2. RELATIONSHIP BETWEEN EVAPOTRANSPIRATION AND DRY MATTER PRODUCTION OF *INDICA* RICE

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In many monsoon Asian countries, rice culture is usually dependent on the natural rainfall in the wet season. Water sources and irrigation facilities must be secured for the rice culture in the dry season to increase rice production. At first, water consumption by each crop should be calrified to obtain fundamental knowledge for an irrigation project.

Evapotranspiration and irrigation requirement in the temperate and subtropical zones in Japan, Korea and Taiwan have been studied in detail from the point of view in crop science, agricultural engineering and agricultural meteorology. Most of these studies have been conducted with *japonica* rice under the condition of alternating temperature.

As to the data in the tropical monsoon Asia which is under nearly constant temperature, the studies on the relationship between evapotranspiration and meterological conditions, and water management by IRRI,[4,5,6)] irrigation requirement in Bangladesh and Thailand by Kung[10,11)] and water requirement and management by Matsushima[12)] and Murakami[13)] are noticeable.

In this paper, similar and dissimilar points of evapotranspiration and water requirement between temperate and tropical zones will be discussed as well as the relationship between the change of evapotranspiration, plant growth and meteorological factors, and the varietal difference of evapotranspiration principally on the basis of data obtained in the tropical monsoon Asian countries by the author[20)] or other Japanese scientists.

The author also intends to clarify the difference in efficiency of water use between improved and local varieties from the viewpoint of the relationship between transpiration and dry matter production. He also wishes to introduce some experiments on the effective water management to increase grain yield from 3 tons up to 4 tons per hectare in average.

1. Evapotranspiration of *indica* rice

(1) Change of evapotranspiration in paddy field

Evapotranspiration (ET) is usually determined by means of the water balance method with some small tunks installed in paddy fields. Fig. 1 shows the results of experiments conducted by the author[20)] on the paddy fields in Malaysia. The evaporation (E) in average during 10 days is about 5 mm a day at the early stage of growth but declines gradually according to the growth of plants and reaches to 2 mm a day.

The transpiration (T), on the contrary, is very little at the early stage of growth but it increases linearly and reaches about 3 mm at the maximum tiller number stage and about 5 mm at the heading time showing a bipeak curve. The transition of ET is nearly similar to that of T and it is about 5 to 7 mm a day. Its maximum value appears around the dough ripe stage not always being accompanied with a bipeak

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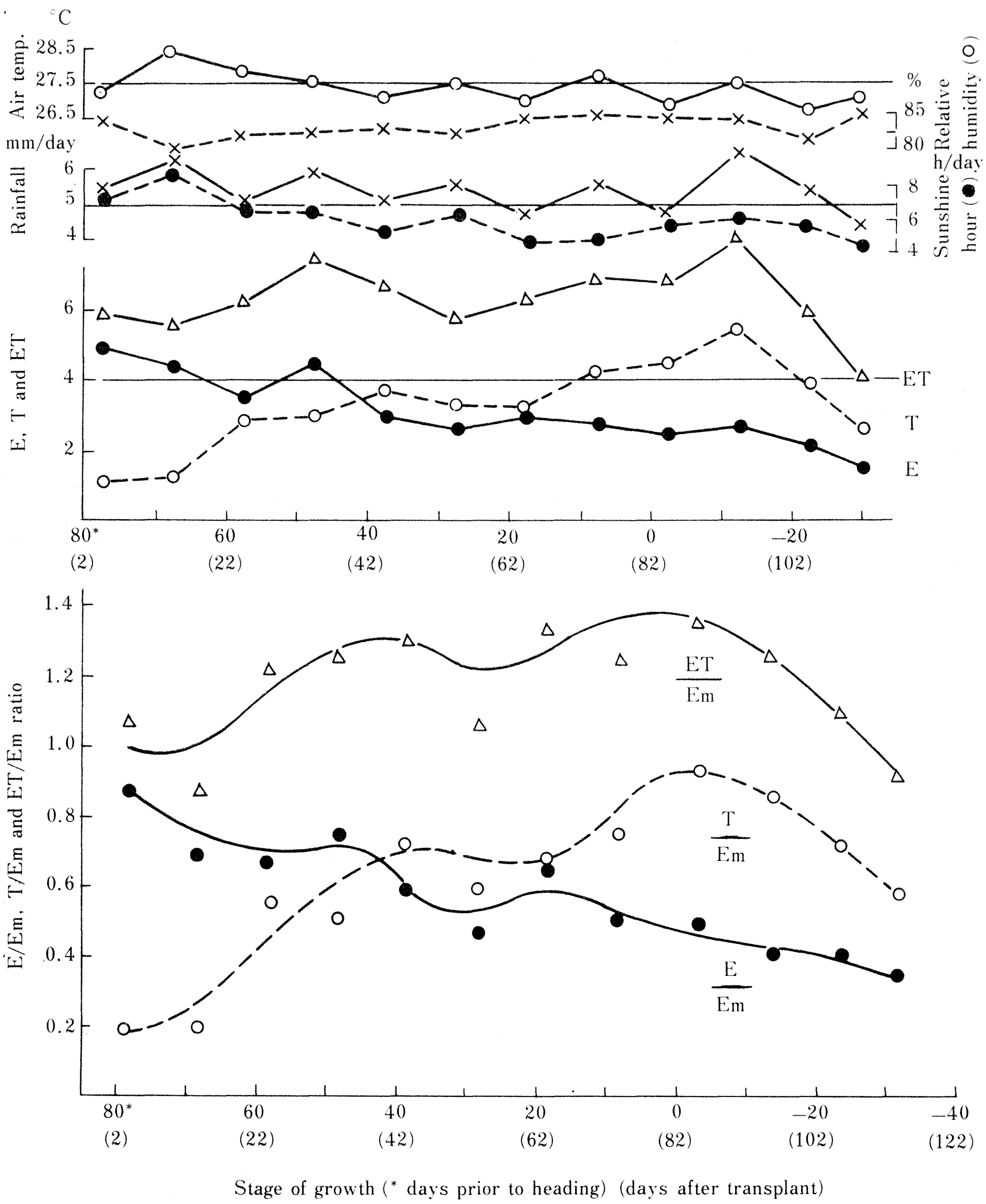


Fig. 1. Changes in evaporation, transpiration, evapotranspiration, and their ratios (Bahagia, Malaysia)[20]

phenomenon. The values of E, T and ET are variable every day depending on the meteorological factors such as solar radiation, air temperature, relative humidity and wind velocity as well as the biological factors, that is, plant growth and leaf area.

To eliminate the effect of these meteorological factors, the values of E, T and ET are divided by the value of pan evaporation (Em) to obtain the ratios of evaporation, transpiration and evapotranspiration. The comparison between the experiments under different conditions such as varieties, cropping seasons and latitudes will be more reasonable by making use of these ratios.[11,14,15,18,21)

As to the transitional patterns of evaporation, transpiration and evapotranspiration ratios, the author could not find any great difference by varieties and cropping seasons in his experiments.[20)] Although the evaporation ratio is as large as 0.8 at the early stage of growth as shown in Fig. 1, it decrease gradually according to the decrease of the water surface area shaded by grown plants and declines to 0.5 to 0.6 at the heading time and 0.2 to 0.3 at the maturity time. The transpiration ratio rises continuously immediately after the transplanting and attains to about 0.7 around the maximum tiller number stage. Then, after about a 20 day stagnating period it shows the maximum value of 0.9 just after the heading time and then rapidly declines to about 0.5 at the maturity time.

Thus the transpiration ratio in the paddy field of the tropics shows transitionally a bipeak curve around the maximum tiller number stage and heading time. This bipeak curve is also recognized in the experiments by Kung *et al.* (Thailand)[10)], Kotter (Laos)[9)] and Nishio (Malaysia).[17)] Murakami (Sri Lanka)[13)] has reported a monopeak phenomenon at the heading time. In the temperate zone, it is not fixed whether the transpiration ratio shows a bipeak curve or not.

Evapotranspiration ratio shows similar transition as the transpiration ratio. That is, the evapotranspiration ratio is 1.0, nearly the same value as Em immediately after the transplanting, and it reaches 1.3 showing a peak at the maximum tiller number stage and then shows the maximum value 1.4 just before or at the heading time. It rapidly decreases during the period of ripening and reaches 0.6 to 0.9 at the mautrity time. In the tropics, the evapotranspiration ratio shows a bipeak phenomenon in many cases except that of Murakami.[13)] Nakagaw[15)] has reported that evapotranspiration ratio in many cases in Japan shows a monopeak curve of which peak appears in the later stage of growth and no apparent bipeak curve has been reported.

(2) Varietal and seasonal differences of evapotranspiration

Table 1 shows the daily average and total amount of evapotranspirtation during the whole growing stage. The author[20)] has made some experiments with three varieties in three cropping seasons. As the result, E is in the range from 2.5 to 3.2 mm, T is 2.5 to 3.2 mm and ET is 5.3 to 6.4 mm. There is no significant difference among three varieties. The varietal difference of daily ET is especially little, and no difference is recognized between E and T.

Varietal difference is significant as to the total amount of E, T and ET, but the difference between each daily average is not great. Consequently a high positive correlation is recognized between growth duration after transplanting and each cumulative value as shown in Fig. 2. Thus the total E, T and ET in the tropics are all dependent on the proper growth duration of each variety. But the effect of growth duration on these three values is obscure in the temperate zone because rice culture is carried out from the season of rising temperature to that of falling temperature.

In the comparison of the percentage of T and ET in each total amount, the percentage of water consumption of local long term variety in the period of reproductive growth corresponds to only a half of that of improved variety, while the consumption of the former variety during lag vegetative phase is as large as 30 percent. Therefore

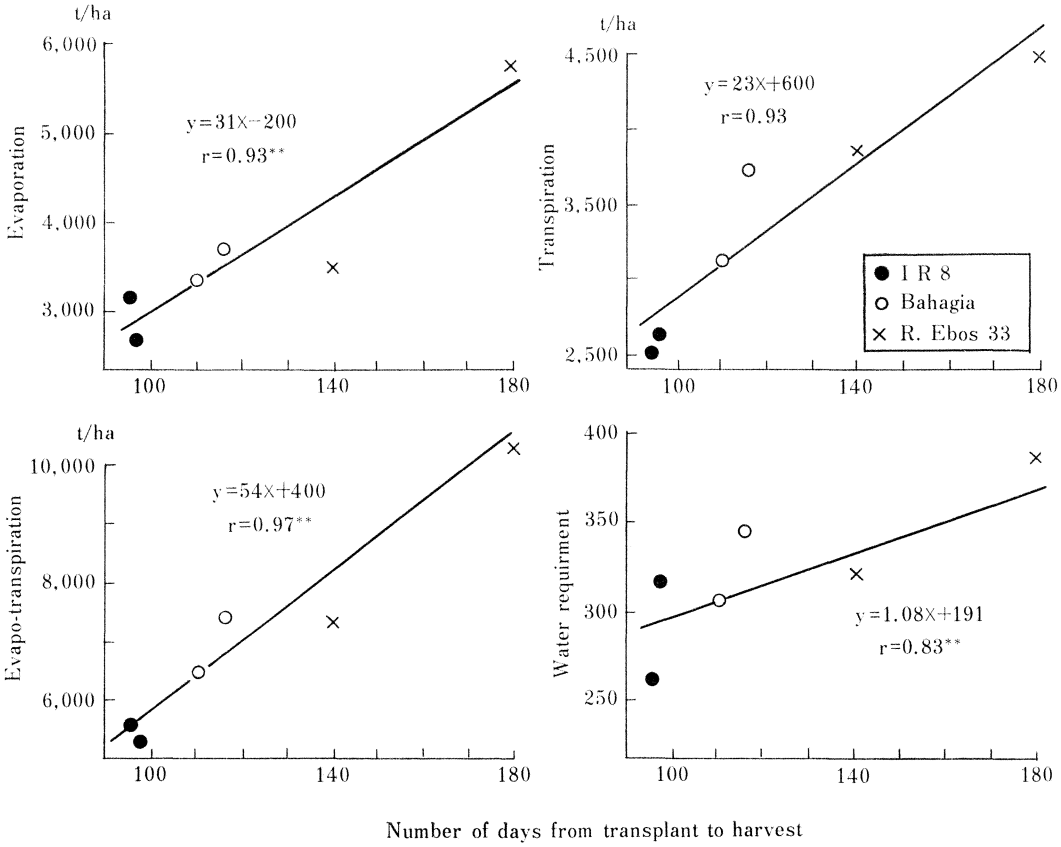


Fig. 2. Relations of evapotranspiration and water requirement to growth duration (Population, Malaysia)[20]

it may be concluded that long term variety is unfavorable from the point of water use.

When the dry season cropping is compared to the wet season one using same variety, daily E shows no difference but T and ET in dry season becomes a little large (daily increase is 0.5 mm) and their cumulative values also increase because of the influence of meteorological conditions. Nishio (Malaysia)[17] has also reported that the daily and cumulative values of ET in the dry season is larger than that in the wet season. Similar result is reported by IRRI.[6]

The average evapotranspiration ratio of Bahagia, however, is about 1.20, and no difference is recognized between dry and wet seasons in the author's data shown in Table 1. Nishio[17] has also reported similar results. But in the experiment conducted at IRRI,[6] the evapotranspiration ratio in the dry season is remarkably higher than that in the wet season. Since Em value in the dry season is 20 percent higher than that in the wet season, the absolute value of ET in the dry season becomes naturally higher even if evapotranspiration ratios of two seasons are of same value.

(3) Comparison of evapotranspiration and irrigation requirement in Asian countries

Table 1 shows the values derived from important data of Asian countries. Daily water consumption may be calculated with these values. In Japan T is higher than E and the ratio of T to E is nearly 6:4 in many cases. In the data from Korea[25] and Taiwan, T becomes scarcely higher than E. In the tropics T becomes higher than E in the case of dense planting reported by Murakami[13], but no clear inclination is observed as to the difference between T and E. This may be caused by rather sparse planting and less fertilization compared to Japan.[18,19]

The daily average of Et is 5.3 to 6.4 mm in the author's experiment,[20] while it is 4.9 mm (4.4–5.5 mm) in the average of 37 plots in Japan (by Nakagawa[14]), and 5.0 mm in the average of early season, usual season and late season rice cultivation (by Ishikawa and Nishio[7]), and 4 to 5 mm in in the experiments of Korea.[25] Although the author's values are a little higher than the other values, the former is nearly the same as those in tropical and subtropical countries.

The daily average of ET in the tropics is about 5.5 to 6.5 mm (except the results of Kung[11] (Bangladesh) and Murakami[13]). This is a little higher than that in the temperate zone. Generally the values of ET range from 4 to 6.5 mm throughout temperate, subtropical and tropical zones, and its difference by latitude is not so great.

The daily average of ET in the dry season is about 26 percent (8–51%, except Bangldesh[11]) higher than that in the wet season. This may be caused by the difference of meteorological factors. In the same region, the total amount of ET of long growth duration is apt to be larger in Malaysia, Thailand and Japan. This tendecny, however, is not clear in the Philippines and is not recognized in Bangladesh. In general, there may be some relationship between the total amount of ET and the growth duration.

Nakagawa[15] has reported that the evapotranspiration ratio is 1.3 average (0.9–1.7) in Japan, but it is about 1.1 in other data.[7] It is about 1.2 (1.1–1.3) throughout the temperate, subtropical and tropical zones, and it does not show great difference by latitude or season. There is no evidence that the evapotranspiration ratio in the tropics is high. The evapotranspiration ratio, however, does not always indicate the degree of ET because the value of Em is variable by region or season. With this evapotranspiration ratio, the value of ET which is the basis of irrigation requirement (IR) may easily be estimated when the normal value of Em of the region is known.

Percolation (P) is affected by the location of paddy field, soil texture and ground water level, etc. The daily average of P (Table 1) is 1 to 3 mm in the coastal alluvial paddy fiields or in the paddy fields of delta in the tropics because of the vertical percolation restrained by the ground water level elevated during the flooding period of paddy fields. This value may be negligible. In Sri Lanka (dry season)[13] and India[27], the value of P is remarkably high,, and it overpasses the value of ET.

The value of P is generally high in the temperate and subtropical zones. In these regions it is important in respect of the control of root-rot and increase of grain yield. The daily average of IR is usually larger in the dry season than in the wet season. The daily average of IR in Asian countries ranges from 6.1 to 30.8 mm. This disparity may chiefly be caused by the difference of P. The total amount of IR ranges usually from 700 to 1,200 mm, and its maximum is 3,447 mm while its minimum is 599 mm. The deviation in the range of IR is greater than that of ET. No relationship is found between the total IR and the growth duration. This may be the evidence that IR is considerably affected by P.

It may be concluded with the data from Asian countries that IR is affected by ET as a controlling factor when the daily IR is less than 1 mm, while IR is controlled by P when the daily IR is more than 10 mm.

2. Relation of evapotranspiration to plant growth and meteorological factor

(1) Relation of transpiration of leaf area index and dry weight of rice

The transpiration and transpiration ratio gradually increase according to the growth of rice plants as described above. The author[20,21] has recognized a parabolic relation

Table 1. Irrigation requirement in some Asian countries

Country	Author	Location	Season	Meas. period	Total (Average daily amount)					ET/Em ratio
					E	T	E T	P	I R	
				day	mm	mm	mm	mm	mm	
Thailand	Kung *et al.*	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.	Notheast 15°N	Main season	94	233 (2.5)	255 (2.7)	488 (5.2)	278 (3.0)	766 (8.2)	
Cambodia	Hatta	Battambang 13°N	Dry season 1965/66	106 (22/XII— 7/IV)			710 (6.7)	244 (2.3)	954 (9.0)	(Rainfall 152mm)
Laos	Kotter	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)	
Bangladesh	Kung	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 541mm)
			Dry season 1958/59	101	436 (4.3)	515 (5.1)	951 (9.4)	54 (0.5)	1,005 (10.0)	(0)
Sri Lanka	Murakami	Dry zone 8°N	Dry season 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.*	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	Kedah 6°N	Main season 1967/68	97 (20/IX—26/XII)	266 (2.7)	262 (2.7)	527 (5.4)	61 (0.6)	558 (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)	−19 (−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	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—20/VIII)			834 (6.3)	618 (5.1)	1,452 (11.9)	1.12
		P. Wellesley	Main seasou 1970/71	103 (29/X— 9/II)			576 (5.6)	321 (3.1)	897 (8.7)	1.10

		6°N	Off season 1971	117 (25/IV—20/VIII)			725 (6.2)	358 (3.1)	1,083 (9.3)	1.10
Philippines	IRRI	Southern Ruzon 14°N	Dry season 1965	91					559 (6.1)	
			Wet season 1966	86			396 (4.6)	172 (2.0)	568 (6.6)	
			Dry season 1968	91 (27/I—27/IV)			607 (6.7)			
			Wet season 1968	97			430 (4.4)			
Taiwan	Citied by Maki	Cantral 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 1963/26	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 season 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)
Korea	Tsubouti	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	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 season 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	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	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 irrigation requirement of rice determined in tropics, subtropics and temperate zones. However, only the papers in which average daily consumption of water can be calculated are selected and listed in the table.

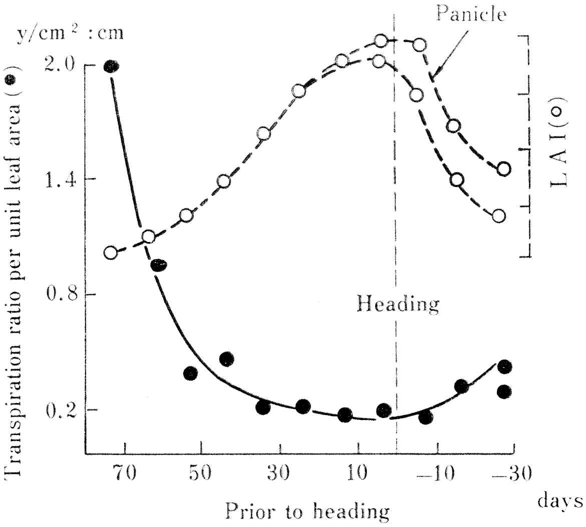


Fig. 3. Changes in transpiration ratio per unit leaf area and leaf area index (Bahagia, Malaysia)

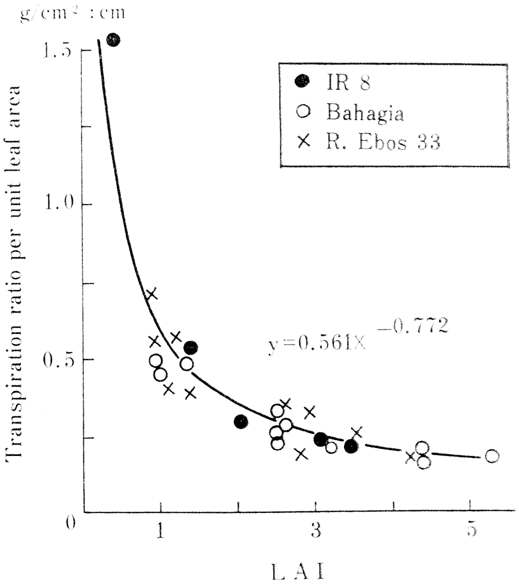


Fig. 4. Relation between transpiration ratio per unit leaf area and leaf area index (Malaysia)[20]

between the transpiration ratio (y) and leaf area index (LAI) (x), that is, $y=a\,x^b$. In other words, though the transpiration ratio increases in parallel with LAI while the value of LAI is little, it does not show apparent increase and attains to saturated condition according to the increasee of LAI because of the effect of mutual shading by grown leaf blades. This saturation may be achieved when LAI reached 3.5.

In Japan, the saturation point is LAI 4 to 5 (by iNshio[16]) or LAI 4 (by Naito[14]). Therefore, it seems that rice plants in the tropics have a vegetation structure which easily causes mutual shading compared with the rice plants in the temperate zone.

The transpiration ratio per unit leaf area can be obtained from the transpiration amount during a fixed period (g) divided by the leaf area at the measurement time (cm^2) and then divided furthermore by Em (cm). This value shows the transpiration activity per unit leaf area from which the effect of meteorological factors is eliminated. Fig. 3 shows this value and the transition of LAI in the paddy fields of the tropics. In accordance with the increase of LAI, this value shows a sharp decline at the period of tillering and reaches the bottom at the spikelet differentiation stage and then slightly increases at the period of ripening. Fig. 4 shows the relation between the transpiration ratio per unit leaf area and LAI.

The transpiration ratio per unit leaf area (y) decreases according to the increase of LAI (x) showing a hyperbolic relation ($y=0.561x^{-0.772}$). The decline of the transpiration ratio per unit leaf area is stabilized when the saturation point described above overpassed LAI 3.5. The transpiration ratio per unit leaf area of rice plants in the tropics is always less than that in the temperate zone at any value of LAI. It suggests that the form of light interception tends to become worse in the tropics because of the mutual shading of leaf blades.

Fig. 5 shows daily increase of dry weight. Although its transition is similar to that of transpiration, its peak appears in an earlier stage of growth. That is, the daily increase of dry weight continues gradual increasing from the early stage of growth and reaches the maximum value aruond booting stage, then it shows a sudden decline

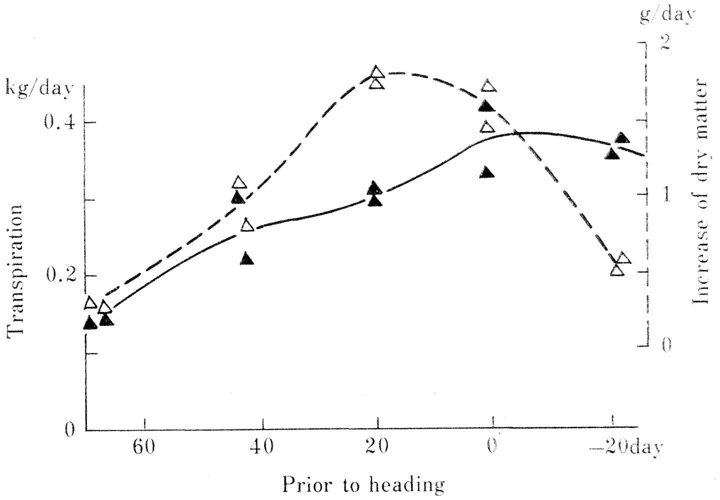


Fig. 5. Changes in transpiration and dry matter production per hill (Bahagia, Malaysia)

after the heading time. The transition of the daily increase of dry weight, therefore, draws a monopeak curve.

The daily increase of dry weight of a rice population is less than that of individual plant during the ripening stage. This trend is especially apparent in the local long term variety. Naito (Japan)[14] has also reported that the transpiration and increase of dry weight in population of rice plants go out of paralleled relation after the heading time. Murakami[13] and the author[20] have reported that the paralleled relation between transpiration and increase of dry weight of individual plant is maintained. It may be a characteristic of the rice population that dry matter production declines in the later growth stage while transpiration does not change as it was before in the temperate or tropical zone.

The transition of daily transpiration per unit leaf area (tarnspiration rate) and net assimilation rate (NAR) are described in the author's datum[20]. Each of them reaches its maximum in the early stage after transplanting because of less mutual shading of leaves. Both of them rapidly decline according to the progress of growth and show stagnation from the neck node differentiation stage to the heading time. The transpiration ratio shows an upward trend after the heading time. The transition of transpiration rate and dry matter production suggests the existence of a paralleled relation between them.

(2) Comparison of transpiration in each organ

In the rice plant, transpiration takes place not only in the leaf blade but also in the leaf sheath and panicle. Tsuboi[24] has studied on the transpiration of each organ and reported that the transpiration amount of panicle and leaf sheath attain 20 to 40 percent of the total transpiration after the heading time. Naito[14] has reported that the transpiration of panicle reaches 12 to 17 per cent of the total transpiration at the middle ripening stage. He has suggested that this may be caused by the increased ratio of panicle's surface area to the total active leaf area. In the author's datum[21] on the transpiration of individual plant, the percentage of the transpiration of each organ is as follows:

leaf blade: 40 to 60 percent, leaf sheath: 30 to 35 percent and Panicle: 15 to 25 perecnt.

The A/C ratio (panicle's surface area/panicle's surface area + active leaf area) of the rice population in the tropics is 0.19 to 0.27 at the full heading time and 0.26 to 0.49

at the middle ripening stage. The A/C ratio of local varieties is larger than that of improved varieties. In Japan, this ratio of rice population is 0.16 to 0.29 at the full heading time and 0.31 to 0.65 at the maturity time (Naito[14]), and that ratio of individual plant is 0.07 to 0.12 at the early ripening stage (Tsuboi[24]). Since the active leaf area shows a sharp decline after the heading time, A/C ratio increases remarkably as shown in Fig. 3. As a result, it seems that the peak of transpiration appeared just after the heading time is greatly affected by the transpiration of panicles.

An unbalanced relation recognized between transpiration and dry matter production after the heading time has been described in the former paragraph. This unbalanced relation may be caused by the fact that though the panicle plays a new role in the transpiration after the heading time and the gross assimilation of panicles attains fairly big amount dry matter production may be scarcely affected by such factors because of the active respiration of rice plants[22].

(3) Relation between evapotranspiration and meteorological factors

Naito[14] has reported that in Japan the transpiration is affected by LAI at the early growth stage where leaf area is still not large, and the influence of meteorological factors is greater than that of LAI after the canopy formation; among the meteorological factors, solar radiation, net radiation, saturation deficit and air temperature show high correlation with the transpiration, and the evapotranspiration is highly related with meteorological factors throughout the growth stage.

It is reported by IRRI[6] that the evaporation and evapotranspiration averaged at every 10 days are highly affected by solar radiation, air temperature and then humidity. In the author's datum[20], the evaporation is affected by LAI and meteorological factors in the former growth stage before canopy formation, and the transpiration and evapotranspiration in this author's datum are nearly the same as those shown by Naito[14].

The source of heat which is necessary for the vaporization from the leaf surface of rice plants and water surface among hills is mainly derived from solar energy. By means of the heat balance method with ET values measured at every district of Japan, Uchijima[26] has determined that ET corresponds to 70 percent (59–86%) of the solar radiation. It is reported by IRRI[4] that the latent heat which is needed for ET corresponds to 63 percent of the solar radiation in the dry season cropping. On the same subject, the author has obtained the value of 74 percent in average using three varieties in a wet season cropping. It seems, therefore, that about 65 to 70 percent of the solar radiation may be used for ET in the tropics, though the percentage is variable by variety, planting density and cropping season.

Em can be regarded as a representative factor of meteorologyical conditions because it shows a high correlation with the transpiration and each meteorological factor in many data.

3. Correlation of dry matter production to transpiration and water requirement

(1) Correlation among transpiration, dry matter producion and water requirement, and its varietal difference

A parallel relation between the transpiration and cumulative value of dry weight has been recognized by Naito[14] except the later growth stage, and a high positive correlation has been found by Nishio[16] between the transpiration ratio per unit leaf area and NAR.

Murakami[13] has reported that there is a high positive correlation between the transpiration at every growth stage and dry matter produtcion in the tropics. Tanaka *et al.*[23]

has recognized a corresponding relation between the transpiration and the cumulative value of dry weight except the late growth stage. A parallel relation is also recognized by IRRI[5)] between ET and the cumulative value of dry weight. The author[20)] has also found a positive correlation between the transpiration rate and NAR respectively. With respect to this correlation, the improved variety is higher than the local long term variety and indivdual plant is higher than the rice population.

Water requirement (transpiration coefficient: necessary transpiration for the production of 1 g dry matter) is shown by the ratio of transpiration to dry matter production (photosynthesis). Therefore the water requireemnt is variable by the conditions which make changes in the transpiration and photosynthesis.

Water requirement is generally high at the early growth stage. It reaches the minimum during the middle growth stage (especiaally at the booting stage), and its maximum appears at the late growth staeg. Tanaka *et al.*[23)] and IRRI[5)] have reported that the water reuirement is less variable except the late growth stage. Further study should be made on this point.

Water requirement (y) decreases when dry matter production (x) increases, and it increases when the daily dry matter production decreases as in the late growth stage. There may be a hyperbolic relation between them ($y=ax^{-b}$). The transition of the water requirement is the reverse of that of transpiration. As a result, rice plant effectively utilizese water for increasing dry matter production when the daily transpiration is high, and consequently, reducing water requirement. The local long term variety, however, shows low efficiency of water not increasing so much dry matter production inspite of high daily transpiration.

(2) Correlation of total dry matter production and water requirement to growth duration and cropping season

It has been reported by Murakami[13)] and the author[20)] that the increase of transpiration and growth duration results in the increase of total dry matter production in the tropics. It has also been reported by Vergara *et al.*[28)] and the author[20)] that the local long term variety of rice plant of which growth duration is more than five months shows stagnation in dry matter production and a decline in grain/straw ratio, and that the improved variety of which growth duration is about 130 to 150 days results in the highest yield.

Matsushima[12)], Murakami[13)] and the author[20)] have reported that the water requirement (y) is in proportion to the growth duration (x) of the variety and can be expressed by means of the linear equation $y = ax + b$. But it is reported by IRRI[5)] that there is no greater varietal difference in water requirement.

As for the local long term variety, its dry mater production does not increase in parallel with the increase of the transpiration, and furthermore its yield declines and water requirement shows a extreme increase. Therefore the improved variety is apparently superior to the local variety on the point of water requirement and yield. The water requirement determined by means of pot culture is usually greater than that of paddy fields as shown in Table 2 and Fig. 2.

The water requirement of a variety of which growth duration after transplanting is 110 days (nearly the same as in Japan) has been calculated by many researchers as follows by means of an equation derived from pot culture experiments; Matsushima[12)]: 551, Murakami[13)]: 365 (wet season) 472 (dry season), the author[20)]: 283 to 317 (wet season and 320 (dry season). Murakami and the author have reported that the water requirement of dry season cropping is great than that of wet season one.

Table 2 shows the water requirement in Asian countries. The water requirement in those countries are much different from each other by the difference of growth du-

Table 2. Water requirement in some Asian countries[20)]

Country Author	Variety	Season	Measurement period	Transpira. coefficient	Season	Measurement period	Transpira. coefficient	Method of culture
			days			days		
Sri Lanka Murakami	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	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	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				〃
	R. Ebos 33	Main season 1967/68	147	393				〃
		Main season 1968/69	142	444				〃
	S. Intan 16	Main season 1967/68	147	431				〃
		Main season 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	〃
	R. Ebos 33	Main season 1967/68	138	321				Field
		Main season 1968/69	178	386				〃

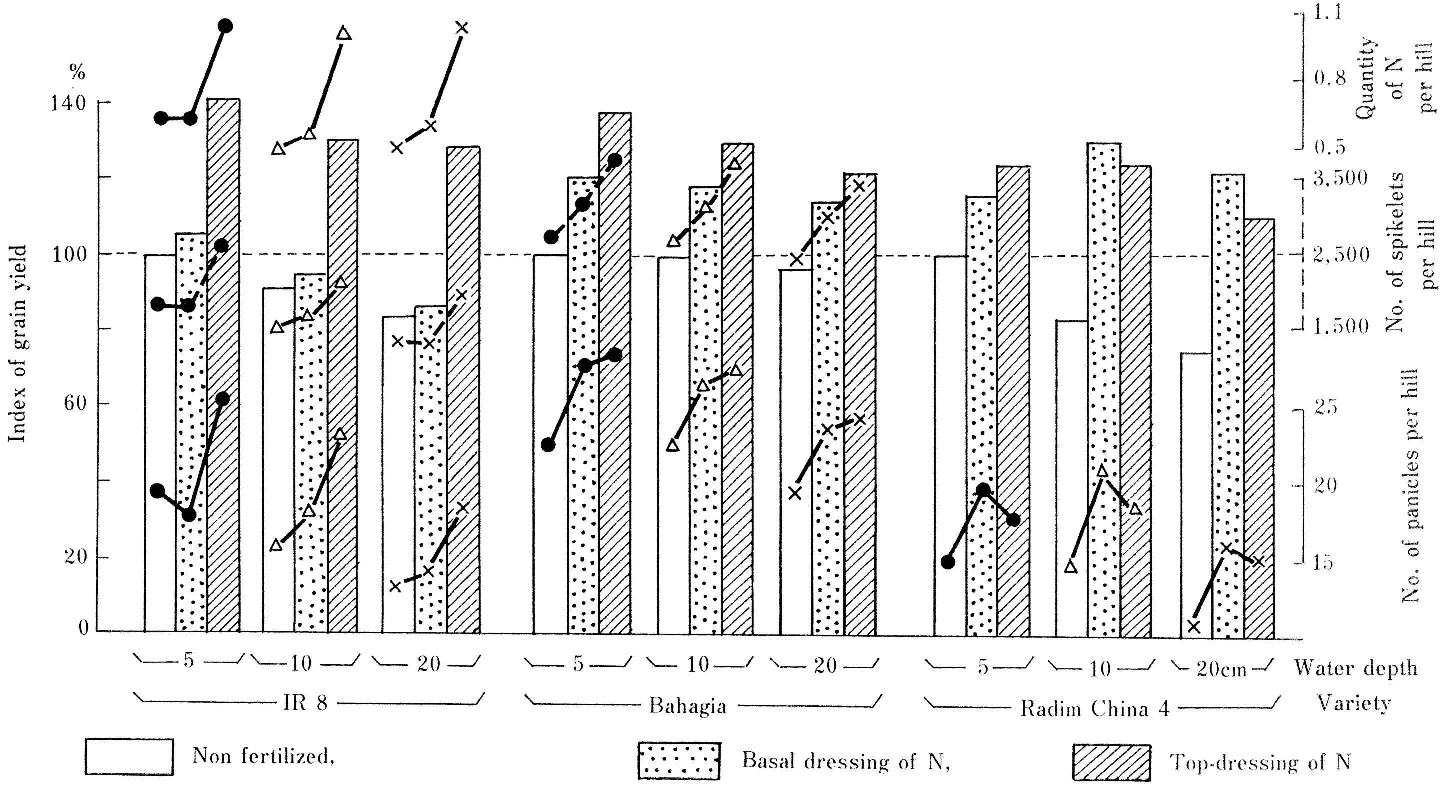
Table 2. Continued

Country Author	Variety	Season	Measurement period	Trans-pira. coefficient	Season	Measurement period	Trans-pira. coefficient	Method of culture
Taiwan Cited by Maki		Intermediate season 1923–26	yads 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	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.*	Yachikogane	Normal season 1962	101	310				Field
		Normal season 1963	108	305				〃
Japan Ishikawa and Nishio	Norin 17	Early season 1956–59	105	393				Field
	Mihonishiki	Normal season 1956–59	112	308				〃
	Norin 37	Late season 1956–59	81	234				〃

ration, cultivation and latitude. The water requirement is usually 260 to 500, though it ranges from 200 (the minimum) to 700 (the maximum).

In the temperate zone, the variation of growth duration is not large and no fixed relation is found between growth duration and water requirement. Wu[29] has reported that the water requirement increases with the increase of growth duration, and high yielding variety shows less water requirement in Taiwan. The water requirement in Japan may be about 300. The water requirement of the rice population in the tropics will be nearly as same as that in Japan when the growth duration is restrained.

Fig. 6. Relations of water depth and fertilizer application method to grain yield and yield components (Frame test, Malaysia)[20]



4. Relation of water management to growth and yield of rice

(1) Relationship between water depth and grain yield

Matsushima[12] has reported that the shallower the water, the more the number of panicles and the yield, and that the yield decreases when the water depth is 0 cm because of the denitrification of soil nitrogen. Murakami[13] has also reported similar results as Matsushima. He has insisted that water depth must be kept less than 11.4 cm at the period of vegetative growth, and has also reported that the influence of water depth scarcely appears at the period of reproductive growth.

Fig. 6 shows the author's results[20] on this subject. The yield of improved variety decreases according to the increase in water depth, while the yield of local variety is not so much affected by the water depth except the non-fertilized plot and reaches the maximum when the water is 10 cm in depth. The effect of top-dressing appears evidently on the yield of the improved variety. It has been reported by De Data *et al.* (IRRI)[1], however, that the yield of an improved variety such as IR8 is not affected by the water depth less than 10 cm though soil saturation decreases yield.

By and large the suitable water depth may be about 5 cm for the improved variety and may be less than 10 cm for the local variety which is resistible against adverse condition, in the tropics.

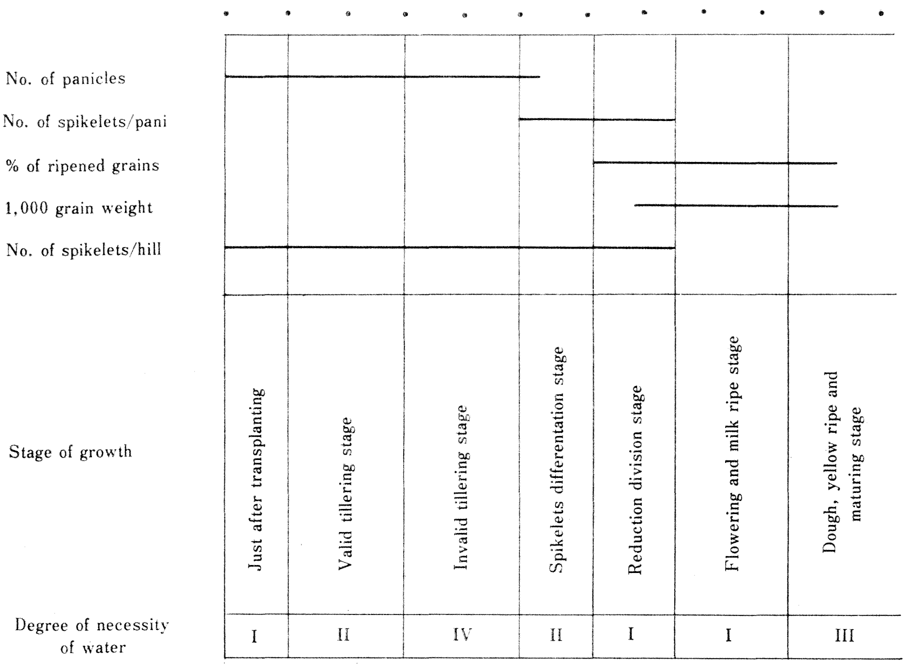
(2) Effect of soil moisture stress on grain yield at different stages of growth

The drought damage which lowers the percentage of ripened grains resulting in the decreased yield appears most violently at the reduction division stage (two weeks before the heading) and then at the heading time and spikelet differentiation stage (Matsushima[12], Table 3).

The damage caused by suspension of water supply is severest at the booting stage (5 to 15 days before the heading) and at the most active ripening stage (5 to 15 days after the heading); and the poor growth caused by the suspension of water supply during

Table 3. Effect of drought at different growth stages on grain yield and yield components (Variety: Radin China 4, Pot test, Malaysia)[12]

Treat. period (Days from heading)	No. of panicles	No. of grains per panicle	% of ripened grains	Wt. of 1,000 grains	Grain yield	Index
			%	g	g/hill	%
1 (−92)	15	156	87	21.4	40.8	86
2 (−80)	12	188	88	21.3	41.3	87
3 (−68)	16	157	90	21.7	47.4	100
4 (−56)	19	133	83	21.5	44.3	93
5 (−44)	18	156	80	21.0	45.9	96
6 (−32)	18	134	85	20.3	40.6	85
7 (−20)	17	164	74	19.5	39.5	83
7·8 (−14)	20	129	59	19.5	27.2	57
8 (− 8)	20	122	50	20.0	23.1	49
9 (+ 4)	15	144	75	19.2	31.9	67
10 (+16)	16	137	86	21.2	39.1	82
11 (+28)	16	130	84	21.7	37.3	78
Control	18	150	88	21.2	47.6	100



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

Fig. 7. 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)[13),20)]

the stages of tillering and before spikelet differentiation can be recovered afterward (Sugimoto[20)]). The influence of suspension of water supply appears on the decrease of yield during one month centered the heading time, and the decline in percentage of ripened grains is remarkable in this period (Murakami[13)]).

Consequently the degree of necessity of water at different stages of growth may be summarized as in Fig. 7, that is, it nearly corresponds to the degree of transpiration.

The yield begins to decrease when soil moisture tension reaches 15 centibar. One of the factors which causes this decrease may be the loss of soil nitrogen. The yield of improved varieties such as IR 20, 22, 24 is superior to that of local varieties at the soil moisture tension up to 33 centibar (De Data *et al.*[2)]).

(3) Effect of drainage and intermittent irrigation on grain yield

Hatta[3)] has conducted water-saving culture avoiding the critical stage in Cambodia. Compared to continual flooding culture, 30 to 40 percent of water can be saved by water-saving culture without any reduction in yield despite of decreased number of panicles.

Table 4. Effect of intermittent irrigation on grain yield and yield components in wet and dry seasons (Variety: Bahagia, Alor Star, Malaysia)17)

Irrigation method	Nitrogen application method	No. of panicles per m^2	No. of spikelets per m^2	% of ripened grains	Wt. of 1,000 grains	Grain yield	Index	Net irrigation water
	kg/ha		$\times 10^4$	%	g	t/ha	%	mm
Flooding	102a)	156	2.1	81	25.6	4.39	100	360
	136b)	162	2.4	79	25.6	4.70	107	
Intermittent	102a)	167	2.2	80	26.1	4.64	106	298
	136b)	171	2.5	77	24.9	4.79	109	
Flooding	102b)	188	2.4	77	26.7	4.96	100	451
	136a)	203	2.7	80	27.4	5.93	120	
Intermittent	102a)	186	2.3	83	26.8	5.01	101	198
	136b)	207	2.5	79	27.4	5.34	108	

Note: Intermittent irrigation was introduced one month after transplanting,
a) ½ nitrogen applied basally and
b) ⅜ nitrogen applied basally.

Intermittent irrigation after one month since transplanting is very effective for water-saving. It is effective to increase yield in the wet season cropping but not in the dry season cropping (Nishio17), Table 4). Although 12 day mid-season drainage increases the percentage of ripened grains and yield of IR 8, six day mid-season drainage and 19 day intermittent irrigation are not effective (Sugimoto20)).

Kanareugsa *et al.* (Thailand)8) has made an experiment of intermittent irrigation with the variety of RD 1 which resulted in six percent increase of yield in average. The effect of water management, however, is seldom found in the data of Thailand.

In the experiment carried out with IR 8, water management may be effective for water-saving but not so effective to increase the yield in many cases (De Data *et al.*)1). As described above, the mid-season drainage and intermittent irrigation are evidently effective for water-saving but the percentage of increased yield remains within 10 percent. Such water management has not been regarded to be effective in many cases.

Drainage eases heavy reduce condition making soil dry and prevents root-root, while it makes loss of soil nutrients by denitrification. Although the mid-season drainage at the non-productive tiller stage does not result in the decrease of yield, drainage canal and other facilities are necessary for the vast area of plain fields. The effect of drainage must be further studied from the veiwpoints of soil texture, cultivation method, target yield and farm mechanization.

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Question and Answer

T. Murakami, Japan: Bipeak transition T/Em ratio are seen in Fig. 1. But isn't it desirable for yield production to change the transition of T/Em ratio from bipeak type to monopeak one which has a peak near the heading stage?

Answer: Monopeak type is desirable for high yield production in theory, but bipeak type is recognized in population plants ever in IR 8. This phenomena is characteristic of tropical rice and is probably due to the mutual shading around the maximum tiller number stage.

J. A. Lewis, Sri Lanka: What varieties did Matsushima and Murakami used for water requirement trial?

Answer: The varieties are shown in Table 2 of my report.