8. AGRO-ECOLOGICAL ROLES OF IRRIGATION IN RICE CULTURE

Ichiro TANAKA*

The primary and secondary centers of origin of *Oryza sativa* are considered to be the tropical and subtropical regions of East India, Bangladesh, Burma, Thailand, Indo-China and South China, basing on the genetic evidences or the diversity of forms and varieties of rice.

In these regions, the rice plants have been grown under various water environments which are characterized by abundant rainfall, uneven seasonal distribution of rainfall and periodical flooding of rivers. The annual rainfall amounts to 1500–2500 mm on the plains and 4000–5000 mm in the mountains. Since the rainfall distribtuion is mainly governed by the south-west monsoon, 70–80% of the annual rainfall is centered around the period from June to October. Most of the rice fields in these regions are solely dependent on the monsoon rainfall for their water supply. Even in the heavy rainfall regions, the water shortages are common because of extreme differences in annual rainfall, failure of rainfall to match the seasonal water demand of rice and high evapotranspiration due to high temperature. On the other hand, the extensive rice growing areas in the basin of large rivers are often covered with the flooded water of several meters in depth at mid to late monsoon.

Rice varieties which are well adapted both physiologically and morphologically to such water environments have come into existence due to natural selection and artificial selection.

In this review, attention will be focussed on the complex interrelations between water, rice, weeds and soil. The discussion opens with a review on water environment and differentiation of rice varieties.

I. Water Environment and Differentiation of Rice Varieties

The water environments in the low-lying areas along large rivers such as the Ganges, Irrawaddy, Brahmaputra, Mekong, Menam and Tung Kiang become too deep for ordinary rice varieties during monsoon season. Over centuries, the farmers have grown the floating rice in deep water areas where the water levels reach by as deep as 5 meters. The floating rice has well-developed aerenchyma tissue and may elongate as long as 6 meters in response to the rising water level, floating the leaves on the water surface. The plants form roots on the upper nodes in the standing water and are capable of absorbing nutrients from the water. Vergara et al. (1974), reviewing the response of floating rice to deep water stress, stated that the increasing rate in plant height was as much as 2 to 10 cm per day at a normal state, and the maximum rate was 25 cm per day. If the water level rises rapidly, the plants may be severely injuried, resulting in sterility and death. Floating character of floating rice expresses itself only under deep water conditions. Ramiah and Ramaswani (1948) reported that the floating character was controlled by duplicate recessive genes and the F_2 from crossing between ordinary rice and floating rice gave 15:1 ratio of normal plants to plant with the floating character.

The adaptability to deep water, as shown in Table 1, is remarkably higher in float-

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* National Institute of Agricultural Sciences.

Table 1. Influence of deep water on grain yields of floating rice and ordinary rice (Klong Luang Rice Station, Thailand.)

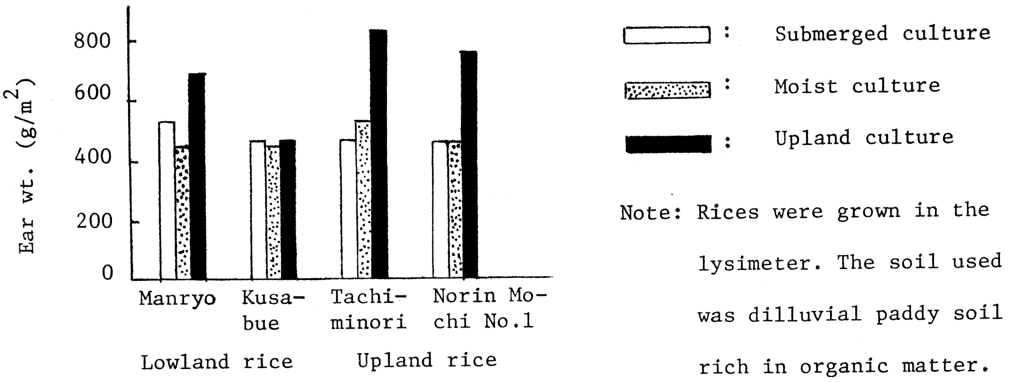
Variety type	Yield (t/ha)				
	1970		1971		
	50cm	100cm	30cm	80cm	100cm
Leb Mue Nahng 111 (floating)	2. 1	2. 4	2. 8	2. 4	1. 9
T442-57 (deep water tolerant semidwarf)	4. 2	4. 0	4. 3	3. 0	1. 6
Puang Nahk 16 (non-floating tall)	3. 7	1. 3	4. 4	0. 0	0. 0
RD1 (ordinary semidwarf)	1. 2	0. 0	3. 6	0. 0	0. 0

Note: Date from the IRRI Repoter, 1975.

ing rices than in non-floating tall rice and ordinary semidwarf rice. Vergara et al. (1974) reported that the yield of floating rice were 1.5 to 2.0 tons per hectare in Thailand which was as much as or even higher than the national average for non-floating rice areas; 0.9 tons per hectare in Madras of India; 3 tons per hectare under optimum condition in Bangladesh. The maximum yield was 9.9 tons per hectare obtained in India. The breeding of new floating rices which are well adapted to extremely varying water environments appears to be one of the most important problems for increasing rice yield in tropics.

Most of ordinary lowland rices are grown in the shallow water regions where the standing water depths range from 5 cm to about 30 cm. The flooded irrigation is common to all lowland rice culture. Needless to say, considerable amounts of water are consumed by the plant for maintaining the optimum physiological functions. The water requirements of rice are 250 to 390 in Japan and 400 to 700 in the tropics, depending on the length of growth and climatic factors. The evapotranspiration rates in rice field of Japan range from 4 to 8 mm per day in decreasing water depth and may reach a maximum during the period from the booting stage to the heading stage when the leaf area of the population becomes highest.

When the water loss due to evapotranspiration is made up by adequate irrigation, the flooded condition does not appear to be indispensable factor for rice growth. Figure 1



Note: Rices were grown in the lysimeter. The soil used was dilluvial paddy soil rich in organic matter.

Fig. 1. Water environment and rice yield (Tanaka. 1970)

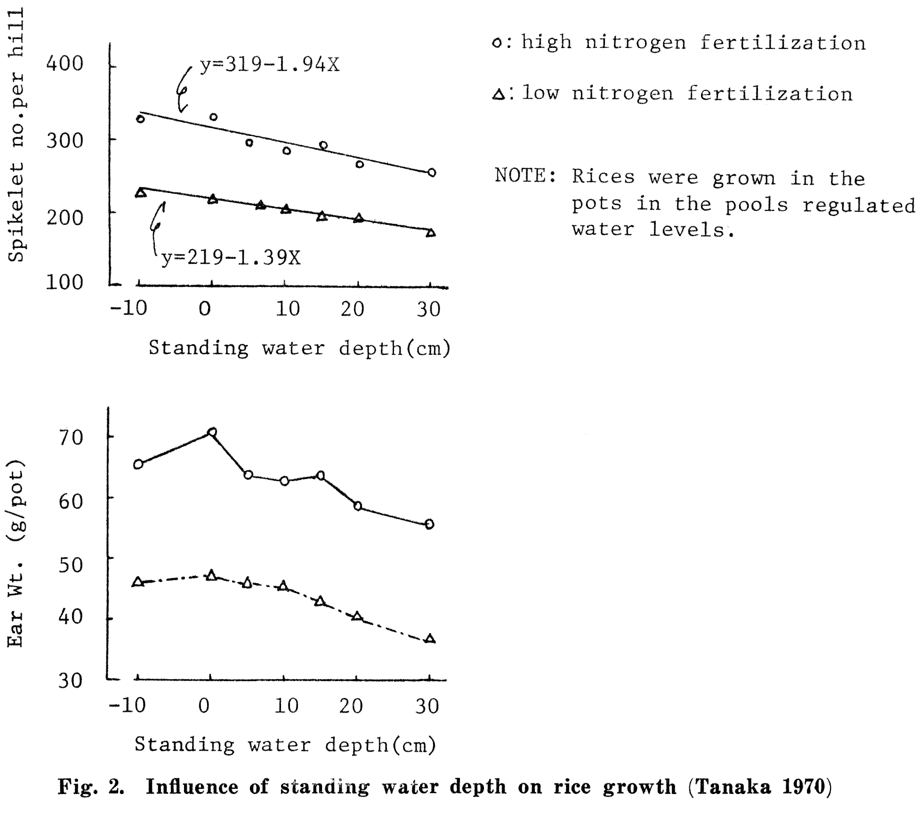
indicated that the rice yields from upland plots kept at field water capacity during growing season were equal to or even higher than those from continuously flooded plots and moist plots where the underground water level was 5 cm below the soil surface. It was also observed that the plants in upland plots contained higher concentrations of nitrogen and potassium and lower concentrations of phosphorus, silica and manganese than the flooded plants. The plants in the moist plots, as compared to the flooded plants, showed higher concentration of manganese with no significant differences among the other. The increased yields from upland plots were attributable to the high root activity and the increased amount of available nitrogen in the soil which resulted from aerobic decomposition of organic matter.

The relationships between water level and rice growth are shown in Figure 2. From this, the water level-spikelet numbers per hill relations are expressed by the following equation, irrespective of the fertilized amount of nitrogen;

$$Y=a-bX \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where Y represents spikelet number per hill, X represents water level ranging from 10 cm below the soil surface to 30 cm above the soil surface, and a and b are constants. Also, the ear weight per hill increases gradually as the water level decreases. It follows from this that if water and mineral nutrient are not limiting, the optimum standing water depth is not expected to be deep.

However, lowland rice grown under upland conditions is susceptible to lack of water since it has a very shallow root system. More than 80% of the total water absorbed by the roots of lowland rices was obtained from soil depths of less than 20 cm (Hasebe et al., 1963). Available soil moisture at these depths fluctuates considerably according



NOTE: Rices were grown in the pots in the pools regulated water levels.

Fig. 2. Influence of standing water depth on rice growth (Tanaka 1970)

to evapotranspiration. Iyama and Murata (1961) indicated that the photosynthesis of rice plant began to decline as soil moisture droped below 57% of the maximum water capacity. In upland crops such as groundnut, wheat, barley and soybean, the photosynthesis began to decline at a moisture level below 32 to 45% of the maximum water capacity. This suggests that rice requires high soil moisture to maintain high dry matter production. Many evidences indicated that drought damage in rice plant was especially severe during the period from the meiosis stage to the heading time when transpiration was at its maximum. Kawahara (1944) reported that the grain yield of rice which was grown initially under upland condition and kept under submerged condition only for 10 days at meiosis stage was as same as that in continuously submerged plot.

On the other hand, it was reported that the rice plants under unflooded conditions, even when the soil was moist, showed poor tillering, depressed leaf area, delayed flowering and lower grain yields than flooded rice plants (Ueda, 1935; Baba, 1958; Senewiratne and Mikkelson, 1961; Chaudhry and Maclean, 1963). These suggest the lower yield of rice grown under unflooded conditions are caused not only by water shortage, but also by some chemical or biological factors.

Water influences on the amount and kind of mineral nutrients in soil and their availability to plants. The decomposition of organic matter proceeds at a higher rate in a well-aerated soil than in a flooded soil. Considerable amount of nitrate is produced as an end product of mineralization in a well-aerated soil, but a part of it is lost by leaching and denitrification due to heavy rainfall and fluctuation of underground water level. Under heavy rainfall condition, the rice plants in unflooded culture where the water level was 5 cm below the soil surface showed lower grain yield than the flooded rice plants in the cases of less fertilization and/or rapid-responsive fertilizer, although there were no significant differences between two treatments in the cases of much fertilization and/or slow-responsive fertilizer (Tanaka, 1970). This suggests that the flooding in rice culture plays an important role to maintain the soil fertility. Also, drying a soil provides conditions to decrease the solubility of phosphorus, slica and iron, often retarding the uptake of these nutrients by the plant. The rate of ^{32}P transfered from the root to the top and the content of ^{32}P in the top were smaller in the unflooded plot than in the flooded plot (Tanaka, 1970). In the region where phosphorus uptake is limited, flooded irrigation may be effective for rice production.

Many varieties of upland rice are grown on hillsides. One of the distinguishing characteristics of upland rice is its deeper root development. Hasegawa (1962) showed that upland rice, in contrast to lowland rice, is capable of extending its roots deeper into the soil, utilizing the available water more easily. Hasebe et al. (1963) found that when upland rice and lowland rice were grown under upland conditions, the percent of water absorbed from soil depth below 20 cm to the total absorption was 40% in upland rice and 20% in lowland rice at booting stage susceptible to water shortage. The adaptability of upland rice to dry-land conditions may be attributed to their deeper root development. The upland rice still have the aerenchyma tissues which transfer oxygen from leaves to roots. Thus, upland rice can grow better than other upland crops in fields where drought and flooding conditions occur alternately because of the extreme fluctuation in rainfall.

The great diversity in water environments in the Asian monsoon regions must have contributed to development of rice varieties which are adapted to wide range of water environment from deep water condition of several meters to completely upland condition.

II. Influences of Irrigation Methods on Mineral Nutrient Uptake and Yield of Rice

In rice fields, constantly high yields can be obtained even when the same crop has been grown for many years. Experimental results in Japan indicated that the rice plants grown under flooded conditions without fertilizer produced about 70% of normal yield for several years. The relatively high yield in flooded rice culture may be partially attributable to nitrogen fixation by blue-green algae and other organisms. Blue-green algae grow well in the flooded environments with neutral or slightly alkaline soils at temperature of 30–35°C. De and Mandel (1956) reported that nitrogen fixation rates by blue-green algae were 16 kg to 79 kg per hectare, depending on soil types and fertilizer kinds. In addition to this, natural supply of inorganic nutrients and soil colloid dissolved in irrigation water are believed to be responsible for stable yield of rice. These may be important factors in the regions where the soil fertility limits rice production.

However, the rice culture in Japan is conducted with heavy application of fertilizer, especially nitrogen, in order to get high yield from the limited land for rice growing. The rice plants grown with heavy application of nitrogen are susceptible to the influences of fluctuations of light intensity and temperature, and sometimes result in over-growth, severe lodging and decreased yield. Under such cultural conditions, it is important to regulate the nitrogen absorption by means of improved irrigation methods.

Flooded condition has some deleterious effects. It restricts gaseous exchange between the atmosphere and the soil. This consequently leads to the accumulation of the products of anaerobic decomposition such as hydrogen sulfide and organic acids. Some of these products interfere with the normal physiological functions of rice roots. Rice has specialized aerenchyma tissues which transfer oxygen from leaves to roots and secretes the transferred oxygen into the soil to cope with the reductive condition. However, root rots may occur if the oxidation-reduction potential in the soil becomes too low and the plants are unable to supply adequate oxygen to the roots. This indicates that continuous submergence may not always be beneficial for maintaining the physiological functions of rice plant at optimum.

It is also pointed out that the flooded rice culture requires considerable amount of irrigation water. In ordinary rice field of Japan, the farmers use the water of 10,000 to 14,000 tons per hectare. Even in the region with irrigation facility, water shortage may occur because of extreme difference in annual rainfall and failure of rainfall to match the seasonal water demand of rice. Besides, the utilization of water is important problem in the regions coincident with the expansion of industry. Saving irrigation water is common to all rice culture.

Many trials have been conducted to minimize water use, keep root activity high and regulate nirtogen absorption by rice plant. The late submerged irrigation and intermittent irrigation are typical of the improved irrigation methods.

The are no good agreements concerning the effect of irrigation method on rice growth. The rice plants in the late submerged irrigation in which the field remained in upland condition during the tillering stage followed by submerged condition after young ear formation stage showed higher grain yield than the continuously submerged plants (Yoshioka, 1947, Amatsu et al., 1954, Takai, 1962). However, Watanabe (1950) and Kido and Ueda (1950) reported that the grain yield were decreased by the late submerged irrigation.

Relationships between irrigation method, nutrient absorption and grain yield, as shown in Figure 3, varied largely dependent upon rainfall amount and underground water level for unflooded period and applied amount of nitrogen. In this experiment, the treatments were; (a) early submerged irrigation in which the field was submerged 5 cm deep from tillering stage to ripening stage, (b) late submerged irrigation in which the field was under upland condition during tillering stage and then submerged 5 cm deep after young ear formation stage, (c) intermittent irrigation in which the field was kept under submerged condition for 3 days followed by unflooded condition for 4 days.

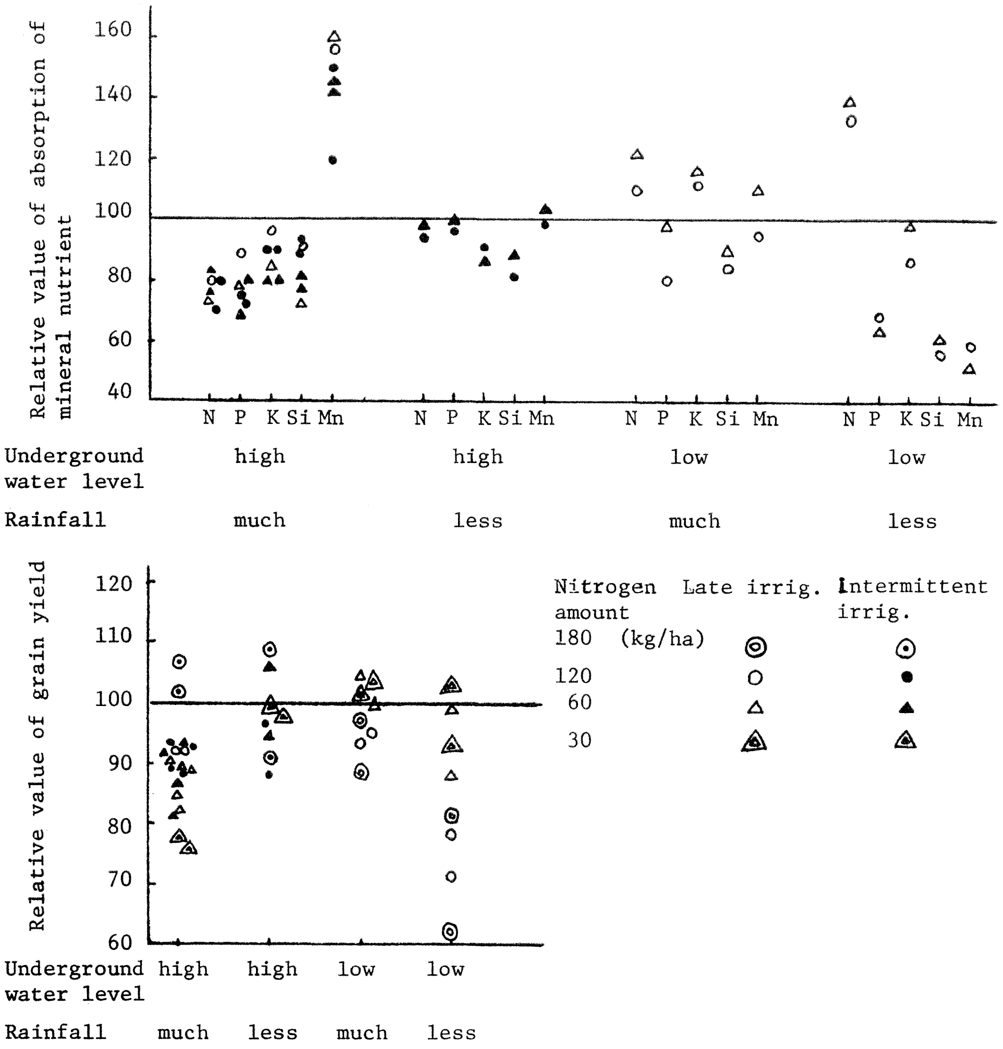


Fig. 3. Effects of late submerged irrigation and submerged irrigation on mineral nutrient absorption and grain yield of rice.

(Tanaka, 1970)

Note: Relative value is represented by the ratio by late submerged irrigation or intermittent irrigation to early submerged irrigation.

Underground water: High: 7cm to 18 cm below soil surface.
Low: 25 cm to 35 cm below soil surface.
Rainfall: Much: 5.0 mm to 5.3 mm per day.
Less: 3.0 mm per day.

Underground water level and rainfall amount represent the measured values for no irrigated period (tillering stage) of late submerged irrigation.

The effects of intermittent irrigation and late submerged irrigation on nutrient absorption of rice can be classified into four groups according to the combination of underground water level and rainfall amount during the unflooded period. In addition to this classification, the effects of irrigation methods on grain yield varied considerably dependent upon the fertilized amount of nitrogen (Figure 3).

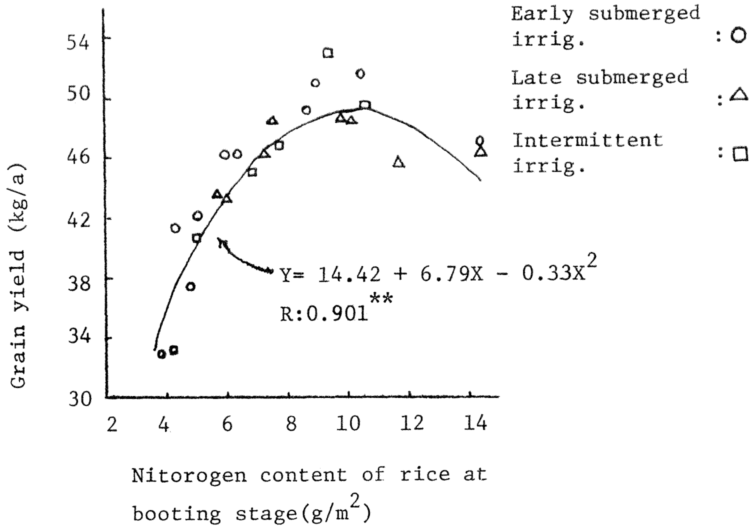


Fig. 4. Relations between absorbed nitrogen amount and grain yield of rice in different irrigation methods (Tanaka, 1970)

1) When the underground water level was high and the rainfall was less: The absorbed amounts of nitrogen, phosphorus, potassium and silica were decreased by late submerged irrigation and intermittent irrigation, while only manganese was increased by these irrigation methods. The rice plants grown in the plots of late submerged irrigation and intermittent irrigation showed lower yields than the early sugmerged plants under low levels of nitrogen fartilizer, but under excessively high nitrogen level the former was as much as or even higher than the latter.

2) When the underground water level was high and the rainfall was less: There were no significant differences in nutrient uptake and yield between intermittent irrigation and early submerged irrigation, irrespective of nitrogen applied amounts.

3) When the underground water level was low and the rainfall was much: The absorbed amounts of nitrogen and potassium were increased by the late submerged irrigation. The grain yields in the late submerged irrigation were slightly higher than those in the early submerged irrigation under low nitrogen levels, while the reverse was true under high nitrogen levels.

4) When the underground water level was low and the rainfall was less: The rice plants in the late submerged irrigation showed higher content of nitrogen and lower contents of phosphorus, silica and manganese than those in the early submerged irrigation, resulting in delayed flowering and severe lodging. Under excessively high nitrogen levels, the rices in the late submerged irrigation were significantly lower than those in the early submerged irrigation, while there were no differences under low nitrogen levels.

It is also observed in Fig. 4 that the grain yield-nitrogen content of rice plant relations were expressed by the following equation:

$$Y=14.42+6.79X-0.33X^2 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$$R: 0.901^{**}, \qquad 3.8 \leq X \leq 14.5,$$

where Y represented that grain yield (kg/a), X represented the nitrogen content of plant (g/m^2) at booting stage in each irrigation plot, and R showed regression coefficient. It follows from this that the effect of irrigation method on rice yield changes according to whether the nitrogen contents in the plants as affected by the variations in the underground water level and the rainfall amount approach to the optimum content of nitrogen under given climatic condition or not.

From these, rainfall and underground water level for unsubmerged period, and soil fertility may be important factors determining the irrigation method. Major rice-producing areas of the world distribute in the regions with a heavy rainfall. Furthermore, most of rice fields distributes in the lowland with high underground water level. Under such conditions, irrigation method-rice yield relations may be the same as the above-stated type 1.

In South East Asia and India, the rice plants are grown with a little or even no application of fertilizer. In these regions, late submerged irrigation and intermittent irrigation may result in decreased yield as compared with continuously submerger irrigation, except on the soil where harmfull substances generate under submerged conditions. The continuously submerged irrigation will maintain a high and stable yield in rice culture with low fertilization.

On the other hand, in the regions where the rice plants are grown with heavy application of fertilizer, intermittent irrigation may play an important role to keep the plant healthy under unfavourable climatic conditions, because this irrigation regulates excessive nitrogen absorption through the accelerated denitrification by repeating of oxidation and reduction. The intermittent irrigation has become popular in the fertile rice field in warm regions of Japan, with the purpose of controlling the root rot as well as regulating nitrogen absorption.

III. Water Environment and Weed

Rice plants are grown under high temperature and high light intensity during most of the growing season. These climatic conditions are more favourable for some weed species than for rice plant. It has been often observed that poor cultural management of rice field quickly leads to severe infestation by vigorus weeds such as *Echinochloa crus-galli, Cyperus microira, Digitaria ciliaris* and *Setaria viridis.*

Competition among plants is governed by many complicated interactions between the physiological and morphological characteristics of plants and the environmental factors in their habitats. Photosynthetic capacity may be one of the most important factors which determine the competitive ability of plant. The adaptability of this important physiological factor to given environmental conditions may determine the ultimate composition of a plant community. Higher plants are divided into two groups according to their photosynthetic carbon fixation pathway; C_3 species having the Calvin cycle and C_4 species having the C_4 dicarboxylic acid pathway. The rice plants assimilate CO_2 through Calvin cycle (C_3 species) and have photorespiration system which release a large amount of CO_2 in light. On the other hand, most species *Gramineae* of tropical origin such as maize, sugarcane and sorghum assimilate CO_2 through C_4 dicarboxylic acid pathway (C_4 species) and do not show photorespiration. The photosynthetic rates of C_4 species are usually higher than those of C_3 species under conditions of high temperature and high light intensity.

Echinochloa, Digitaria, Cyperus, Panicum, Setaria, Amarantus and *Portula* are all common summer weeds in cultivated fields and they belong to C_4 species. The high photosynthetic capacity of these weeds under high temperature and high light intensity make them very efficient competitors in the tropics and in temperate regions in summer.

Efficient use of water is another distinguishing characteristic of C_4 species. Black et al. (1969) compared water requirements for weeds and crops with different CO_2 fixation pathways from the data of Shantz and Piemeisel (1927). The data indicated that C_4 species required about one half as much as water to produce 1 g dry matter as C_3 species

Table 2. The changes in the distributions of summer weeds with different phtosynthetic pathway as affected by soil moisture (Tanaka, 1974)

Photosynthetic pathway	Weeds	Submergence	Water saturated	Upland
C_3 Type	Elatine orientalis Makino.	1. 55 g	0 g	0 g
	Monochoria vaginalis Presl.	0. 70	0	0
	Cyperus difformis L.	0. 35	0	0
	Dopatorium junceum Hamilt.	1. 50	+	0
	Lindernia pyxidaria All.	0. 20	+	0
	Eleocharis acicularis R. Br.	0. 60	+	0
	Rotala indica var. uliginosa (Miq.) Koehne.	3. 55	0. 05	0
	Eriocaulon sieboldtianum Sied.	0. 20	0. 15	0
	Poa acroleuca Steud.	0	0. 25	0. 05
	Polygonum blumei Meisn.	0	1. 20	2. 20
	Acalypha australis L.	0	0. 50	0. 05
	Chenopodium album L.	0	+	1. 10
	Subtotal	8. 65 (89)	1. 70 (6)	3. 85 (7)
C_4 Type	Echinochloa crus-galli Beauv. var. oryzicola Ohwi.	0. 70	7. 95	5. 75
	Cyperus microia Steud.	0. 25	3. 90	4. 85
	Fimbristylis littoralis Gaudich.	0. 10	1. 10	1. 55
	Amaranthus blitum L.	0	0. 10	0. 50
	Echinochloa crus-galli Beauv. var. platicala Ohwi.	0	3. 20	5. 55
	Setaria viridis Beauv.	0	9. 25	10. 10
	Digitaria ciliaris Pers.	0	3. 60	25. 35
	Portulaca oleracea L.	0	+	0. 35
	Subtotal	1. 05 (11)	29. 10 (94)	54. 00 (93)
	Total (C_3+C_4 Type)	9. 70 (100)	30. 80 (100)	57. 85 (100)

Note: Submergence: 6 cm in standing water depth, Water Saturated: 80–90% of maximum moisture capacity, Upland: 40–60% of maximum moisture capacity.

did. Therefore, the weeds of C_4 species may be serious potential competitor for rice which belongs to C_3 species. The competition must be especially critical during the periods of water shortage brought about by irregular distribution of rainfall.

The water environment of rice field is governed primarily by the seasonal distribution of monsoon rainfall. Most of the rice fields change from upland conditions to submerged conditions during the monsoon rainfall. Arai et al. (1955) reported that the distribution of weed species and its growth varied depending upon soil moisture condition. Tanaka (1974) classified the distribution of weeds according to their presence in varying soil moisture conditions and the types of their CO_2 fixation pathway from the data of Arai et al. Table 2 shows that the total dry weight of weeds per unit area is significantly retarded by submergence. In water saturated and upland plots the C_4 species accounts for more than 90% of the total dry weight, in a sharp contrast to 10% in submerged plots. Thus, the dry matter production of C_4 species is significantly reduced under submerged conditions as compared to water saturated or upland conditions. These results indicate that the submerged conditions resulting from the monsoon rains play an important role in protecting rice plants from severe competition with weeds of C_4 species. Therefore, it may be deduced that the submerged conditions created by irrigation also tend to give rice plants more competitive advantage over weeds of C_4 species.

IV. Water, Sold-Borne Disease and Nematodes

Rice yield are severely reduced under continuous cropping of rice in upland fields even heavy applications of fertilizer and compost. Rice plants under continuous cropping in upland culture showed depressed growth, brownish discoloration of roots, foliar chlorosis and 30–40% lower grain yield than those grown under rotation cropping (Watanabe et al., 1963). The decrease in yield under continuous cropping occurred in the second year and was most severe in the third year, showing gradual recovery thereafter. Such injury was not recovered by irrigation without submergence (Hasegawa et al., 1964).

Many investigations were conducted to elucidate the causes and the mechanism of injury to rice plants under continuous cropping in upland fields. Yamazaki et al. (1957) reported that the population of cyst nematodes of upland rice significantly increased soon after the beginning of continuous cropping. Rice growth was retarded inversely as the infestation of cyst nematodes increased. Watanabe et al. (1963) reported that the injury to rice plants under continuous cropping was primarily due to the infestation of cyst nematode (Heterodera oryzae). Injury was not due to iron and manganese deficiencies and toxic substances excreted from roots. It was also pointed out that secondary injury to rice plants was promoted by the soil-borne disease (Fusarium)) and insect pests such as Ropalosiphum prumifoliae. Soil fumigation with chloropicrin and dischloropropane-dichloropropene were effective in preventing continuous cropping injury. Many evidences suggested that most soil-borne diseases and nematodes in upland field were effectively controlled by submerging the field during the rice growing period. The submerged irrigation minimize the injury to rice plants by soil microbes and may stabilize rice production.

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Question and Answer

M. R. Islam, Bangladesh (c/o Nippon Koei Co., Ltd.): 1) At page 7, para. 2 of your paper, you have opined that high dosage of N-application induces over growth, severe lodging and fluctuations in yield. Should such practices of heavy application are unwelcome. What sort of improved irrigation method would you suggest in the context of your paper outlined here? Would you mind elaborating on it?

2) Do you opine intermittent irrigation method is the best one for the best efficiency of N-fertilization? If so, that are'nt you afraid of the danger of N-loss during the alternate dry and water logged conditions?

Answer: There is optimum nitrogen uptake for grain yield as shown in Fig. 4. The farmers, basing on many experimental results and experiences, have grown the rice plants with adequate amount of nitrogen fertilizer which obtains maximum yield under average climatic condition at given site. However, climatic factors such as air temperature and light intensity vary considerably year by year. Optimum nitrogen uptake under unfavourable climatic condition becomes lower, because of severe lodging and over-growth. It is necessary to decrease the nitrogen uptake up to optimum point at given climatic condition. The intermittent irrigation decreases the nitrogen uptake through repeating the oxidative and reductive condition, but increases the root activity. If intermittent irrigation is conducted under low levels of nitrogen fertilizer, the rice plants may show the decreased grain yield due to nitrogen loss as shown in Fig. 3. Therefore, the intermittent irrigation seems to be effective for rice yield only in the case of much nitrogen application.

S. Okabe, Japan: Figure 1 shows that the rice yields in the upland plots are equal or even much higher than those in the flooded or moist plots. Do you believe that the result indicated in the figure could be generalized or widely applicable to other varieties and to higher-yielding levels of rice plants?

Answer: The rice plants in this experiments were grown under small amount of nitrogen fertilizer, considering the effect of aerobic decomposition of soil organic matter in upland culture. The rice plants in upland culture showed the remarkable increase in nitrogen uptake at early growth stage and significantly increased spikelet numbers per hill due to the increased amounts of available nitrogen in soil which resulted from rapid and high decomposition of soil organic matter. This led to the increased grain yield. However, the plants in upland culture indicated lower nitrogen uptake at late growth stage and lower phosphorus uptake than flooded plants. Thus, the responses of rice varieties to aerobic irrigation such as upland culture in Fig. 1 vary dependent upon the adaptability to the pattern of nutrient uptakes, especially nitrogen. On the other hand, the results in Fig. 1 is one aspect of complicated relations between rice, water, and soil. In order to obtain high level of rice production in aerobic irrigation method, we need to establish the improved fertilization method such as top dressing, slow-responsive fertilizer, and heavy phosphorus application. In addition to this, aerobic irrigation brings about rapid decrease in soil fertility. Thus, it is important to find how to keep soil fertility high for long period in order to obtain high level of rice yield in aerobic irrigation.

H. Sakai, Japan (Comment): I would like to introduce my experience on fungal root infestation in shallow water in India. It occurs in flooded bed as well as in the main field just after transplanting. Stimulating factors are low temperature and alkaline soil reaction. The reason is that soil itself is not reductive enough to decrease fungal growth. The causing fungus is Pythsum, one of water fungi. Indica varieties are more susceptible than Japonica varieties. Regarding to water depth in saline soil it should be kept fairly deep.

Answer: The relations between rice, soil-borne diseases, insect pests, nematodes and natural enemy as affected by water environments are very complicate. Therefore, it is very important to analyze the above relations for establishing unflooded irrigation and partial flooded irrigation. The salinity in soil may be one of many factors determining optimum standing water depth, because of low tolerance of rice plant to salinity.