stage	Invalid tillering stage	Spikelets differentiation stage	Reduction division stage	Flowering and milk ripe stage	Dough, yellow ripe and maturing stage
No. of panicles	——	——	——	—			
No. of spikelets/pani				——	——		
% of ripened grains					——	——	—
1,000 grain weight					—	——	—
No. of spikelets/hill	——	——	——	——	——		
Yield per spikelet				——	——	——	—
Degree of necessity of water	I	II	IV	II	I	I	III

Note: Horizontal lines shown in the table indicate the period when each of yield component is determined.

$$\text{Grain yield}=\begin{pmatrix}\text{No. of}\\ \text{panicles}\end{pmatrix}\times\begin{pmatrix}\text{No. of spikelets}\\ \text{per panicle}\end{pmatrix}\times\begin{pmatrix}\text{\% of ripened}\\ \text{grains}\end{pmatrix}\times\begin{pmatrix}\text{Wt. of 1,000}\\ \text{grains}\end{pmatrix}$$

I Most essential, II Essential, III Fairly essential, IV Not essential.

treatments.[32] However, the indica rice normally has the tolerance to the reduced conditions as compared with japonica rice.[33] On the other hand the loss of soil nutrients caused by the drying of soil and also saving of water should be taken into consideration.[18, 26]

In general, yield components, indicated by the number of spikelets per unit area, percentage of ripened grains and weight of 1,000 grains, were poor in the treatments during the booting stage (15 to 5 days before heading) and the most active ripening stage (5 to 15 days after heading) as compared with the control. This was largely due to the water deficiency at these critical stages and it brought a distinct decrease in yield.[18, 22]

However, there was a case where the treatments during the heading stage or initial ripening stage for 10 days gave no significant decrease in yield (Appendix 6). It can be presumed that whether both stages had a slight tolerance for the water deficiency as compared with booting stage and most active ripening stage, or the drought treatment was not done sufficiently because of rainfall during these treatments.

The drying of soil during the tillering stage or before spikelet differentiation stage did not bring any significant decrease in yield as compared with the control,[18,31] even though the plant height or number of tillers were reduced. This was due to the recovery of growth after treatments. It can be said that the reduction division stage and the most active ripening stage were most susceptible to water defficiency. All these results are consistent with the results obtained by Matsushima[18] and other research workers,[21,22,26] and can be applicable to rice cultivation in Malaysia.

The periods during which inadequate irrigation would affect the grain yield components are summarized in Table 40. The relative necessity of water at various stages of growth is also indicated with Bahagia in off season in this table.

(5) Effect of Mid-Season Drainage on Growth and Yield of Rice

To determine the effect of mid-season drainage, i.e. a drainage at the invalid tillering stage, on growth and yield of rice, a field experiment was carried out.

The mid-season drainage is a farm practice commonly used in Japan,[23,30,31,45] and purpose of this experiment is to know the effect of this practice on newly developed indica variety to be used for double cropping in Malaysia (Plate 19).

1. Method and Material

Location: Bukit Merah Padi Experiment Station (Appendix 3).

Soil: Recent riverine alluvium and light clay.[11,20]

Variety: Ria (IR 8, growth duration about 125 days).

Layout: 10 randomized plots, with 4 replications.

Spacing: 25 cm × 25 cm, using 3 seedlings per hill.

Treatment:

Plot no.	Treatment	Fertilizer applied kg/ha (lb/acre)			Remarks
		N	P_2O_5	K_2O	
1.	Control	0	0	0	No drainage treatment
2.	〃	101 (90)	67 (60)	39 (35)	〃
3.	Drainage for 6 days	0	0	0	Treatment started 29 days after transplanting
4.	〃	101 (90)	67 (60)	39 (35)	〃
5.	Drainage for 12 days	0	0	0	〃
6.	〃	101 (90)	67 (60)	39 (35)	〃
7.	Drainage for 18 days	0	0	0	〃
8.	〃	101 (90)	67 (60)	39 (35)	〃
9.	Intermittently irrigated for 19 days	0	0	0	4 days of watering and 4 days of drainage were alternately repeated. Treatment started 29 days after transplanting.
10.	〃	101 (90)	67 (60)	39 (35)	〃

Method of fertilizer applications:

Basal dressing—70% of N plus full dose of P_2O_5 and K_2O were applied.

Top-dressing—30% of N at young panicle formation stage, i.e. 23 days before heading was applied.

Procedure:

The border dike of each plot was coated by vinyl film in order to prevent plot border seepage. Water supply was discontinued during the treatment period. When it rained during the treatment period, rain-water was ladled out after the rain.

Transplanting: 1/6/1967 (23 days seedling).

2. Results and Discussion

Plant growth, rainfall records, pH and Eh of soils, grain yield and yield components are shown in Tables 41 to 45.

Table 41. Record of plant growth (Off season, 1967. Aver. of 4 rps.).

Plot no.	28/6 (27)		12/7 (41)		19/7 (48)		LAI	Culm ht.	4/9 No. of panicles		% of effctive tillers
	Plant ht.	No. of tillers	Plant ht.	No. of tillers	Plant ht.	No. of tillers			per hill	per m²	
	cm		cm		cm			cm			%
1.	48	8.8	61	14.9	63	15.9	2.26	62	13.3	213	83
2.	52	13.4	72	19.0	73	19.5	5.07	64	18.1	290	93
3.	45	9.5	57	15.2	60	16.7		61	14.0	224	84
4.	53	12.9	70	19.2	74	20.2		67	18.0	288	89
5.	48	7.9	58	13.8	62	16.2	2.00	63	13.3	213	82
6.	52	15.5	70	20.4	75	21.8	4.94	66	19.6	314	89
7.	48	8.8	58	15.6	60	17.8		63	14.9	238	84
8.	50	15.2	69	20.9	73	21.6		67	19.9	318	92
9.	48	8.3	58	15.0	61	16.5		62	13.8	221	84
10.	53	13.1	74	19.4	76	20.8		66	18.8	301	90

Figures in parentheses show number of days after transplanting.

1) Plant growth

No difference in plant growth during and after the treatments was found between the control and treated plots at the same level of fertilizer application. However, at the stage after flowering, plot nos. 6, 7 and 8 showed a little more panicles than the controls (Table 41). Fertilizer application resulted in taller plants with more tillers and panicles than non-fertilized plots.

Table 42. Amount of rainfall during treatment.

Plot no. and treatment	Period of drying	Days before heading	No. of rainy days	Rainfall			
	days	days	days	//		mm	
3. & 4. Drainage	6 (30/6- 5/7)	45—39	1	.59		15.0	
5. & 6. Drainage	12 (30/6-11/7)	45—33	2	.66		16.8	
7. & 8. Drainage	18 (30/6-17/7)	45—27	3	.75		19.1	
9. & 10. Intermittently irrigatted	4 (30/6- 3/7)	45—41	1	.59		15.0	
	4 (8/7-11/7)	37—33	1	.07	.70	1.8	17.8
	4 (15/7-18/7)	30—26	1	.04		1.0	

Leaf area index of plot nos. 5 and 6 were almost the same as that of plot nos. 1 and 2, respectively. Its value in fertilized plots, nos. 2 and 6, was around 5. This was the highest figure which the author experienced in Malaysia.[34]

2) Rainfall during treatment

It was recorded that there was not much rainfall during the period of treatments except plot nos. 3 and 4 (Table 42). The drying of soil in plot nos. 3 and 4 was imperfect as compared with that of other plots.

Table 43. pH and Eh of soil.

Plot no. and treatment	10/6		6/7		13/7		20/7		27/7		10/8	
	pH	Eh_6	pH	Eh_6	pH	Eh_6	pH	Eh_6	pH	Eh_6	pH	Eh_6
		mV		mV		mV		mV		mV		mV
1. Control Non fertilized	6.7	73	6.7	103								
2. Control Fertilized	6.7	10	6.8	219	5.3	89	5.8	28	6.0	74	5.7	−43
6. Drainage for 12 days Fertilized					4.2 (2)	2	4.7 (9)	−26	5.8 (16)	114	5.7 (30)	−3
7. Drainage for 18 days Non fertilized			6.9 (0)	119	4.1 (0)	224	4.5 (3)	121	4.7 (10)	49	5.5 (24)	−22
8. Drainage for 18 days Fertilized			6.1 (0)	89	4.3 (0)	130	4.6 (3)	231	5.0 (10)	83	5.6 (24)	−39

Figures in parentheses show number of days after completion of treatment.

3) Changes in pH and Eh of soil

A rise in Eh was observed with only 18 day-drainage treatment, and pH went down with 12 day- and 18 day-drainage treatments. The changes in pH values of the treated plots were between 4.1 to 6.9.

Table 44. Grain yield and yield components (Off season, 1967. Aver. of 4 rps.).

Plot no. and treatment	Wt. of straw	No. of spikelets per panicle	No. of spikelets per m^2	% of ripened grains	Wt. of 1,000 grains	Grain/straw ratio	Yield		Index	
	t/ha		$\times 10^4$	%	g	%	lb/ac	t/ha	%	%
1. Control Non f.	4.0	95	2,0	48	28.3	69	2,459	2.76	**100**	
2. 〃 Fertilized	5.8	94	2,7	60	29.4	83	4,283	4.80	174	**100**
3. 6 days drain Non f.	3.9	81	1,8	45	28.5	69	2,302	2.58	94	
4. 〃 Fertilized	5.6	91	2,6	58	29.3	80	3,947	4.42	161	92
5. 12 days drain Non f.	4.2	92	2,0	54	28.8	72	2,669	2.99	109	
6. 〃 Fertilized	6.0	84	2,6	67	30.0	88	4,654	5.22	189	109
7. 18 days drain Non f.	4.4	84	2,0	55	29.3	74	2,877	3.22	117	
8. 〃 Fertilized	5.6	85	2,7	60	29.5	85	4,218	4.73	172	98
9. Intermittent irri. Non f.	3.9	93	2,1	46	28.3	70	2,413	2.70	98	
10. 〃 Fertilized	5.6	91	2,7	59	29.3	85	4,229	4.74	172	99

4) Grain yield and its components

The heading date in all treatments was almost the same as the control.

In general, the mid-season drainage of different periods and intermittent irrigation practiced for 19 days gave no remarkable effect on plant growth and yield. However it can be recognized from the Table 44 that yields of treatment no. 6 was slightly higher than no. 2 (control) and yields of nos. 5 and 7 were also higher than no. 1 (control).

Yields of the 6 day-drainage plots were slightly less than that of controls. It seems that the drainage treatment for 6 days may be too short to expect the effect or the effect was not exhibited because of rainfall occurred during the treatment period.

Table 45. Statistical analysis of yield.

Source	d.f.	S.S.	M.S.	F
Total	39	38703479.4		
Block	3	361429.1	120476.4	0.52 N.S.
Treatment	9	31526680.7	3502964.5	14.98***
Non f.—Fertilized	1	29664895.3	29664895.3	126.83***
1—7	1	349448.0	349448.0	1.49 N.S.
3—7	1	660675.2	660675.2	2.82 N.S.
4—6	1	998284.5	998284.5	4.27*
2—4	1	224785.2	224785.2	0.96 N.S.
2—6	1	275653.2	275653.2	1.18 N.S.
Error	27	6315369.6	233902.6	

L.S.D.: 5% 702 1b/ac (0.79 t/ha), 1% 948 1b/ac (1.06 t/ha), 0.1% 1.262 1b/ac (1.41 t/ha).

The trends of increase in yield in 12 day-drainage plots, nos. 5 and 6, and in a 18 day-drainage plot, no. 7, were due to the increased percentage of ripened grains and weight of 1,000 grains.

The mid-season drainage to be practiced at the invalid tillering stage for 10—20 days starting from 35 days after transplanting with double-cropping varieties is a desirable farm practice from a viewpoint of saving irrigation water. Amount of 145 mm of water is estimated to be saved during a 18 day-treatment (8 mm/day).[26,34] In addition, a yield increase to some extent is also expected by the treatment.[18] Intermittent irrigation in this case seems to be no use.

IV. DISCUSSION AND SUMMARY

A series of experiments have been conducted since the off season 1967, for four seasons with the following three broad objectives in view:—

(A) To study the water requirement (evaporation, transpiration and percolation) in the paddy fields and also to measure the transpiration coefficient of double-cropping varieties in comparison with the long term local varieties.

(B) To study the relation between different depths of water and fertilizer, particularly nitrogen application methods.

(C) To find out the critical stages of plants for water deficiency and to evaluate the effect of the practices of specified water management in combination with other practices on the growth and yield of rice.

This report is primarily based on the studies carried out in the double-cropping areas in the Kedah Plain which is the rice bowl of West Malaysia.

A. Factors affecting the water requirement of rice.

Water requirement

Measurement of water requirement of 3 leading varieties was made both in Telok Chengai Padi Experiment Station and Sala Kanan Padi Test Station, which are located on the alluvium coastal area of the Kedah Plain, for three seasons.

In order to eliminate the climatic effects on evaporation and transpiration, the ratios of evaporation, transpiration and evapo-transpiration to the pan evaporation from free water surface were used.

1) The evaporation gradually decreased with the advance of plant growth. This was due to the mutual shading of plants according to an increase in leaf area and dry matter. Contrary to the above, the ratios of transpiration and evapo-transpiration were smaller during the early stage of growth, and later they increased gradually. Two peaks were noticed around the maximum tiller number stage (45 days after transplanting) and heading stage. The former peak was lower in value than the latter. The change in transpiration according to plant growth was largely due to the growth of plants in size, particularly the leaf area. However, the transpiration ratio per unit leaf area was gradually decrease with the increase of LAI and became almost constant when the value of leaf area index reached beyond 3.5.

2) It was found that the evapo-transpiration ratio was 1.2 on an average throughout the growth period and a range of its variation was 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. If mean values of pan evaporation for a period of certain stages of growth were known, the evapo-transpiration can be calculated from the evapo-transpiration ratio.

3) Total evaporation, transpiration and transpiration coefficient were all correlated with the growth duration. The total evaporation was almost equal to the total transpiration. Evapo-transpiration per day expressed as averages for measurement of each ten day period was 4.2 to 7.3 mm/day and did not vary among three varieties tested. These figures depended on leaf area index and are influenced by prevailing weather conditions.

Table 46. Results of water requirement determined in some Asian countries.

Country	Author	Location	Season	Meas. period	Total (Average daily amount) E	T	ET	P	WR	ET/Em ratio
				day	mm	mm	mm	mm	mm	
Thailand	Kung et al.[15]	Central Plain 15°N	Main season 1964	151 (25/VI-22/XI)	294 (1.9)	591 (3.9)	885 (5.9)	97 (0.6)	983 (6.5)	
			Off season 1965	91 (20/II-21/V)	346 (3.8)	348 (3.8)	695 (7.6)	48 (0.5)	748 (8.2)	
	Royal Irri. Dept.	Northeast 15°N	Main season	94	233 (2.5)	255 (2.7)	488 (5.2)	278 (3.0)	766 (8.2)	
Cambodia	Hatta[7]	Battambang 13°N	Dry seoson 1965/66	106 (22/XII- 7/IV)			710 (6.7)	244 (2.3)	954 (9.0)	(Rainfall 152 mm)
Laos	Kotter[13]	Vientian 18°N	Wet season 1967	102 (10/VIII-20/XI)	270 (2.7)	245 (2.4)	515 (5.1)	742 (7.3)	1,257 (12.4)	
East Pakistan	Kung[14]	Kushtia 24°N	Wet season 1959	78	382 (4.9)	733 (9.4)	1,115 (14.3)	78 (1.0)	1,193 (15.3)	(Effect. rainfall 541 mm
			Dry season 1958/59	101	436 (4.3)	515 (5.1)	951 (9.4)	54 (0.5)	1,005 (10.0)	0)
Ceylon	Murakami[22]	Dry zone 8°N	Dry seasan 1965	112 (31/V-19/IX)	420 (3.8)	552 (4.9)	972 (8.7)	2,475 (22.1)	3,447 (30.8)	ET/Em 1.29
India	Vamadevan et al.[42]	New Delhi 29°N	Wet season 1968	87 (10/VI- 4/X)			493 (5.7)	1,189 (13.7)	1,683 (19.3)	
Malaysia	Sugimoto[34]	Kedah 6°N	Main season 1967/68	97 (20/IX-26/XII)	266 (2.7)	262 (2.7)	527 (5.4)	61 (0.7)	588 (6.1)	1.21
			Main season 1967/68	139 (29/VIII-15/I)	347 (2.5)	387 (2.8)	734 (5.3)	201 (1.4)	935 (6.7)	1.09
			Off season 1968	116 (14/V- 7/IX)	364 (3.1)	372 (3.2)	737 (6.4)	−191 (−0.2)	718 (6.2)	1.17
			Main season 1968/69	110 (14/VIII- 1/XII)	336 (3.1)	312 (2.8)	649 (5.9)	57 (0.5)	705 (6.4)	1.20
			Main season 1968/69	179 (11/VII- 5/I)	574 (3.2)	448 (2.5)	1,022 (5,7)	204 (1.1)	1,226 (6.8)	1.18

	Nishio[26]	Kedah 6°N	Main season 1970/71	102 (13/X-23/I)			542 (5.3)	371 (3.6)	913 (9.0)	1.04
			Off season 1971	122 (19/IV-18/VIII)			834 (6.8)	618 (5.1)	1,452 (11.9)	1.12
		P. Wellesley 6°N	Main season 1970/71	103 (29/X- 9/II)			576 (5.6)	321 (3.1)	897 (8.7)	1.10
			Off season 1971	117 (25/IV-20/VIII)			725 (6.2)	358 (3.1)	1,083 (9.3)	1.10
Taiwan	Cited by Maki[17]	Central 24°N	Interme. season 1923-26	103 (VI-X)	352 (2.9)	323 (3.3)	675 (6.2)			1.17
		Southern 23°N	Interme. season 1923-26	96 (VII-X)	259 (2.6)	304 (3.1)	557 (5.7)			1.08
		Southern 23°N	Interme. season 1923-26	93 (VII-X)	485 (5.0)	296 (3.1)	784 (8.1)			1.48
			Average	97	355 (3.5)	317 (3.2)	672 (6.7)			1.24
	Shibuya	Southern 23°N	Second seoson 1919-22	106 (VIII-XI)	416 (4.0)	93 (0.9)	509 (4.8)	160 (1.6)	669 (6.4)	1.10 (0.98-1.37)
Corea	Tsubouti[40]	Central 37°N	Normal season 1931	90 (22/VI-20/IX)	231 (2.6)	241 (2.7)	472 (5.2)			1.28
Japan	Ishikawa and Nishio[38]	Shikoku 34°N	Early season 1956-59	105 (6/V-19/VIII)	201 (2.0)	315 (3.1)	517 (5.1)	487 (4.8)	1,004 (9.9)	0.97
			Normal scoson 1956-59	112 (21/VI-10/X)	199 (1.8)	372 (3.5)	571 (5.3)	808 (7.5)	1,379 (12.8)	1.19
			Late season 1956-59	81 (29/VII-18/X)	156 (2.0)	219 (2.7)	375 (4.7)	445 (5.5)	820 (10.2)	1.11
			Average 1956-59	99	185 (1.9)	302 (3.1)	487 (5.0)	580 (6.0)	1,067 (11.0)	1.09
	Nakagawa[23]	37 places in the country 32-44°N	Normal season 1947-64	100 (VI-IX)			440-550 (4.4-5.5)			1.30 (0.9-1.7)
	Iwakiri[8]	Kyushu 23°N	Early season 1960-63	91 (1/V-30/VII)	120 (1.3)	233 (2.6)	353 (3.9)	223 (2.5)	575 (6.4)	1.05
			Normal season 1960-63	108 (1/VII-16/X)	160 (1.5)	251 (2.3)	411 (3.8)	420 (3.9)	830 (7.7)	0.96

Note: There are several other papers reporting water requirement of rice determined in tropics, subtropics and temperate zone. However, only the papers in which average daily consumption of water can be calculated are selected and listed in the table.

In general weather conditions affected more on the evaporation than transpiration before the stage of maximum tiller number and later they affected on the transpiration rather than the evaporation.

4) The percolation amount was very small and almost negligible. This could be attributed to the coastal plain where the tested fields were located. It can thus be concluded that the seasonal variations of evapo-transpiration were the dominant factor which caused changes in water requirement in depth in the tested area.

5) On the other hand, an exceptionally low ground water level was observed just after the dry period (March and April) in the field. This, therefore, would induce the delay in the water distribution during the presaturation of off season cropping because of the big seepage caused by low ground water level and cracks of soil profile.

Further investigation is needed on percolation and puddling water in the different types of soil area of the Kedah Plain.

6) The total consumption of water including nursery for a cultivation of Bahagia, 130–140 day variety, by providing standing water throughout the rice season, was estimated approximately to be 1,340 mm=53 in. (9.5 mm/day) during off season (dry season) and 980 mm=38 in. (7.4 mm/day) in main season (wet season) (Table 9). The greater value for off season (greater by 38% than the value for main season) can be attributed to: (a) the greater pan evaporation caused by the weather conditions during off season and (b) the growth duration which was longer by 10 days in off season. If Ria, 120 to 125 day variety, was used in place of Bahagia, 10% and 5% of water could be saved in off season and main season respectively.

According to the author's estimation, 400 mm of water required for presaturation including puddling and supply to nursery in off season would approximately be equal to 40% of the capacity of the two reservoirs in the Muda Irrigation Project. Therefore, in order to shorten the number of days for presaturation, a measure must be taken so as not to increase the peak discharge by means of dividing the benefited area into several districts so called "staggering of irrigation". If it is impossible to increase the unit duty of water, construction of a new field channel diverging from the distributary would be required as a measure to reduce the number of days for water distribution within the irrigation compartment.

Although no data was available for effective rainfall, the water remaining in the field and the conveyance loss, these factors have to be taken into account for actual designing of duty of water.

7) Water requirement determined in some Asian countries in recent years are summarized in Table 46.

Not much difference is found between average daily evaporation and transpiration and there is no extreme difference in daily evapo-transpiration among countries, though data obtained in the tropics particularly East Pakistan and Ceylon are rather high. However extreme differences are found in daily water requirement among countries and seasons, due mainly to the variation of daily percolation.

Percolation loss is extremely high in Ceylon during dry season and in India also, where percolation loss is greater than evapo-transpiration. On the other hand, the percolation data obtained in Thailand, East Pakistan and in Malaysia are very small. This may be due to the heavy clay alluvial soils and rather high ground water level prevalent in the plain.

Most of findings on total water requirement are from 700 mm to 1,200 mm, with extremes of 575 mm and 3,447 mm. The wide range of figures indicates the variation of local conditions which influence primarily the percolation loss. Thus it can be concluded that the value of percolation is a ruling factor determining the value of water requirement when the daily water requirement is more than 10 mm in depth.

However ET/Em ratio ranges 1.1 to 1.3 (mean about 1.2) showing not much difference between the tropics and temperate zone and also among seasons. Evapo-transpiration constitutes a major portion of water requirement when the daily water requirement is less than 10 mm in depth.

Evapo-transpiration can easily be estimated by using ET/Em ratio if the data of pan evaporation in the standard year are available. The water requirement can be estimated by taking into consideration the rate of percolation at a given place on the top of the evapo-transpiration.

Transpiration coefficient

1) According to the measurement of transpiration coefficient of five leading varieties for three seasons, the transpiration coefficient (y) was directly proportional to the growth duration in number of days from transplanting to harvest (x), and can be expressed by the following equations:

$$y=3.27x-75 \quad (r=0.96^{**}) \quad \text{for main season, 1967/68.}$$

$$y=4.71x+201 \quad (r=0.96^{**}) \quad \text{for main season, 1968/69.}$$

The transpiration coefficient calculated by these equations is: 227 in Ria, 275—289 in Mahsuri and Bahagia, and 406—468 in Subang Intan 16 and Radin Ebos 33. It was found that the longest term variety needed twice as much water required for shortest term variety. It means that varieties of short growth duration utilize water more efficient in producing dry matter than varieties of longer duration.

The grain yield of long term variety was normally lower than that of shorter term variety. Therefore the use of long term varieties is inadvisable as the grain production does not commensurate with the greater amount of water consumed.

2) A distinct correlation was observed between dry matter increase per day and the transpiration per day in relation to each stage of growth. A higher value for transpiration coefficient was obtained during the early stage and the least value in mid-growth stage, and the highest was obtained during the ripening stage in general.

There exists a negative correlation between transpiration coefficient and dry matter increase per day throughout the growth period, particularly with Ria (IR 8). This relation signifies that plants utilized water most efficiently when the plants grew most actively.

3) The change of transpiration and transpiration coefficient according to the plant growth was found to be similar to those reported so far in the tropics and Japan. These findings were rather similar to the results obtained by Murakami in Ceylon but partly inconsistent with the results obtained by Matsushima in Malaysia.

4) Transpiration coefficient of rice plants determined in some Asian countries is summarized in Table 47.

Most of findings of transpiration coefficient are from 260 to 500 with extremes of 200 and 760. They are proportional to the growth period particularly evident in data of the tropics. This means that long term varieties in tropics are less efficient for water to produce dry matter than that of short term varieties.

Data of transpiration coefficient in the tropics and subtropics are generally high than those of the temperate zone. This is largely due to the longer growth duration of the former and also the rise in figures of transpiration coefficient during dry season (off season).

Table 47. Results of transpiration coefficient determined in some Asian countries.

Country / Author	Variety	Season	Measurement period	Transpira. coefficient	Season	Measurement period	Transpira. coefficient	Method of culture
			days			days		
Ceylon Murakami[22]	P. P	Wet season 1965	79	305	Dry season 1964/65	79	445	Pot
	Murunga 307	〃	79	312	〃	81	380	〃
	H 4	〃	105	336	〃	116	452	〃
	M 302	〃	103	341	〃	121	490	〃
	Podiwee a-8	〃	135	435				〃
	Ptb-16	〃	136	440				〃
	Remadja				〃	128	530	〃
	Sigadis				〃	128	570	〃
Malaysia Matsushima[18]	Pebifun	Main season 1960/61	87	401	Off season 1960	96	453	Pot
					Off season 1961	90	439	〃
	R. China 4	〃	121	611				〃
	Serup 50	〃	154	766				〃
Malaysia Sugimoto[34]	Ria (IR 8)	Main season 1967/68	92	254	Off season 1968	99	291	Pot
		Main season 1968/69	91	257				〃
	Mahsuri	Main season 1967/68	107	248	Off season 1968	119	319	〃
		Main season 1968/69	104	274				〃
	Bahagia (Sister line of IR 5)	Main season 1967/68	110	274	Off season 1968	119	338	〃
		Main season 1968/69	104	259				〃
	S. Intan 16	Main season 1967/68	147	393				〃
		Main season 1968/69	142	444				〃
	R. Ebos 33	Main season 1967/68	147	431				〃
		Main seafon 1968/69	137	483				〃
	Ria (IR 8)	Main season 1967/68	96	316				Field
		Main season 1967/68	94	262				〃
	Bahagia	Main season 1968/69	109	306	Off season 1968	115	344	〃

Table 47. Continued.

Author Country	Variety	Season	Measurement period	Transpira. coefficient	Season	Measurement period	Transpira. coefficient	Method of culture
			day					
Malaysia Sugimoto[34]	R. Ebos 33	Main season 1967/68	138	321				Field
		Main season 1968/69	178	386				〃
Taiwan Cited by Maki[17]		Intermediate season 1923–26	97 (93–103)	486				Field
China (Manchuria) Kojima	Waseono	Normal season 1933	92	344				Pot
Korea Sato	Ginbozu	Normal season 1932–38	90	205 (171–327)				Field
Korea Tsubouti[40]	Rikuu 132	Normal season 1933	50	258				Field
	Kamenoo	〃	50	303				〃
	Odashiro	〃	50	334				〃
	Nakateginbozu	〃	70	319				〃
	Tamanishiki	〃	80	260				〃
	Kokuryomiyako	〃	80	276				〃
	Omachi	〃	90	290				〃
Japan Tamai et al.	Yachikogane	Very early season 1958	118	290				Pot
		Early season 1958	105	322				〃
		Normal season 1958	—	381				〃
Japan Hasegawa	Fujisaka 5	Early season 1957–58	111	285				Pot
		Normal season 1957–58	111	291				〃
		〃	96	281				Field
Japan Kato et al.[10]	Yachikogane	Normal season 1962	101	310				Field
		Normal season 1963	108	305				〃
Japan Ishikawa and Nishio[38]	Norin 17	Early season 1956–59	105	393				Field
	Mihonishiki	Normal season 1956–59	112	308				〃
	Norin 37	Late season 1956–59	81	234				〃

These figures therefore are not much difference between two zones when comparison is made on similar growth duration. The figures in temperate zone are averaged around 300 and they are somewhat similar with author's data in the tropics.

Seasonal differences in transpiration coefficient are particularly evident in data of the tropics, due to the rise of transpiration coefficient during dry season. The figures of transpiration coefficient in pot culture are less than those of field culture in general.

B. Relation between depth of water and fertilizer application.

1) It was found that yields were decreased in proportion to the depth of water, but the extent of yield reduction was not so noticeable in Bahagia as that of Ria, indicating that Bahagia is more tolerant than Ria to an adverse condition like deep water submergence.

2) Comparing the yield increasing effect of basal dressing with top-dressing of nitrogen, it was observed that the top-dressing of nitrogen was significantly more effective than the basal dressing particularly with Ria. This was due to an increase in quantity of nitrogen of plants, which resulted in an increase of the number of panicles and number of spikelets per hill in the top-dressing plots.

3) Total quantity of nutrients absorbed particularly N, was highly correlated to the grain yield. Nitrogen utilization ratio by plants was also higher with top-dressing than basal dressing, and this caused more yield increase by top-dressing than by basal dressing. It is desirable to maintain the water depth as shallow as possible for double-cropping varieties to get high yield.

C. Effect of drought and mid-season drainage on growth and yield of rice.

Critical stage for water deficiency

1) Water shortage at the tillering stage causes reduced plant height and decreased number of tillers. However, plants show a recovery from the retarded growth when the condition is favorable during the succeeding period, and grain yield is higher than that expected from the reduced number of tillers.

2) Water shortage at the invalid tillering stage causes no adverse effect on plant growth and yield.

3) Water shortage at and after the stage of panicle formation, particularly during reduction division stage, and at the most active ripening stage gives no significant effects on plant growth such as plant height and number of tillers, but it causes a distinct decrease in yield by reducing number of spikelets per panicle and per hill, percentage of ripened grains or weight of 1,000 grains.

4) It can be said that the reduction division stage (15 to 5 days before heading) and the most active ripening stage (5 to 15 days after heading) are most susceptible to water deficiency. All these results are consistent with the results obtained by Matsushima and other research workers, and can be applicable to rice cultivation in Malaysia.

The periods during which inadequate irrigation would affect the grain yield components are summarized in Table 40. The relative necessity of water at various stages of growth is also indicated with Bahagia in off season in this table.

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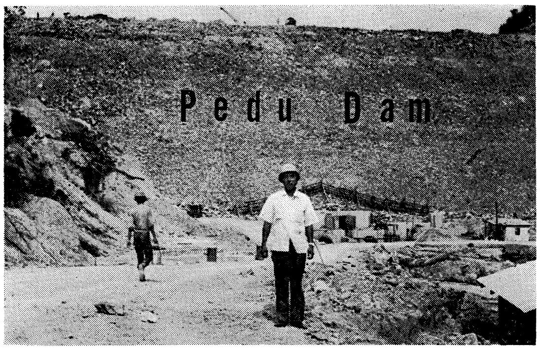

Plate 1. Pedu Dam under construction (1968).

Plate 2. Secondary canal in Muda Irrigation Project area.

Plate 3. Sight of Telok Chengai Padi Experiment Station from behind (1968).

Plate 4. Nursery at Telok Chengai Padi Experiment Station.

Plate 5. Pulling of seedlings.

Plate 6. Transplanting of experimental plot.

Mid - season drainage

1) There was not much difference in plant growth between control and treated plots at the same level of nitrogen application. The increase in yield in 12 day-drainage plots and a 18 day-drainage plot was due to the increase in percentage of ripened grains and weight of 1,000 grains. In general, a 6 day-drainage was insufficient to give an increase in yield.

2) The mid-season drainage during invalid tillering stage for 10—20 days is desirable farm practice from a viewpoint of saving irrigation water with some expectation of yield increase. Amount of 145 mm of water (8 mm/day) is estimated to be saved during a 18 day-treatment without sacrificing the grain yield.

3) It was found that drying of soil had an effect to prevent the heavily reduced conditions of the soil during the treatments and also to a certain extent after the completion of the treatments. However, the indica rice normally has tolerance towards the reduced conditions as compared with japonica rice, and accordingly the loss of nutrients caused by the drying of soil and also saving of water should be taken into consideration.

There is, therefore, a need for proper drainage facilities to practice the mid-season drainage for 2 to 3 weeks after the final stage of valid tillering (30—35 days after transplanting), and so the cost of drainage should also be taken into consideration.

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Plate 7. Arrangement of evaporation and transpiration tanks in paddy field.

Plate 8. Evaporation tank.

Plate 9. Evapo-transpiration tank.

Plate 10. New double cropping varieties at maturing stage.

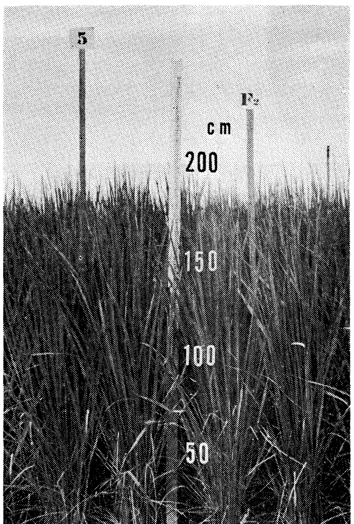


Plate 11. Plant growth of Radin Eboss 33 before heading stage.

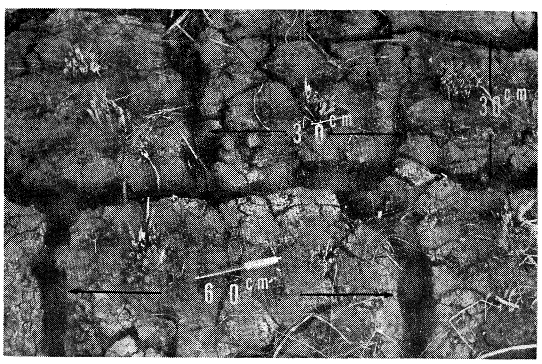


Plate 12. Cracks of field surface during dry period (March 1968).

Plate 13. Measurement on transpiratinon of pot plants.

Plate 14. Measurement on transpiration of pot plants.

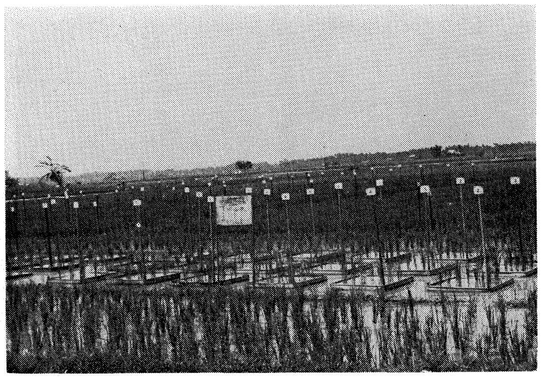


Plate 15. Experiment on water depth and fertilizer application (Frame test).

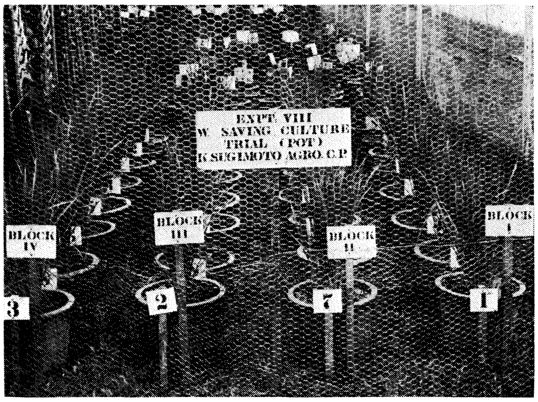


Plate 16. Experiment on water saving culture.

Plate 17. Experiment on drought.

Plate 18. Withered plants by intermittent irrigation.

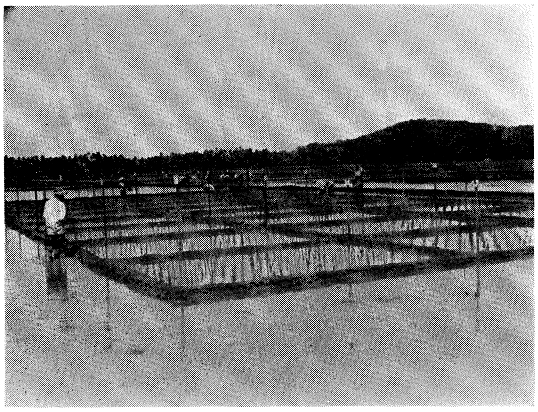
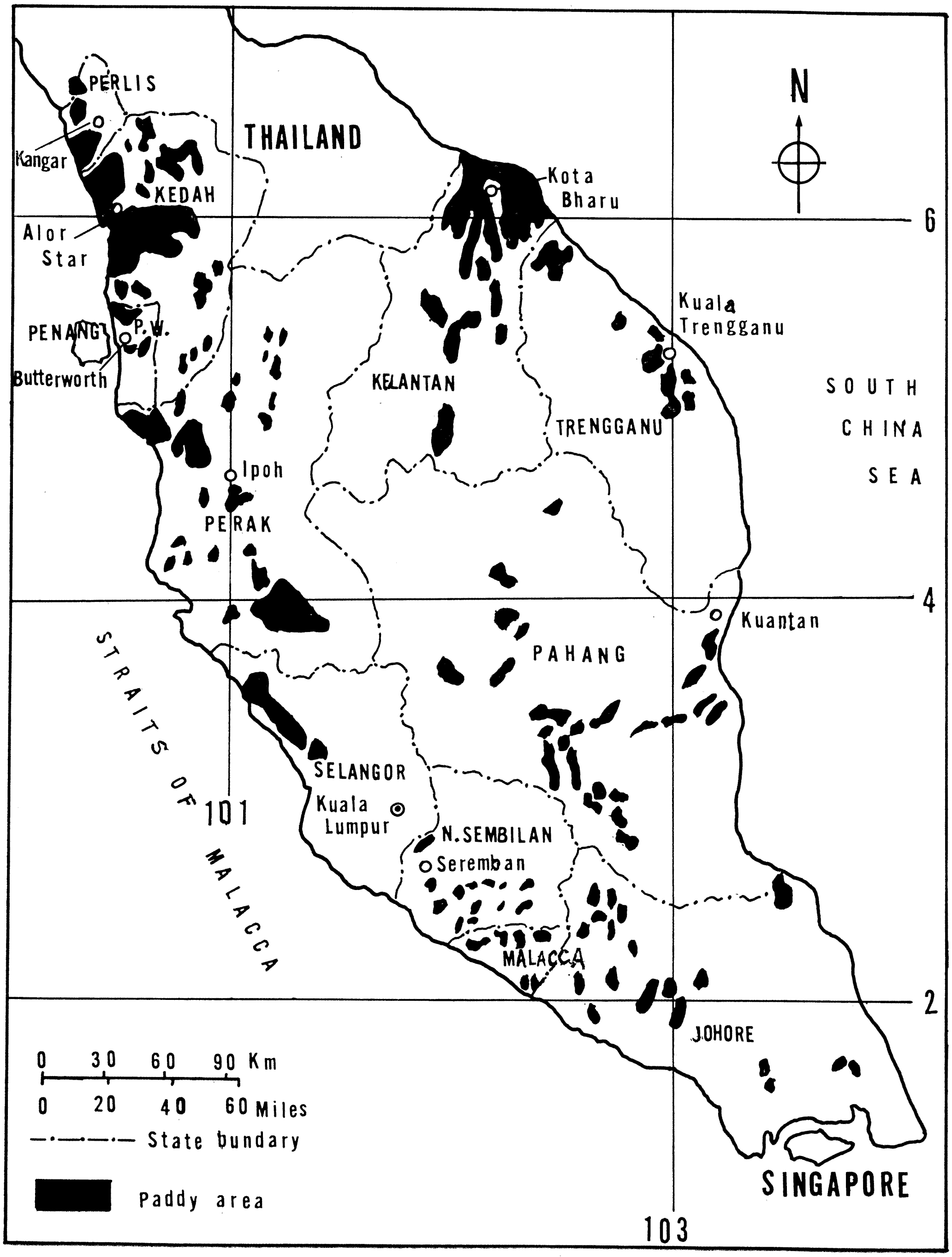


Plate 19. Experimental field of mid-season drainage.

Plate 20. Survey for double cropping Pilot Project in Kubang Sepat (Variety: Ria).

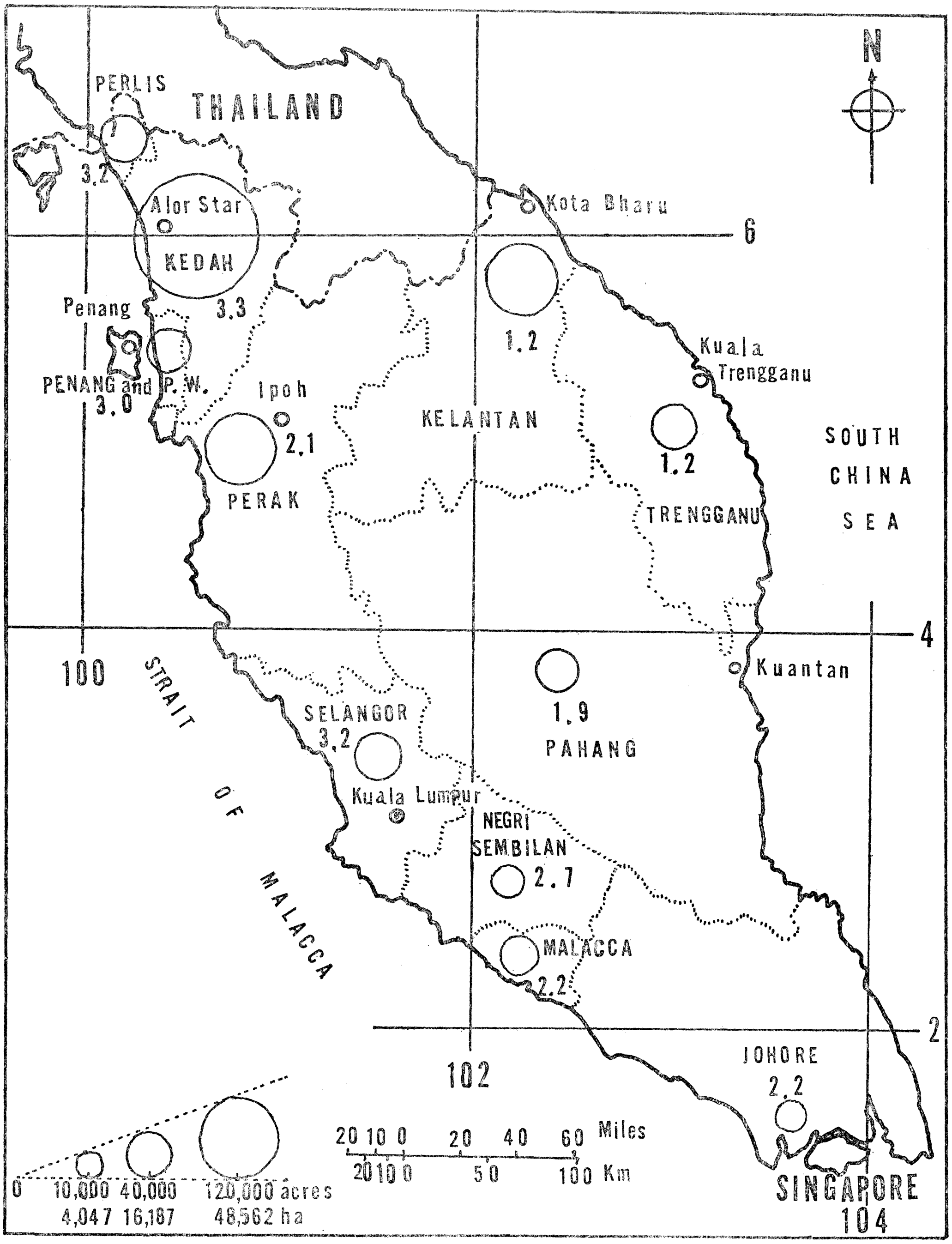
APPENDIX 1

Distribution of paddy areas in West Malaysia



APPENDIX 2

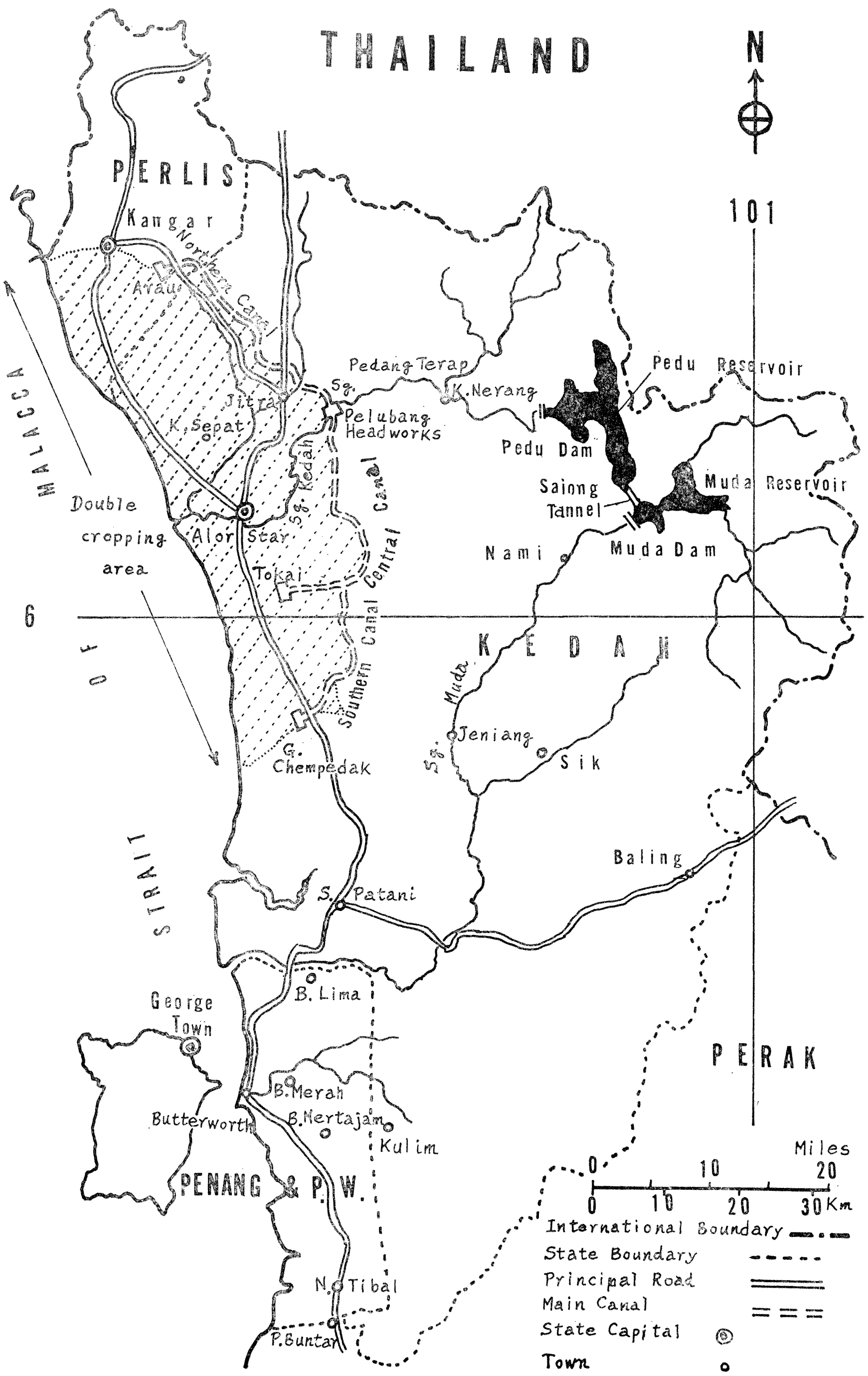
Acreage of main season paddy and its average grain yield (t/ha) (1964-66).



Note: Figures with the circles indicate the average yield in that locality.

APPENDIX 3

Muda River Irrigation Project area



APPENDIX 4

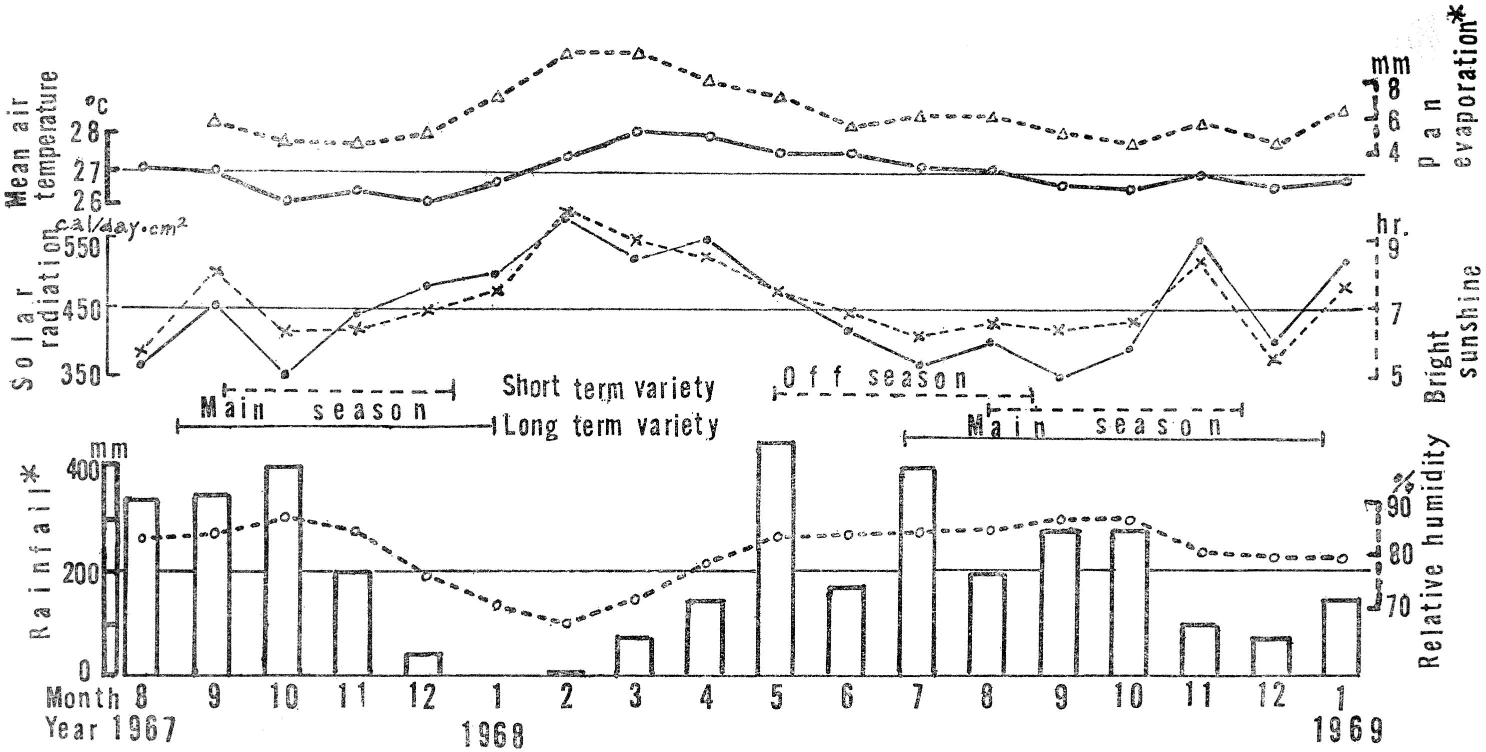
Meteorological records (Telok Chengai Padi Experiment Station ; Lat. 6°5′N, Long. 100°20′E)

Month	Rainfall 1948–68 mean	Rainfall 1951–62* mean	Rainfall 1967	Rainfall 1968	Relative humidity* 1967	Relative humidity* 1968	Bright sunshine* 1967	Bright sunshine* 1968	Air temperature* 1967 Max.	Air temperature* 1967 Mean	Air temperature* 1968 Max.	Air temperature* 1968 Mean	Pan evaporation per day 1967	Pan evaporation per day 1968
	mm	mm	mm	mm	%	%	hr.	hr.	°C	°C	°C	°C	mm	mm
1	27.7	49.3	73.7	1.8		70.3		248.5 (8.02)			33.0	26.6		7.2
2	37.8	58.2	13.7	2.8		66.3		279.7 (9.64)			34.9	27.3		9.6
3	89.9	152.1	29.2	75.2		70.6		264.2 (8.52)			34.8	28.0		9.6
4	151.6	223.0	74.9	153.2		78.2		242.9 (8.10)			34.3	27.8		7.9
5	222.8	223.8	297.9	449.1		83.2		229.1 (7.39)			32.6	27.5		6.8
6	184.7	188.7	359.7	163.3		83.0		189.7 (6.32)			32.2	27.4		5.2
7	229.9	238.3	152.9	385.8		83.6		165.3 (5.33)			31.2	27.2		6.1
8	232.7	251.2	333.2	189.2	83.2	84.8	161.5 (5.21)	188.2 (6.07)	31.2	27.1	31.1	26.9		6.1
9	286.3	284.7	348.5	273.3	84.1	85.9	212.7 (7.09)	153.3 (5.11)	31.1	26.3	30.8	26.6	5.6	4.9
10	393.4	311.4	390.4	283.2	87.1	86.3	157.9 (5.09)	178.7 (5.76)	30.6	26.1	31.2	26.4	4.6	4.4
11	189.7	237.0	185.2	89.2	83.9	80.2	205.3 (6.84)	265.6 (8.85)	31.5	26.3	33.2	26.8	4.3	5.5
12	74.9	74.9	37.3	68.1	74.9	79.3	238.0 (7.67)	190.4 (6.14)	31.3	26.1	32.2	26.5	5.1	4.6
Total	2,021 in (79.6)	2,293 in (90.3)	2,297 in (90.4)	2,134 in (84.0)				2,595.6						
Mean						79.3		(7.09)			32.6 °F (90.7)	27.1 °F (80.8)		6.5 in (0.26)

* Records of Meteorological Station (Lat. 6°12′N, Long. 100°25′E, Height above M.S.L. 5 m) in Alor Star.

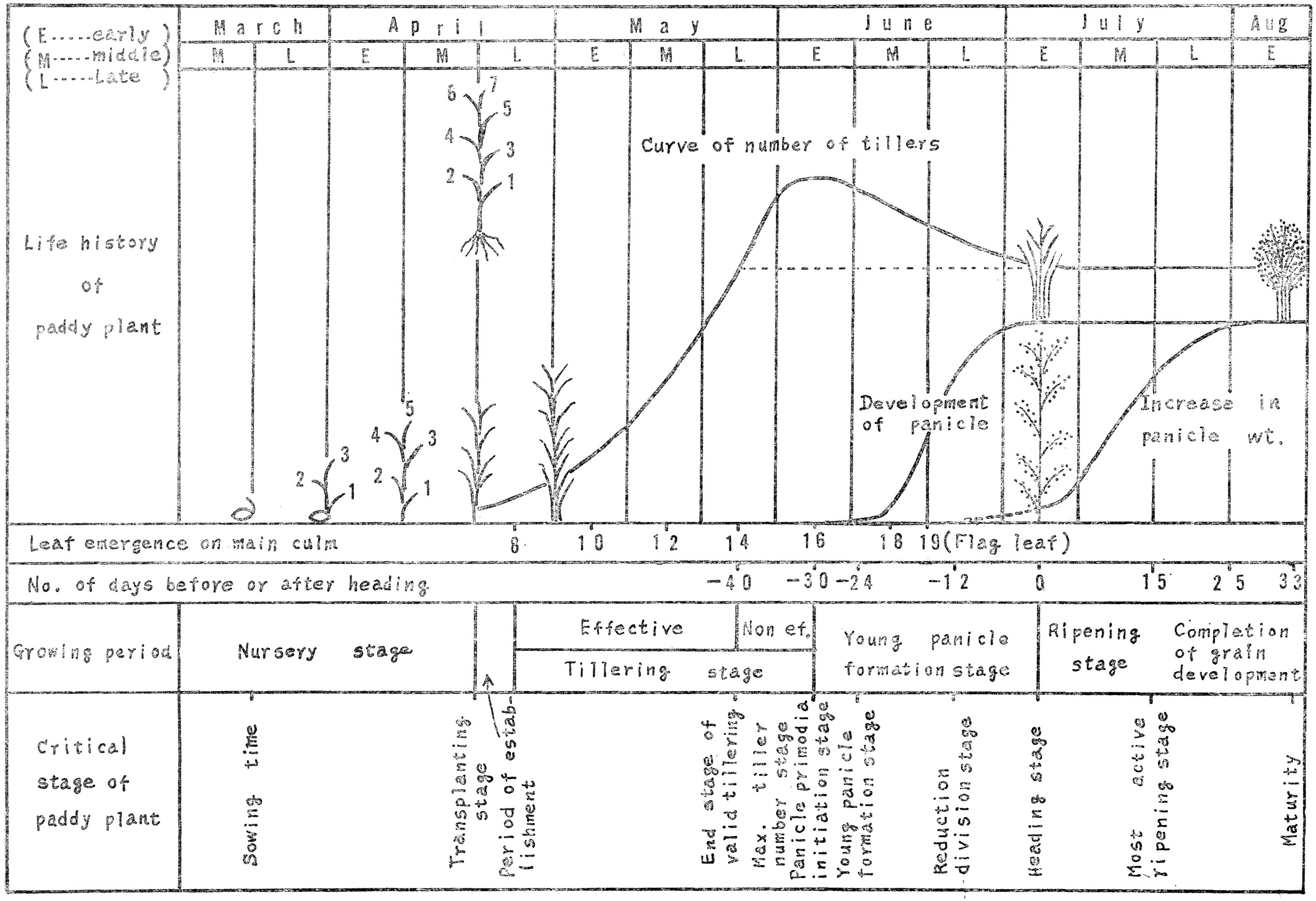
APPENDIX 5

Rice growing period and its meteorogical records (Telok Chengai Padi Experiment Station* and Meterological Station in Alor Star).



APPENDIX 6

Life history of rice plant (an example of Rahagia in off-season).



和　文　抄　録

マレィシアにおける稲の蒸発散量および水管理に関する研究

杉　本　勝　男

目　　次

ま　え　が　き

西マレィシアでは1969年に約260万ha（650万エーカー）の耕地があり，そのうち7割弱はゴム園であり，次いで15％で40万ha（99万エーカー）の稲作（4万エーカーの陸稲を含む）が位置する。人口の6割が農林漁業に従事しており，主産業の生ゴムは輸出額の5割を占めている。米の自給率は1969年に7～8割を示す。1957年の独立以来政府は食糧の自給達成とマレー人農民の所得向上のために，かんがい施設の拡充により，二期作の普及を主体に稲作振興に努めており，1969年には二期作の面積は9.3万ha（23万エーカー）で水田面積の25％に達した。この10年間に米は約10割の生産増を示し，消費量（人口）の増加を上回わり，徐々に自給率を高めている。

西北海岸のケダー平原は西マレィシア全水田の4割を占める最大の穀倉である。第1次経済開発5カ年計画（1966～70年）の農業部門（全投資額の1/4）の最大のエベントとして，ムダ川かんがい計画の工事が1966年に発足した。この目的はMudaとPeduの2つの人造湖（貯水量10億トン）と運河を造成し，かんがい水をおもに3～7月の乾期のOff seasonにケダー平原に供給し，その水田の8割に当る約10万ha（26万エーカー）を二期作化しようという米自給化の中心となる大計画である。1970年のOff seasonから漸次二期作化が進められている。

筆者は1967年4月から69年の7月の2年3カ月，このかんがい計画地域の中心にある国立Telok Chengai稲試験場を主体に，熱帯農業研究の在外研究員とし試験研究に従事した。これは1962年から64年にかけてのコロンボプラン専門家としての業務を合わせると第2回の西北海岸への駐在になる。今回は主要な業務として二期作化にともなう用水量の調査，二期作用適品種の蒸散係数の研究，用水の必要時期の究明などを中心に稲と水の関係について研究を進めた。

本研究の実施に当り，現地においてVan Thean Kee（農務局研究部長），Mohd. Tamin bin Yeop（ケダー州農務部長），Chee Sek Pan（稲中央試験場長），Goh Khek Boon（前Telok Chengai稲試験場主任），永井阜太郎（前在外研究員・現熱帯農研センター研究部長），川上潤一郎（前コロン

ポプラン育種専門家・現熱帯農研センター）の諸氏から助言と援助を賜わり，また助手の Khairani bin Sanusi, Idris bin Ashaari の諸君には直接試験の調査を分担された。記して謝意を表する。

I．用水量について

（1） 水田における蒸発散と蒸発散比の変化

1) 方法と測定法　水収支法により有底の蒸発散測定器 (91 cm×91 cm×61 cm) と同一面積の長方形の特製株間蒸発計を用い，前者には9株の水稲を，後者の周辺には稲を栽植した。Main season (雨期作 9〜1月) には二期作用の Ria (IR 8, 生育日数125日) あるいは Bahagia (IR 5 姉妹品種，132日) と在来種の Radin Ebos 33 (170日), Off season (乾期作 4〜8月) には Bahagia (142日) をそれぞれ用い，肥料は a 当り N 0.34〜0.67 kg, P_2O_5 0.67 kg, K_2O 0.34 kg を施し，3 season にわたり測定を行なった。

2) 水田用水量　$WR=E+T+(P_1+P_2)$ のうち，葉面蒸散量 (T) は蒸発散量 (ET) と株間蒸発量 (E) の差から，縦横浸透量 (P_1+P_2) は減水深と蒸発散量の差からそれぞれ求めた。豪雨の降った日は観測値の精度が落ちるので，測定値の集計のさいには除外した。気象条件の変化による変動を消去するため，株間蒸発量，蒸散量，蒸発散量を気象観測による計器蒸発量 (Em) で除し，それぞれ蒸発比 (E/Em), 蒸散比 (T/Em), 蒸発散比 (ET/Em) を10日ごとに算出した。これらの比数は比較的精度が高く，蒸発散を検討する場合に考察に便利なので，以下これらの比数を主体に述べる。

3) 蒸発比は葉面積や乾物重の増加につれて減少し，葉面積指数 (LAI) との間に相関 ($r=-0.50^*$) がみられた。逆に蒸散比や蒸発散比は稲の生育につれて漸次増大し，葉面積指数との間に相関 ($r=0.62^{**}$) がみられた。しかし蒸散力を示すといわれる単位葉面積当りの蒸散比は LAI の増大にともない指数曲線的に減少を示し，LAI 3.5 以上では停たいを示す。この単位葉面積当り蒸散比の数値は本邦の稲よりどの LAI においても低く，またより小さい LAI において下降が停たい状態に達する。蒸散比や蒸発散比の変化には移植後 45 日前後の最高分けつ期と出穂前後に二つの山がみられ，後者が極大値を示す。

蒸発散比は生育初期には 1.0〜1.2，最高分けつ期当時は 1.2〜1.3，出穂当時は 1.4 を示し，全生育期間平均で 1.2 となり，品種・作期間の差はきわめて少ない。したがって計器蒸発量がわかれば蒸発散量は概算される。

全蒸発量と全蒸散量は大差がなく，全蒸発散量は生育日数の長短 ($r=0.97^{**}$) に左右され，気象条件の影響も受ける。10日間平均の日当り蒸発散量は 4.2〜7.3 mm の範囲にあり，葉面積や気象条件ひいては計器蒸発量の多少の影響を受ける。

4) 減水深はほとんど蒸発散量の動きに左右された。これは供試田が沿海低湿地にあるため浸透量がきわめてきん少になるためである。また乾期末期の 3〜4 月には極端な地下水位の低下が観察された。このため田面に生ずるき裂と相まって，Off season 初期の配水のさいに漏水の主因となると推察される。浸透量としろかき用水量の測定は今後も必要である。

5) ここで苗しろ期間やしろかきの用水は推定値を用い，全用水量を見積ると，Bahagia で Off season には1,340 mm (日当り 9.5 mm), Main season には 980 mm (同 7.4 mm) と概算される。Off season の 38% の増加は蒸発散比は両 season で差がないにもかかわらず，計器蒸発量が大幅に増大することに関連があり，しろかき用水量の増大と生育日数の延長も関与している。生育日数125日の Ria では 5〜10% の用水の節約になる。以上の見積には有効雨量と水路損失が考慮されて

いない。

（2） 蒸散係数（要水量）の変化と品種間差異（ポット試験）

1） 方法と測定法　品種は 1. Ria (生育日数 125 日), 2. Peta×Tankai Rotan 系統もしくは Bahagia (以下 Bahigia と総称する，(同 130～140 日), 3. Mahsuri (同 130～140 日), 4. Subang Intan 16 (同 160～180 日), 5. Radin Ebos 33 (同 160～180 日) とし，3 season にわたり調査した。うち 4. と 5. の長期種は 2 Main season にのみ供試した。約 1/2,200 a のポットを用い，一株本植とした。測定は各品種 2 ポットの減水深を計り蒸発散量とし，無栽植で中心に木製円柱を立てた 2 ポットにより蒸発量をチェックし，差引により蒸散量を算出した。各ポットは雨水の影響を消去するため，透明ビニールの屋根の下に配置した。

2） 各生育期を通じて日当りの乾物増加量とその蒸散量の間には高い相関 (Ria r=0.966**, Bahagia r=0.80**, R. Ebos 33 r=0.63*) が認められた。蒸散量は一般に出穂期ごろに最高となり，蒸散係数（乾物 1 g の生産に要する蒸散量）は生育初期には比較的高く，中期には比較的低く，登熟期に最高を示した。各時期の蒸散係数は日当り乾物増加量と負の相関があり，日当り蒸散量との負の相関は短期種では認められるが，長期種では蒸散量の多い時期ほど蒸散係数が高まる傾向がみられ，水分効率が低いという知見を得た。すなわち長期種を除き，稲は水の要求度の高い時には最も効果的に水を利用していることがうかがわれ，とくに Ria ではこの傾向が著しかった。

3） 蒸散係数 (y) は移植から収穫までの生育日数 (x) に比例して高まり，次の一次式が求められた。

$$y=3.27x-75 \quad (r=0.96^{**}) \quad \text{Main season, 1967/68}$$

$$y=4.71x-201 \quad (r=0.96^{**}) \quad \text{Main season, 1968/69}$$

Main season には蒸散係数は Ria 227 (実測 256) g, Mahsuri と Bahagia 275～289 (同 248～274) g, S. Intan 16 と R. Ebos 33 406～468 (同 393～483) g と算出される。すなわち長期種は短期種に比べて乾物生産に 2 倍近くの水を必要とし，通常わらに比べてもみの生産量が低いので，水利用の上から望ましくない。また日当りの蒸散量や蒸散係数は Off season のほうが Main season より多かった。

4） 生育時期別の蒸散量の変化は熱帯や本邦での成績と同傾向を示した。しかしマラヤでの松島省三氏の調査では日当り蒸散係数は約 5 g で，品種や作期間に差はみられないとしているが，本調査では調査方法の違いもあるが，蒸散係数が全般に少なく，雨期作の数値は乾期作より若干少なかった。筆者の結果は西尾敏彦氏やセイロンで行なった村上利男氏の成績の傾向と類似する。

II． 水深について

（3） 水深とチッソ施肥法の関係（わく試験）

1） 目的と方法　ケダー平原では雨期作には排水施設が不備なため，時には 30 cm に達する深水田もみられる。水深と施肥法の関係を生育・収量に面から検討する。Ria あるいは Bahagia を用い，91 cm×91 cm の約 1/120 a の無底わくを本田に埋設し，9 株の稲を栽植した。水深は全期間 5, 10, 20 cm の 3 段階とし，施肥法は無肥料，チッソ基肥，チッソ追肥の 3 方法の 9 処理を設け，3 連制とした。a 当り P_2O_5 0.67 kg, K_2O 0.45 kg は全量基肥とし，N は 0.67 kg を追肥区では移植後

約1カ月とえい花分化期に等分に施した。

2) 茎数（穂数）は深水区に比べて浅水区が著しく多く，チッソ基肥区と追肥区の間ではRiaの追肥区の穂数がまさったが，Bahagiaでは両区の間に大差がなかった。地水温は水深が深い区ほど最高温度が低く最低温度が高く，温度格差は少なかったが，絶対値としての差は多くなかった。

3) 収量は水深に比例して減収を示すが，その程度はRiaはBahagiaに比べて多かった。無肥料は他の施肥2グループに比べて明らかに減収を示した。基肥と追肥のグループの間では，基肥が減収を示し，とくにRiaにおいて顕著であった。株当り穂数とえい花数とくにえい花数は収量と高い相関を示し，追肥区の高収量は穂数ひいてはえい花数増によると指摘される。

Riaでは各成分とくにチッソの吸収増は収量と深い関連がみられた。追肥区ではチッソの利用率が基肥区に比べて著しく高くなり，収量増加に寄与していることがうかがわれる。

Ⅲ. 干 害 と 節 水

（4） 生育各期のかん水中断試験（ポット試験）

1) 処理方法と試験区の構成　第1 seasonと第2 seasonはBukit Merah稲試験場，第3 seasonにはTelok Chengai稲試験場で，それぞれRia, Peta×Tangkai Rotan系統，Bahagiaと品種を変えて継続した。処理は無処理区（常時たん水）のほかに第1 seasonには分けつ初期から登熟初期にかけて10日から29日にわたるかん水中断の6処理区，第2 seasonには分けつ初期から登熟中期にかけて11日から40日にわたるかん水中断の6処理区，第3 seasonには分けつ中期から登熟初期にかけて10日から15日にわたるかん水中断ならびに7日おきと12日おきかん水の7処理区をそれぞれ設け，4連制とした。

ポットは第1，第2 seasonには雨よけを設けず，処理期間中の降水は雨後に排除し，第3 seasonには雨水の影響を消去するため，ポットを透明ビニールの屋根の下に配置した。

2) かん水中断により処理期間中とその後ある期間のEhは上昇し，土壌還元防止の効果はみられる。しかし通常インド型の稲は日本型に比べて還元障害に対して鈍感であるため，節水栽培を行なう場合は土壌乾燥による土壌中の養分の損失によるマイナスと用水の節減によるプラスの面を比較検討する必要がある。

3) 一般に無処理に比較して，穂ばらみ期（出穂期前15日から5日）と登熟盛期（出穂期後5日から15日）の2時期はえい花数，登熟歩合や千粒重が劣り，水分不足に最も敏感に反応し，著しい減収となった。

第1，第2 seasonの出穂当時の約10日間の処理は無処理に比べて減収がみられなかった。この時期は前記の2時期ほどには水分不足に対して敏感ではないと推察されるが，雨水防止を行なわなかったため，雨水の影響があることも考慮しなければならない。

4) 14日から40日にわたる分けつ期間中や約2週間のえい花分化期以前のかん水中断は，たとえ草丈や茎数が抑制されても処理終了後に生育が回復するため，無処理に比べて収量に有意差が認められなかった。これらの結果より，減数分裂期や登熟盛期は土壌水分の不足に対して最も敏感であることが指摘される。

（5） 中干しが稲の生育・収量に及ぼす影響

1) 試験区と方法　無効分けつ期間の中干しの適正日数を生育・収量や用水節減の面からRiaを

用いて水田で検討する。無処理（常時たん水），短期中干し（かん水中止6日間），中期中干し同12日間），長期中干し（同18日間），間断かん水（4日あての排水・かん水の反復計19日間）の5処理，無肥と標肥の2段階による計10区を設け，4連制とした。

2)　無処理区に比べて18日間の中干しでも生育に差がみられなかった。土壌乾燥によるEh上昇の効果は長期中干し区を除き，前記の(4)ポット試験のようには明らかでなかった。中期中干しや無肥の長期中干し区では無処理や短期中干し区に比べて収量増加の傾向が認められた。これは土壌乾燥の効果が登熟歩合や千粒重などの収量形質の向上にプラスに働いたためとみられる。6日間の中干しでは，収量形質や収量は向上せず，土壌の乾燥が不十分なことがうかがわれた。

3)　要するに移植後35日たった無効分けつ期の10～20日間の中干しは用水節約のみならず，若干の収量向上が期待される。用水節約量は長期中干し区では約140 mm（日当り8 mm）と概算される。