Some Experiments on Soil-Water-Plant Relationship in the Cultivation of Rice*

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Introduction

Rice is the staple diet of the great majority of the inhabitants of Malaya and yet never more than two-thirds of the requirements of the population has been produced locally. For increasing the production of rice without utilising land which might be more profitably employed for the production of export crops, raising the yield per unit area and the off-season (double) cropping of rice have been much emphasized as a national policy.

Increase of yield per unit area can be achieved in many ways, but one of the most important in this country is improvement of water control.

Water control in this country may involve (a) controlling excess water, (b) making best use of a limited supply of water, and (c) controlling adequate water under ordinary conditions. There is no doubt that efficient water control cannot be achieved without the help of public works. It can, however, be stated that water control could also be achieved from knowledge of rice physiology.

It must be emphasized, on the other hand, that in Malaya there are wide areas which are capable of off-season cropping, if only water could be made available. In general, the weather conditions during the off-season are much better than in the main season. In fact the Government has already started to encourage farmers to grow off-season rice. Shortage of water is usually the most serious problem confronting the off-season crop. To solve this problem, it is necessary to improve irrigation facilities and also to find the most efficient way of using the limited amount of water available. If water consumption can be reduced without sacrificing yield, larger areas can be brought under cultivation.

To study the problem from the points of view of rice cultivation and in particular of rice physiology, there exist three main lines of approach namely, to determine (i) counter-measures for too much water, (ii) counter-measures for too little water, and (iii) the most adequate watering methods under ordinary conditions for getting a maximum yield.

Along these three lines the author planned the

work and made his effort to achieve it so far as circumstances permitted during his assignment term as a FAO expert in Malaya from April 1960 to December 1961. The results obtained may be summarized as follows.

I. Drought Experiment (Effects of drought at different growth stages on the growth and yield of rice)

The object of this experiment was to find out the growth stage most susceptible to lack of water, in other words, the most effective stage for irrigation.

Method: The whole growth period was divided into 11 periods, at each period 4 plots were subjected to the drying treatment and their yields and yield components were compared with each other. This experiment was done in the off-season (variety used was PeBiFun) as well as in the main season (variety used was Radin China 4) with two different soils. (See Division of Agriculture Bulletin No. 112 for the particulars.)

Results: A part of the results is shown in Table 1.

Discussion: The most susceptible stage is found to be the reduction division stage of pollen mother cell which occurred 12 days to 4 days in the off-season and 15 days to 5 days in the main season before the heading date, respectively. This is followed by the heading stage and the spikelet differentiation stage. Roughly speaking, the most susceptible period can be taken as the 30-day period from 20 days before heading to 10 days after heading, centering around the reduction division stage. The most serious drought damage is brought about in general by the reduction in the percentage of ripened grains caused by the interference to fertilization, as can be seen in Table 1.

II. Flooding Experiment (Effects of different depths of flooding at different growth stages on the growth and yield of rice).

The object of this experiments was to clarify the growth stage most susceptible to flooding, in

* Received for publication July 20, 1962

Table 1. The results of a drought experiment in the off-season

Item Period (Days from heading)	Yield g/hill	No. of panicles	No. of grains per panicle	Percent. of ripened grains	1,000 grain weight g	Stage
1 (-58)	18.0	10.5	89	70* (11)	21.8	A
2 (-51)	16.8	11.2	80*	66 (9)	22.0	
3 (-43)	19.5	10.8	101	65 (14)	21.1	
4 (-35)	20.0	11.5	116	60 (11)	20.5*	
5 (-27)	17.0	11.2	112	54° (12)	20.2*	
6 (-19)	15.7	10.8	93	52* (34)	20.8*	E
7 (-11)	6.5*	10.2	105	29* (62)	21.6	F
8 (-3)	8.3*	10.0	100	38* (59)	20.9*	G
9 (+5)	16.5	11.0	94	59 (10)	21.9	
10 (+13)	20.5	10.0	107	66 (7)	22.5	
Control	22.7*	10.2	125*	65 (15)	21.9	

Note: 1. Stage A.....Early tillering stage, B.....Most active tillering stage, C.....Late tillering stage, D.....Primary rachis-branch differentiation stage, E.....Spikelet differentiation stage, F.....Reduction division (Meiosis) stage, G.....Heading stage.

2. Different symbols indicate a significant difference with each other, while same symbols indicate no significant difference.

3. Figures with brackets show the percentage of non-fertilized grains.

other words, to find out the most important stage for draining.

Method: The whole growth period being divided into 11 periods, at each stage 4 plots were subjected to the following flooding treatment: —

- (1) Whole plant submerged (for 4 days in the off-season, 5 days in the main season).
- (2) 75 % of plant height submerged (for 8 days in the off-season, 12 days in the main season).
- (3) 50 % of plant height submerged (for 8 days in the off-season, 12 days in the main season).
- (4) 25 % of plant height submerged (for 8 days in the off-season, 12 days in the main season).
- (5) 5 cm depth of water (control).
- (6) Non-flooded condition but soil saturated.

Results: A part of the results is given in Table 2. The results are in good agreement with different seasons on main points.

Discussion: The most susceptible stage is found in the reduction division stage of pollen mother cells, followed by the heading stage and the spikelet initiation stage. The damage to rice caused by submerging treatment is the more serious the deeper the plant is submerged, but there is a big difference between the whole-plant-submerging treatment and other treatments. In particular it was noticeable that only little damage is recognised at heading time if only heads and top-parts of boot-leaves are above the water surface, while serious damage results when the whole plant is submerged. The remarkable reduction in yield is caused mainly by the reduction in the percentage of ripened grains due to non-fertili-

Table 2. The results of a flooding experiment in the off-season (whole plant submerged)

Item Period (days from heading)	Yield g/pot	No. of panicles	No. of grains per panicle	Percent. of ripened grains	1,000 grain weight g	Stage
1 (-57)	52.5	22.0*	134	74 (6)	21.4	A
2 (-48)	79.0	24.8*	176*	81* (4)	21.7	B
3 (-39)	82.5	35.3	153	75 (10)	21.6	C
4 (-31)	73.8	39.3	123	70 (12)	21.5	D
5 (-23)	62.5*	33.8	143	76 (10)	21.4	E
6 (-15)	42.8*	36.8	82*	67 (12)	22.7	F
7 (-7)	23.5*	23.0*	114	42* (53)	21.9	G
8 (+2)	25.0*	29.0*	123	24* (74)	22.8	H
9 (+9)	77.8	35.8	156	76 (7)	25.5	
10 (+17)	72.8	32.5	158	72 (9)	21.8	
Control	82.3	32.3	157	75 (9)	22.2	

Note: 1. Stage A.....Rooting stage, B..... Early tillering stage, C..... Most active tillering stage, D.....Late tillering stage, E..... Spikelet differentiation stage, F..... Late spikelet differentiation stage and differentiation stage of pollen mother cells, G..... Reduction division stage, H.....Heading stage.

2. The others are same as in Table 1.

zation.

III. Water Requirement (Transpiration ratio) Experiment.

The object of this experiment was to find out how much water is necessary to produce one gram of dry-matter of rice plant, and to know the seasonal distribution of water requirement.

Method: Using specially designed pots with an apparatus to prevent evaporation from the water surface, the amount of transpiration from the plants was measured every day. The measurements were done with a short-term variety (Pe-BiFun) in the off-season as well as in the main season and with a medium-term variety and a long-term variety in the main season.

Results : The author succeeded in determining for the first time the transpiration ratio as well as the seasonal distribution of transpiration of the rice plant in Malaya. A part of the results of the transpiration ratios obtained is given in Table 3.

Discussion: From the table the transpiration ratio is found to vary much with varieties differing in maturation period but it varies little with seasons and vigour of the plants. A noteworthy point is that the yield of grain of PeBiFun in the main season was half of that in the off-season and the weather conditions during the two seasons were considerably different, nevertheless both the values of transpiration ratio resembled each other.

The most interesting and new finding in this experiment is that the necessary amount of water for transpiration per day for producing one gram of dry matter is almost constant (approximately 5 cc) in all cases.

In the present experiments the transpiration ratio has been found to be definitely influenced by the maturation period, as seen in Fig. 1. There exists a surprisingly high correlation between

the transpiration ratio and the maturation period. We can easily understand, therefore, why the amount of water which must be transpired per day to produce one gram of dry matter is nearly constant (5 cc). From the relation between the transpiration ratio and the maturation period shown in Fig. 1, the following regression equation was derived. (Where y is the transpiration ratio, and X is the maturation period expressed by the number of days after transplanting).

$$y = 4.91X + 11.1$$

Therefore, if only the maturation period of a given variety is known, the necessary transpiration ratio can be exactly determined by the above equation. Since this experiment involves different major soil types, different cultivating seasons, the results obtained may be applicable to any circumstances in Malaya.

As a result of calculating the necessary amount of water of transpiration for producing one gram of grains, it was made clear that the longest term variety needs three times as much water as the shortest term variety, and the shorter a variety in maturation period the more economical it is in the use of irrigation water. From this point of view the author cannot emphasize too strongly the effectiveness of the use of short-term varieties in conserving irrigation water.

The amount of transpiration for each 10-day period increased remarkably with the growth of the plant after rooting, attaining 70 % to 90 % of the maximum amount of transpiration at the spikelet differentiation stage and a maximum at the reduction division stage or at the heading stage. Transpiration decreased remarkably after heading as the ripening advanced. Since similar results have been obtained in Japan, it can be assumed that there is probably little difference between tropical countries and temperate countries in the seasonal distribution of water requirement of rice.

Table 3. Transpiration ratios in Malaya

Variety	Season	No. of days after transplanting	Water transpired in cc	Dry matter g			Transpiration Ratio
				Straw	Grain	Total	
PeBiFun (Short-term)	Off	96	123,598	133	140	273	453
	Main	87	55,751	70	69	139	401
Radin China 4 (Medium-term)	Main	121	122,760	131	70	201	611
Seraup 50 (Long-term)	Main	154	157,814	143	63	206	766

Note: Each value is the average of 3 plots.

Fig. 1 Relation between the transpiration ratio and the maturation period of rice varieties

IV. Water-Depth and Water-Movement Experiment (Effects of different depths of irrigation water and its horizontal and vertical movement on the growth and yield of rice).

The object of this experiment was to know the optimum depth of irrigation water and to know whether water should be moving or stagnant for getting a maximum yield.

Method : Combining 4 kinds of water depth (0, 6, 13 and 26 cm) and 3 kinds of water movement (stagnant, horizontal and vertical movement), the rice plants transplanted in tanks (9 hills per tank) were treated for a whole growth period. (The size of the tank was 3' × 3' × 2.5') (See Bulletin No. 112 for the particulars.)

Results: A part of the results is given in Table 4.

Discussion : From this experiment it was conclusively demonstrated that the shallower the water depth the better the yield as long as the soil surface is at all times completely covered with water. The conclusion was also supported by other pot experiments. In these experiments the yield were strongly influenced by the number

Table 4. Effect of water depth and water movement on grain-yield (g/tank)

Movement Depth	Stagnant	Hori- zontal	Verti- cal	Mean
0cm	495*			
6cm (mid-drying)			663	
6cm	695	665	655	672
13cm	671	665	624	653
26cm	613	641	569 ^x	599*
Mean	660	648	616	

of panicles per unit area, i. e. the shallower the water-depth the greater is the number of panicles. The reason the shallow depth of water causes the plant to increase the number of panicles and, thereby, the yield was considered to be that shallow water brings about higher water temperature in daytime and lower temperature at night than does deep water. (This serves to encourage tillering as has been shown previously by the author in Japan). Furthermore, shallow water favours the decomposition of organic matter in the soil resulting in nice development of the root-system. As a result of chemically analyzing the plants and soils used in the experiments, it has been made clear that the reason for the 0 cm treatment always being poorest in yield can be ascribed to the denitrification of nitrogen in the soil.

Since there are hardly any reliable data on the optimum depth of water to be maintained in paddy fields in tropical countries, the results obtained in the present experiments will be of great importance in the improvement of water-management in tropical countries.

Only a slight, or no, significant difference between water-movement treatments was found. The effects of moving water, however, will differ with soil types, quality of irrigation water, rate of movement, water temperature etc., so that the results obtained must be re-examined before any definite conclusions are drawn.

V. Water-table Experiment (Effect of different heights of the water-table in the growing season on the growth and yield of rice).

The object of this experiment was to determine the optimum height of the water-table in the growing season for producing a maximum yield.

Method and Results : The heights of the water-table examined and a part of the results are given in Table 5.

Discussion: According to the results, it is clear that (1) when the water-table is above the soil surface, the shallower the water table, the better in yield and in growth, excepting the 0cm-treatment (which is the worst), and (2) when the water table is below the soil surface, the shallower the water table, the better in yield and in growth. In short, the yields of the treatments are in the following order: - water-table is 5 cm above the soil. > 15 cm above the soil > 30 cm above the soil > 0 cm > 5 cm below the soil surface > 15 cm below the soil surface. These points support the results of the Water-depth and water-movement experiment.

From the results of the above two experiments,

Table 5. Effect of different heights of water-table on yield

Treatment	Grain yield per hill, g
30 cm above the soil surface	43.3
15 cm above the soil surface	44.8
5 cm above the soil surface	49.5°
0 cm same as the soil surface	38.5
5 cm below the soil surface	35.3*
15 cm below the soil surface	31.0*

it has been emphatically clarified that even in tropical countries the shallower the water-depth, the better the yield, but when the soil surface is exposed to the air during a whole growth period (in particular at early growth stages), the yield of rice is remarkably reduced, however wet the soil may be.

VI. Water-Saving Experiment (Experiment to determine the most efficient way of irrigation).

The object of this experiment was to find out how much water can be saved without sacrificing yield.

Method : The following 9 treatments were examined:—

- (1) Shallow flooding throughout the growth
- (2) 100 % water content throughout the growth
- (3) 80 % water content throughout the growth
- (4) 40 % water content throughout the growth
- (5) 40 % water content throughout the growth
- (6) As in (3), but increased to 100 % between the spikelet initiation stage and the middle ripening stage
- (7) As in (4), but increased to 100 % between the spikelet initiation stage and the middle ripening stage
- (8) As in (5), but increased to 100 % between the spikelet initiation stage and the middle ripening stage
- (9) Intermittent irrigation (in the off-season), Ideal irrigation (in the main season).

The water content in each plot was adjusted every other day by the weighing method. In the off-season, only Tanjong Karang soil was used, but in the main season in addition Negri Sembilan soil was also used.

The 'Ideal irrigation' was done as follows:— after transplanting up to the time of the final emergence of bearing tillers water was kept flooding at 5 cm depth, after which the soil was dried up to the initial stage of spikelet differentiation; from the spikelet differentiation stage to the final stage of the most active ripening the soil was flooded but once or twice a week the soil surface was exposed to air for a half day.

Results : A part of the results is shown in Table 6.

Discussion : In the off-season the plots were shallowly flooded, so that their mean yield was much as 94 g per pot (corresponding to 1,550 gantangs per acre). Nevertheless, the 100 % water-content plots attained nearly 80 % of the yield of the shallowly flooded plots, saving the amount of water by 47 %. The 60 % water-content plots showed a remarkable reduction in yield and the 40 % water-content plots barely headed. On the other hand, when the soil moisture was increased to 100 % between the spikelet initiation stage and the milk-ripening stage, even 40 % water-content plots could produce as much as 80 per cent of the yield of the 100 % water-content plots, saving the amount of water by 20 per cent.

In the main season the same trend as in the off-season could also be seen in the Tanjong Karang soil, but a noticeable point was that the ideal plots showed better yields by 6 per cent in the mean value than those of the flooded plots, saving the amount of water by 20 per cent. In the Negri Sembilan soil the flooded plots produced many sterile grains presumably caused by an excessive reductive condition of soil, so that even 100 % water-content plots showed better yields than those of the flooded plots and the ideal plots yielded as much as 159 % of the yield of the flooded plots.

In the three series of experiments all flooded plots were only shallowly submerged (1 inch), so that better yields were probably obtained than had they been deeply submerged. Accordingly, the difference in yield in the Tanjong Karang soil between deeply flooded plots and ideal plots would be much greater than in this experiment.

In conclusion, it is considered that there exists the possibility of reducing the amount of water used in rice cultivation in Malaya by at least 30 to 40 per cent without sacrificing yield. Moreover, the results suggest that adequate water-management should make it possible to save the amount of water used by 15 to 25 per cent and to get much better yield as well.

VII. Soil Drying Experiment (Effect of varying periods of drying the soil before transplanting on the growth and yield of rice plants)

The object of this experiment was to determine the minimum length of drying period which will result in a maximum yield.

Method : Constantly submerged soil obtained from Negri Sembilan was dried for the following

Table 6. The grain-yields and the amounts of water consumed

Treatment	Off-season		Main-season			
	Tanjong Karang soil		Tanjong Karang soil		Negri Sembilan soil	
	Yield	Water consumed	Yield	Water consumed	Yield	Water consumed
Flooded	94 g ⁺ (100%)	137,724cc(100%)	57 g ⁺ (100%)	89,446cc(100%)	6.3 g (100%)	35,373cc(100%)
100%	74 g ⁼ (79%)	72,635cc(53%)	42 g (74%)	65,603cc(73%)	6.8 g (108%)	25,527cc(72%)
80%	54 g ^x (58%)	56,247cc(41%)	24 g [*] (42%)	43,280cc(49%)	5.3 g (84%)	22,023cc(62%)
80—100%	66 g (70%)	64,083cc(47%)	36 g (63%)	53,737cc(60%)	6.0 g (95%)	24,288cc(69%)
60%	13 g [*] (14%)	53,532cc(39%)	40 g [*] (34%)	42,833cc(48%)	3.5 g (56%)	17,787cc(50%)
60—100%	64 g (68%)	62,059cc(45%)	23 g (75%)	60,488cc(68%)	5.8 g (91%)	22,778cc(64%)
40%	0	21,341cc(16%)	0	23,015cc(26%)	2.5 g [*] (40%)	16,725cc(47%)
40—100%	59 g (63%)	5,8515cc(42%)	37 g (65%)	53,919cc(60%)	5.5 g (87%)	21,951cc(62%)
Intermittent	63 g (67%)	6,9853cc(50%)				
Ideal			61 g ⁺ (106%)	76,000cc(85%)	10.0 g ⁺ (159%)	27,850 (79%)

Note: 1. The 40 % -water-content plots did not head in the Tanjong Karang soil. The variety used was PeBiFun (short-term) in the off-season and Radin China 4 (medium-term) in the main-season.

2. Different symbols show a significant difference against any other treatments, while identical symbols indicate no significant difference between them.

periods prior to transplanting: — (1) 3 months, (2) 2 months, (3) 1 month, (4) 15 days (5) Control (Water-logged throughout the year)

Results: A part of the results is given in Table 7.

Discussion: Judging from the significant level of 5 %, 'control' and 15-day drying treatment showed a significant difference against all other treatments, and there is no significant difference between the other three kinds of drying treatments. From the results it can be concluded that one month is the minimum drying period necessary to produce a near maximum yield and the yields are mainly influenced by the number of panicles. The results of chemical analysis of the soils in the five different treatments showed that the amount of available N is much increased by

drying the soil.

These results agree with local Malay paddy planters' saying that when dry weather of 4 to 6 weeks occurs during the non-paddy season it is followed by better growth of the subsequent paddy crop. It is necessary, however, to confirm these results under field conditions and with different soil types as well.

Actually, on one hand, there are many fields which are dried for too long a time in this country and there seems to be a fair possibility of shortening the drying period and raising two crops or three crops a year, provided that there are sufficient irrigation and drainage facilities. On the other hand, in Malaya there are many fields which are water-logged all the year round, and in such fields the yield of grain will be easily

Table 7. Effect of drying soil for different periods before transplanting on the growth and yield (Main season)

Treat- ment	Item	Grain yield g/hill	No. of panicles	No. of spikelets per panicle	Percent. of ripened grains (%)	1000 grain weight g
Control		9.3(100%)*	6.7*	73*	89	20.0
15 days		11.3(121%)*	8.7*	71*	90	19.9
1 month		15.5(162%)	14.5	61	89	20.0
2 months		16.5(177%)	18.0	59	83	19.1
3 months		13.3(143%)	18.2	57	68*	18.9

increased by merely drying the soil. From this point of view the necessity of improving the irrigation and drainage facilities in this country must be emphasized.

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Additional Remark

For further information, see "Division of Agriculture Bulletin No. 112" which is to be published by and obtainable from the Division of Agriculture, Ministry of Agriculture and Co-operatives, Kuala Lumpur, Malaya.

〔和 文 摘 要〕

土・水・稲の関係についての数種の実験

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著者は国連FAOの稲専門技術者に任命され、1960年4月より1961年12月に至る20カ月間マラヤに駐在し、稲作研究所の新設、稲作の理論と技術についての講義等をしたほかに、土・水・稲の関係についての試験研究を依頼された。マラヤ稲作の現況から、緊急を要すると思われるテーマを選び、主要な品種および土壌型を用いると共に、各種の季節に栽培し、多種多様な実験を開始した。これらの実験は著者の離任時になお継続中のものも少なくなかったが、この中で少なくとも2作季以上実験を反復し、ほぼ一応の結論をえられたと見られる主なものは次の諸実験であり、ここにその概要を述べた。なお詳細な報告は、その他の調査をも含めて、マレイ政府農業技術研究所特別報告(英文)として近く発刊される予定である。(I)旱魃に関する試験、(II)浸水に関する試験、(III)要水量試験、(IV)水深および水の縦横滲透が稲におよぼす影響の試験、(V)水位の高低が稲におよぼす影響の試験、(VI)節水栽培試験、(VII)土壌乾燥期間の長短が稲におよぼす影響の試験。

〔追記〕 本論文の詳細は最近 Division of Agriculture Bulletin No. 112 に発表されたので、詳しく知りたい方はこれを見られたい。Division of Agriculture, Ministry of Agriculture and Co-operatives, Kuala Lumpur, Malaya, で1弗(マレイ弗, 120円)で分譲する由の通知を受けた。