3. THE CHANGES IN SOME PHYSICAL AND CHEMICAL PROPERTIES OF PADDY SOILS UNDER WATER MANAGEMENT

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Introduction

In general rice in Thailand has been cultivated under flooding conditions. Flooding is done by irrigation or rainfed system. Paddy soil is submerged in 10 cm. or more water from seedling stage to the harvest, and growing period lasts at least 4–6 months. The flooding brings about such a dramatic change that it creates a reduced state from an oxidized one. Although there are many advantages to plant growth caused by the reduction in paddy soils, the disadvantages should be counted from the fact that rice roots are easily damaged by reduction products which are commonly known as "methane, hydrogen sulfide, organic acid etc." (1). As those harmful products are formed as the results of submergence, high yield of rice is always faced to difficulty under flooding condition. One of the reasons why the yields can not be increased seem to be due to the poor drainage system of paddy field in Thailand. The best method to improve soil condition under such a situation is to drain water out from the soil, at least from its surface.

The research was performed to study changes of some physical and chemical properties of the soils under water management in relation to grain yield, using quite different soils at two different Stations, Surin and Bangkhen.

Materials and Method

1) Experimental sites

Field experiments were carried out at two fields, Surin Rice Experiment Station and Bang Khen Rice Experiment Station, where physical and chemical properties of the soils were quite different each other.

The soil in Surin Rice Station, belonging to Roi Et series, is Low Humic Gley Soils developed on Ground Water Lateritic Soils. The physical and chemical properties of the soil are shown in Table 1. Fine sand (0.2 to 0.02 mm in diameter) dominates throughout the profile, but clay fraction (less than 0.002 mm in diameter) slightly increases with the depth. Organic matter is very poor, total nitrogen ranges 0.01 to 0.02%, and cation exchange capacity is very low, 2 to 7 me per 100 g on dry basis. Almost of all nutrients in this soil seem to be extremely defficient for good growth of rice plant, for example, only 1 to 2 ppm of available phosphorus and 2 to 5 ppm of available nitrogen. In short, this soil seems to represent typical soils of the North-east region in Thailand which are very low fertiilty.

On the other hand, Bang Khen soil, belonging to Bang Khen series, is Marine

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Table 1. Physical and Chemical Properties of Surin Soil

Items	Apg 0–15cm	Blg 15–25cm	B2g 25–60cm	B3g 60cm +
Coarse sand (%)	2. 2	2. 8	2. 0	4. 6
Fine sand (%)	83. 3	69. 7	62. 1	59. 2
Silt (%)	4. 3	11. 7	13. 8	11. 6
Clay (%)	5. 2	15. 8	22. 1	24. 6
Texture	LFS	SCL	SCL	SCL
Max. Water holding capacity	27. 4	36. 3	39. 4	38. 3
Shrinkage limit (%)	19. 5	—	—	—
Volume change (%)	6. 6	—	—	—
pH H_2O	4. 7	5. 0	5. 2	5. 4
KCl	3. 3	4. 3	4. 2	4. 4
Total nitrogen (%)	0. 016	0. 021	0. 015	0. 014
Total carbon (%)	0. 060	0. 070	0. 081	0. 069
Carbon nitrogen ratio	4	3	5	5
CEC me/100 g	2. 20	4. 06	6. 56	7. 28
Exchangeable Ca me/100 g	0. 92	2. 92	3. 98	4. 05
Exchangeable Me me/100 g	0. 29	0. 38	1. 36	1. 17
Exchangeable Na me/100 g	0. 09	0. 09	0. 15	0. 44
Exchangeable K me/100 g	0. 09	0. 01	0. 03	0. 05
Total P_2O_5 mg/100 g	2. 3	2. 3	2. 3	1. 6
Available P_2O_5 ppm	1. 12	0. 80	2. 52	2. 50
Total K_2O mg/100 g	17. 3	32. 2	60. 6	82. 9
Available NH_4-N ppm	5. 1	—	—	—
Available SiO_2 ppm	13. 0	—	—	—

Alluvial Soils intergrading Brackish Water Alluvial Soils. This soil widely distributes on the flood plain area in the Central Plain. The physical and chemical properties of the soil are shown in Table 2. Clay content is very high, and sand fraction very low throughout the profile. This soil has a high cation exchange capacity. Exchangeable bases are characterized by high content of magnesium. Total phosphorus digested by perchloric acid is about 60 mg per 100 g on dry basis and available phosphorus extracted by Bray No. 2 solution is about 12 ppm, indicating to be somewhat insufficient for good growth of paddy rice. On the other hand, the supply of potassium would be sufficient. In other word, the fertility of this soil is considered to be fairly high compared with Surin soil.

2) Drainage treatment

The experimental field was divided into two blocks. The one block was kept in flooded condition throughout the whole growing period, while the other was drained off the surface irrigation water for 7 or 10 days at the end of effective tillering stage and for 3 days at IPP stage.

3) Application of organic matter

As organic matter sources, city compost and rice straw were applied at the rate

Table 2. Physical and Chemical Properties of Bang Khen Soil

Items		Apg 0-15cm	A12g 15-30cm	AIICg 30-45cm	AIICg 45-65cm
Coarse sand (%)		0	0	0.2	2.5
Fine sand (%)		5.9	6.5	5.9	10.2
Silt (%)		26.2	24.1	28.9	30.1
Clay (%)		67.9	69.4	65.0	57.2
Texture (%)		H C	H C	H C	H C
Max. water holding capacity (%)		63.7	61.6	66.3	64.9
Shrinkage limit (%)		45.1	—	—	—
Volume change (%)		88.8	—	—	—
pH	H_2O	5.2	5.1	4.8	5.3
	KCl	4.3	4.0	3.7	4.0
Total nitrogen (%)		0.126	0.108	0.099	0.048
Total carbon (%)		1.41	1.21	0.89	0.42
Carbon nitrogen ratio		11	11	9	9
CEC	me/100 g	33.1	33.0	30.4	28.6
Exchangeable Ca	me/100 g	11.4	10.3	8.8	15.2
Exchangeable Mg	me/100 g	17.1	16.2	16.3	15.2
Exchangeable Na	me/100 g	9.7	7.5	8.0	8.8
Exchangeable K	me/100 g	1.3	1.1	1.0	1.0
Total P_2O_5	mg/100 g	63.7	62.1	51.8	55.2
Available P_2O_5	ppm	12.1	9.0	4.6	2.1
Total K_2O	mg/100 g	1,238.6	1,267.2	1,217.9	973.3
Available NH_4-N	ppm	49.5	—	—	—
Available SiO_2	ppm	220	185	118	146

of 6 tons per hectare. Total amount of organic matter was introduced 3 weeks before transplanting, and stepped down and mixed well with the plowed layer. Chemical analysis of city compost and rice straw used in this experiment are as follows;

	Moisture %		Total N	C	C/N	Total P	Total K
	A*	B**	%	%		%	%
Citry Compost	48.7	5.3	1.13	12.7	11	1.70	0.62
Rice Straw	10.8	3.8	0.79	43.7	55	0.22	1.47

* At the application time
** After dryin at 70°C for 48 hrs.

4) Measurements

Immediately after transplanting, capless soil samplers (5 cm in diameter, 25 cm in length) were put into the plowed layer and taken off periodically. Soil sample taken off from cylindrical sampler was divided into different depth, namely 0–5 cm, 5–10 cm, 10–15 cm and 15–20 cm, respectively. For each soil sample, soil pH, redox potential, ferrous iron and ammonium nitrogen were measured. Methods of analysis taken were as follows:

a) Soil pH: Measured by glasselectrode.

b) Redox potential: Measured by Pt-electrode. Redox potential of soil was expressed as mV at pH (6.0 (Eh_6).

c) Ferrous iron: After extracting with 0.2%$AlCl_3$ solution, Fe(II) was colorimetrically determined by 2,2′-dipyridyl method.

d) Ammonium nitrogen: After extracting with 10% KCl solution, NH_4-N was determined by steam distillation method.

During intermittend drainage treatment, three phases of soil (solid, liquid and air phases) were measured on soil samples taken from the drained plots.

Results and Discussion

1) Changes in soil conditions during the whole growing period

The soil pH and redox potential measured periodically during the whole growing period in Bang Khen Station in wet season of 1970 are shown in Fig. 1 and Fig. 2, respectively.

As shown in Fig. 1, a gradual increase in soil pH was observed during the growing period, and the value of soil pH reached to aobut 7.0 at the end of the period. Soil pH of the uppermost layer (0–5 cm) apparently was higher at the beginning of flooding than those of following layers, but those values came to closer with the growing period proceeded. During intermittent drainage of irrigation water, soil pH of the uppermost layer dropped, but that in the lower part remained still at high level.

As naturally expected, redox potential dropped rather rapidly at the early stage of flooding, and then reached to almost a constant Eh_6 value of 0 mV in one month after transplanting. The potentials showed minimum values for the sub-surface layer (5–10 cm) and the maximum for the third layer (10–15 cm) during the whole period. In the drained plot, redox potential was decreasing in the same way as the undrained plot until drainage treatment started. However, the potential increased rapidly during the draining period, namely, the Eh_6 value in the uppermost layer was rising up to +150 mV at the end of the drainage treatment, while that of lower layer still was stayed at low level. The redox potential dropped to low Eh_6 value, after irrigation started again.

Effects of intermittent drainage of irrigation water on soil pH and redox potential seemed to be limited only in the surface layer. During the drainage period, wide cracks appeared and developed deeply with drying up the surface soil. Surface of large cracks might be easily oxidized by air, but the inside of large cracks would not be oxidized by air and maintained in strongly reduced condition.

Changes in three phases distribution of soil were shown in Fig. 3. By the drainage treatment, solid phase of the soil in Bang Khen field gradually increased with decreasing in liquid phase, and air phase increased steadily until it attained to a constant value. Such changes were taken place much more clearly in the uppermost layer. Cracks began to appear 3 or 4 days after the draining, and strongly developed with decreasing in liquid phase. Bang Khen soil is heavy textured soil, dominating montmorillonite followed by little and kaolinite in clay mineral composition. Accordingly, volume changes due to shrinkage were reached to almost 90%. It means that the soil decreases its volume by nearly one-half of the original. Such a heavy shrinkage resulted in strong compaction of the soil.

Surin soil showed a remarkable contrast to Bang Khen soil on shrinkage. Its solid phase increased only slightly by the treatment, but air phase was kept almost unchanged during the whole period of the treatment. In fact, any cracks were not observed during this treatment. This is probably due to very narrow range between shrinkage limit and

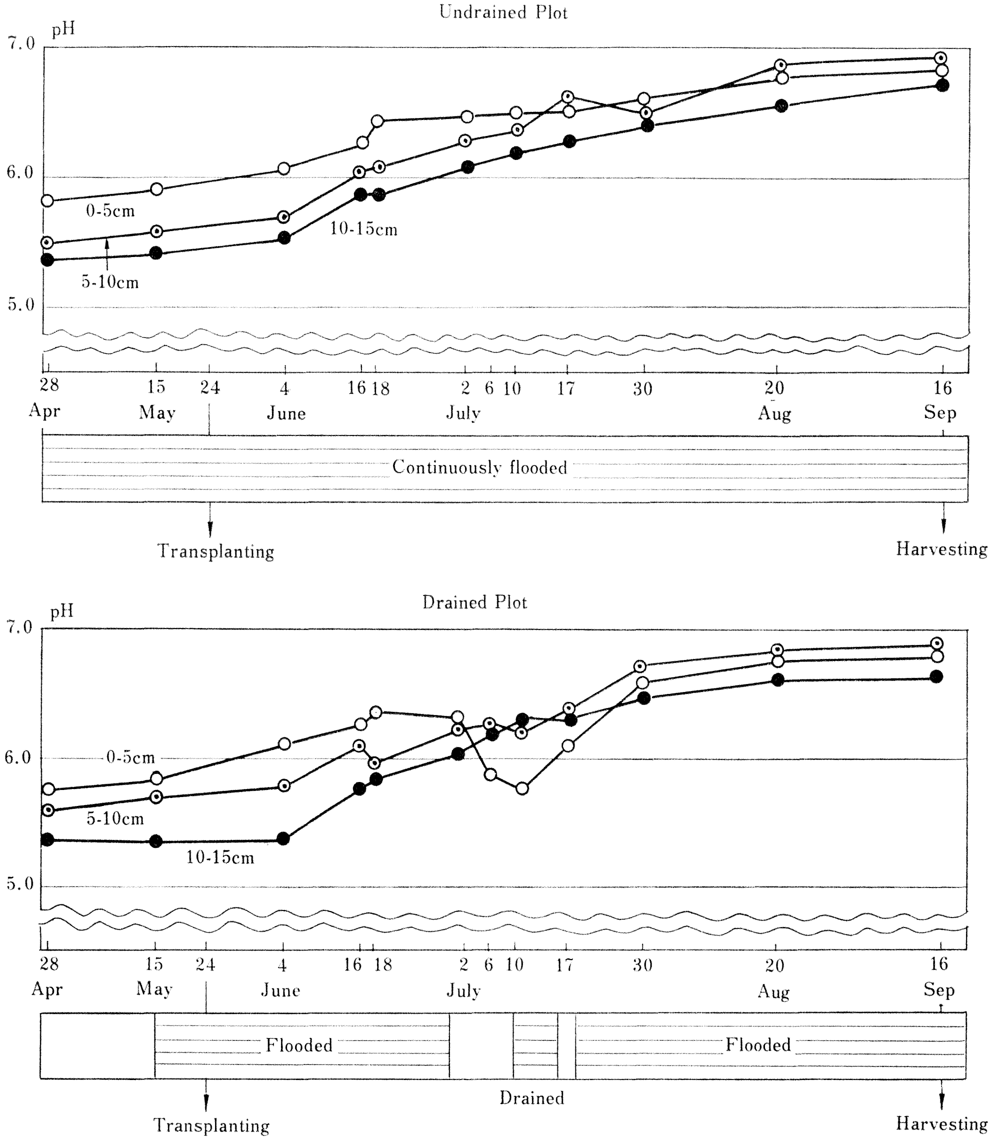

Fig. 1. Changes in Soil pH at Bang Khen Field in Wet Season, 1970

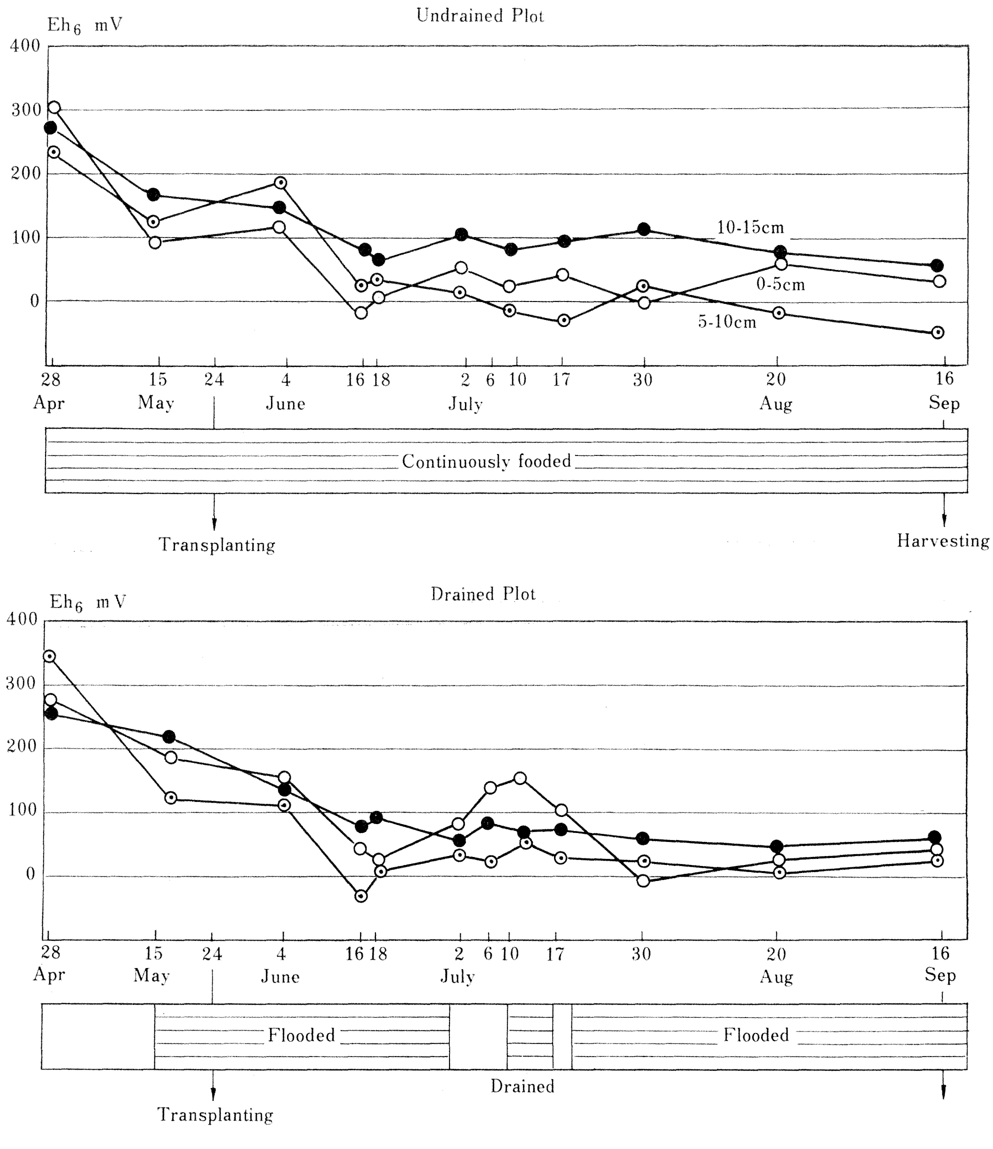

Fig. 2. Changes in Redox Potential at Bang Khen Field in Wet Season, 1970

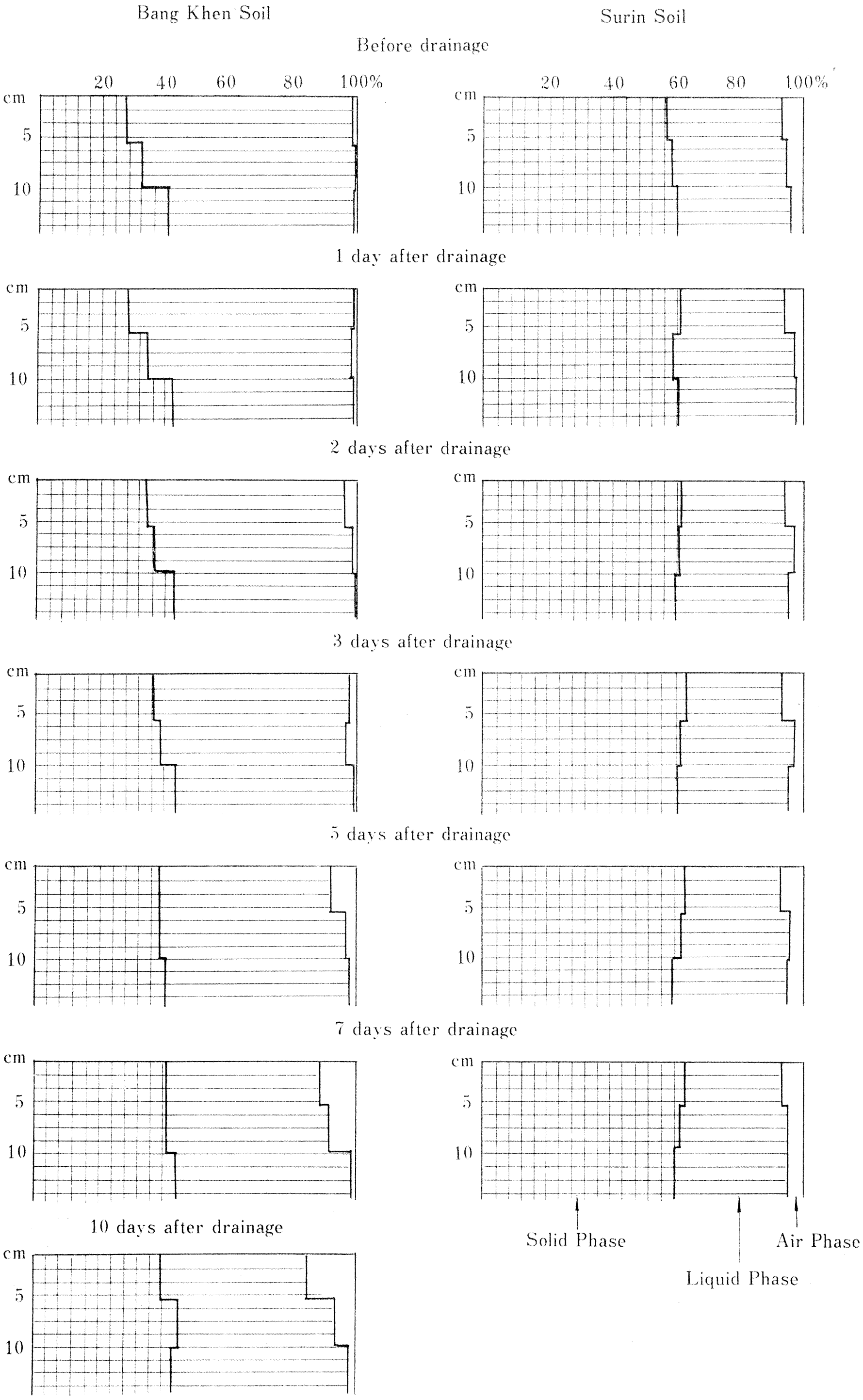

Fig. 3. Changes in Three Phases Distribution during the Water Management

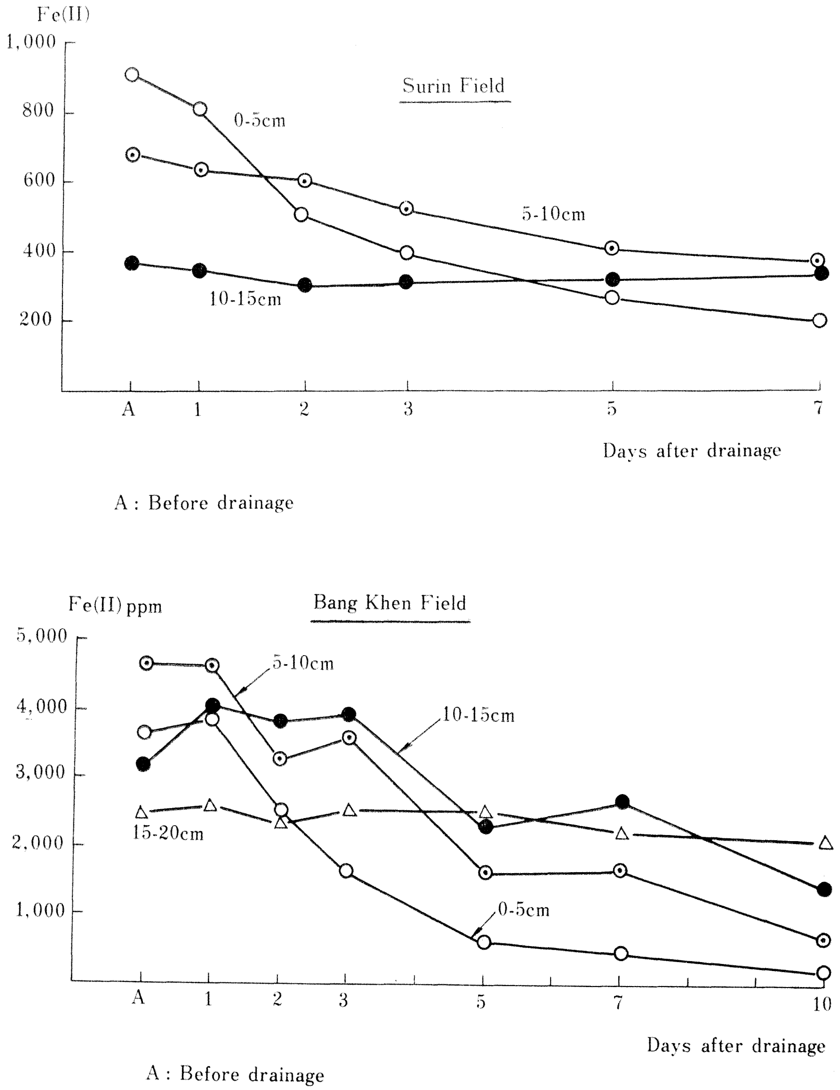

Fig. 4. Changes in Fe (II) Content by Water Management

liquid limit on account of very coarse textured soil.

Changes in ferrous iron concentration during the drainage period are shown in Fig. 4. Ferrous iron content of the uppermost layer and of the second layer in Bang Khen soil rapidly declined with the time passed, that is, the ferrous iron concentration of 3687 ppm or 4676 ppm in the uppermost layerd and the following layer respectively before the treatment was lowered to 91 ppm or 672 ppm at the end. Ferrous iron concentration of the third layer, on the other hand, very gradually dropped from 3155 ppm to 1363 ppm. And the changes in ferrous iron content of the fourth layer were not distinct, the value standing between 2462 ppm and 1935 ppm throughout the treatment. Changes in ferrous iron contents during the drainage treatment at Surin soil

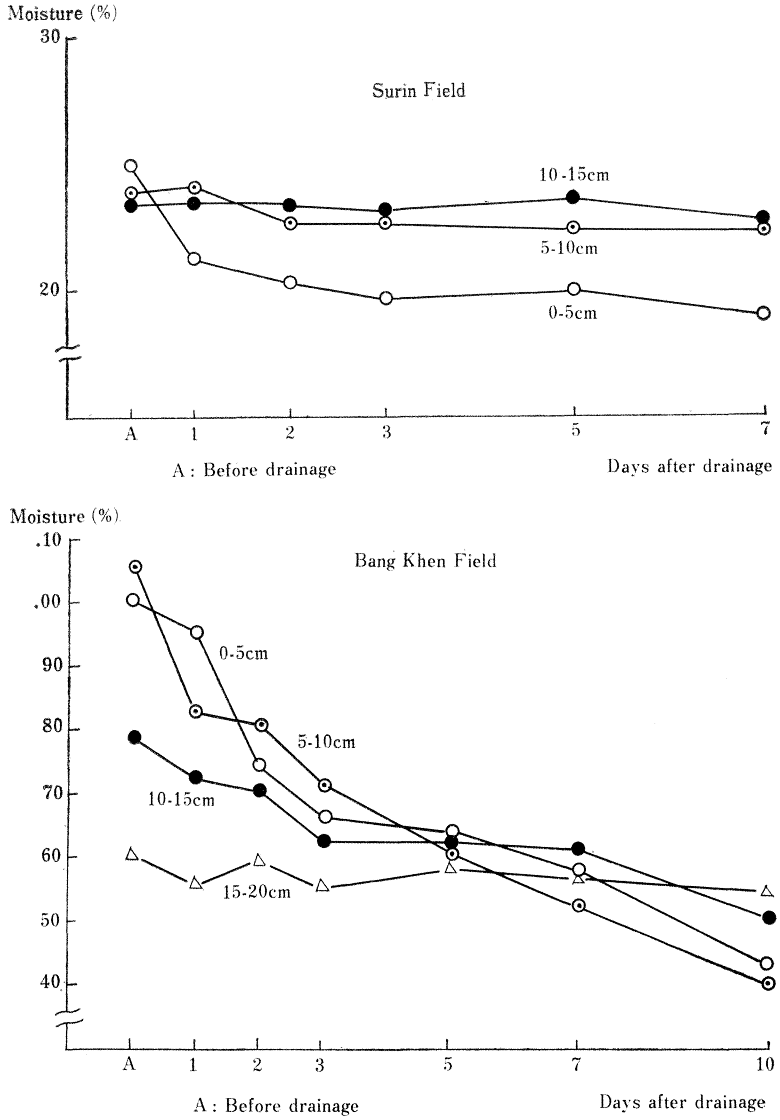

Fig. 5. Change in Moisture by Water Management

showed the same tendency as those in Bang Khen soil. However, ferrous iron concentration was very low compared to that in Bang Khen soil.

Decrease in water content with drainage process was clear for the first and second layers of Bang Khen soil, as shown in Fig. 5. However, almost a constant level of moisture was observed in the deepest layer (15–20 cm), ranging from 59.2% to 53.6%. In the case of Surin soil, changes in water content were limited only to the uppermost layer, ranging from 24.8% to 18.8%, and the moisture in the following layers remained unchanged.

Fig. 6 shows the relationship between moisture and ferrous iron contents during the drainage period. As shown in the figure, ferrous iron concentration has a close re-

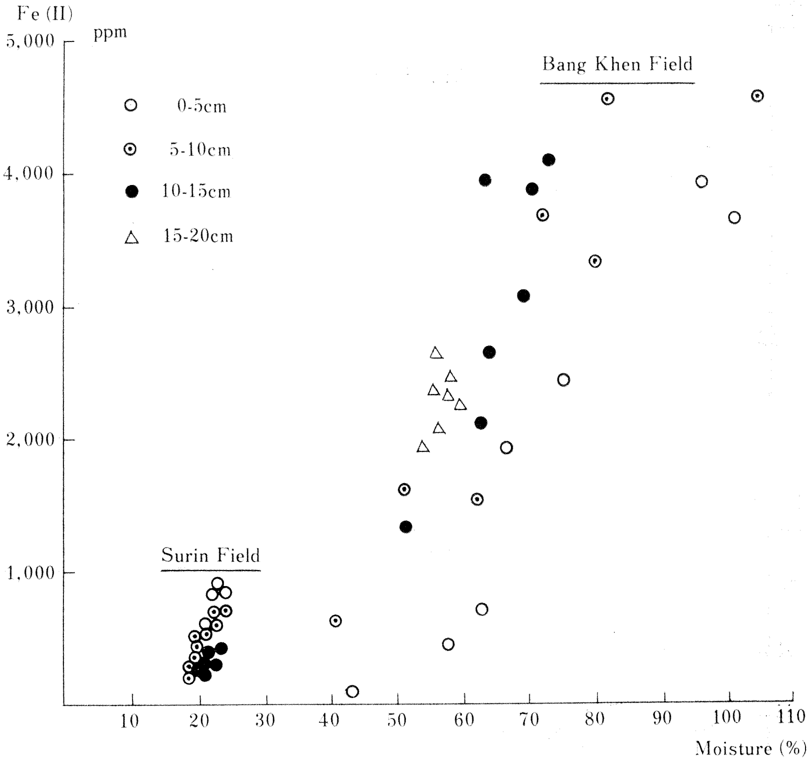

Fig. 6. Relationship between Moisture and Ferrous Iron Content

lation with moisture, in the way of its linear decreases with dropping of moisture. Ohyama and Sakai (2) reported on the same results as mentioned above. An increase in air phase during the drainage treatment implies a fact that air intrudes into the inside of the soil from the surface or along the cracks formed by shrink of soil. Consequently, reduced substances such as ferrous iron may be oxidized. However, formation of large cracks followed by the shrink will possibly result in strong compaction of soil as already mentioned before. Therefore, to improve such strongly reduced soil condition by drainage treatment, it is of importance to ameliorate soil structure so that much air may easily put into the root zone. For this purpose, soil structure of the plowed layer should be improved to make small cracks as many as possible instead of few large cracks.

2) Changes in soil condition by application of organic matter

The development of soil reduction is greatly affected by microbiological activities (3). Consequently, the magnitude and the rate of soil reduction are dependent to a great extent upon soil properties related to microbiological activities, mainly upon quantity and quality of organic matter in the soil.

Tables 3 and 4 give analytical data on soil conditions when organic matter was applied. These data were obtained from Surin field (wet season in 1971) and from Bang Khen soil (dry season in 1972), respectively. The soil was sampled just before basal fertilizer application, at maximum tillering stage (just before drainage treatment practice), at flowering stage (Bang Khen field) or at heading stage (Surin field) and after

Table 3. Soil Conditions of Surin Field in Wet Season, 1971

Treatment	Air dry soil	June 21*	July 21**	Sep. 15***	Oct. 15****
	Soil pH				
Control	5. 65	6. 25	6. 30	6. 40	6. 35
City compost		6. 60	6. 32	6. 55	6. 42
Rice straw		6. 43	6. 46	6. 68	6. 55
	Redox potential (Eh_6, mV)				
Control	+462	+163	+157	+145	+136
City compost		+ 36	+127	+107	+191
Rice straw		+ 62	+ 90	+113	+111
	Ferrous irom, ppm				
Control	0	437	339	341	445
City compost		811	745	823	416
Rice straw		720	706	876	512
	Ammonium nitrogen, ppm				
Control	0	3. 7	5. 5	6. 0	3. 6
City compost		8. 1	14. 5	14. 2	4. 8
Rice straw		3. 5	6. 8	8. 4	4. 1

* Before basal fertilizer application
** Maximum tillering stage
*** Heading stage
**** After heavesting

harvesting.

Surin soil did not show a clear development of reduction which was indicated by changes in soil pH, redox potential, and ferrous iron content. However, the application of organic matter brought about an increase in soil pH, a decline in redox potential and accerelation of ferrous iron formation as a result of stimulation to micro-organisms's action. Ammonium concentration in soil was slightly lower in the rice straw plot, but higher in the city compost plot than that of the control at the beginning stage. It seems to be due to differences in the carbon-nitrogen ratio between both organic matters. But, ammonium concentration of all plots heightened with advance in the stage.

On the other hand, at Bang Khen soil, the soil reduction was developed rather clearly even without the application of organic matter. Therefore, the effect of organic matter on the development of soil reduction was not clear, but a slight increase in ferrous iron concentration was observed by the application of organic matters.

Thus an application of organic matter sometimes brings about drastic development of reduction in soil. In this case, an appropriate water management such as drainage or intermittent irrigation is effective practice to remove the harmful substances and to recover the suitable oxidation-reduction status surrounding root zone.

3) Grain yield

As shown in Table 5, the intermittent drainage of irrigation water in the experiments generally gave favorable effects on grain yields at Bang Khen field in wet season of 1970 and at Surin field in west season of 1971. However, grain yields obtained from

Table 4. Soil Conditions of Bang Khen Field in Dry season, 1972

Treatment	Air dry soil	Feb. 4*	Mar. 3**	Mar. 31***	May 10****
	Soil pH				
Control	5.20	6.68	6.78	6.68	5.90
City compost		6.74	6.80	6.87	6.30
Rice straw		6.68	6.90	6.88	5.95
	Redox potential (Eh_6, mV)				
Control	+425	+98	+88	+44	+313
City compost		+72	+49	+36	+225
Rice straw		+51	+31	+37	+354
	Ferrous iron, ppm				
Control	13	2,786	2,284	3,105	88
City compost		3,384	3,339	3,789	528
Rice straw		3,379	3,431	4,393	92
	Ammonium nitrogen, ppm				
Control	0.3	33.9	18.8	16.7	3.7
City compost		43.6	36.7	31.3	4.2
Rice straw		25.3	19.7	26.8	4.9

* Before basal fertilizer application
** Maximum tillering stage
*** Flowering stage
**** After harvesting

Table 5. Average Yield of Grain

Drainage treatment	Grain yield kg/ha		
	Bang Khen, wet season 1970		
	Low P_2O_5 level (37.5 kg/ha)	High P_2O_5 level (112.5 kg/ha)	
Undrained	2,944	3,283	
Drained	3,484	3,463	
	Surin, wet season 1971*		
	Control	City compost	Rice straw
Undrained	2,865	3,698	3,388
Drained	3,236	4,225	3,136
	Bang Khen, dry season 1972*		
	Control	City compost	Rice straw
Undrained	5,010	5,000	5,291
Drained	4,471	4,819	4,384

N level : 75 kg/ha
K level : 75 kg/ha
*P level : 75 kg/ha

Bang Khen in dry season of 1972 were lower in the drained plot than those in the undrained. Osada, et al. (4) reported about negative effect of intermittent drainage on farmer's field at Nong Khaem in Thon Buri in wet season of 1971, where the soil is thought to be nearly the same condition as the soil in Bang Khen.

Intermittent drainage is considered to give advantages to rice plant as follows: 1) to remove harmful substances from root zone, 2) to recover suitable oxidation-reduction status surrounding root zone, and 3) to regulate nutrients supply, resulting in minimizing non-effective tillers, etc. (5, 6). However, the following disadvantages of drainage should be pointed out: 1) loss of plant nutrients through water percolation and 2) lowering of availability in some nutrients by oxidation.

Higher yields obtained by intermittent drainage might probably be encouraged by the promotion of oxygen supply to root zone, by which the activity of rice root may be not only recovered, but also nutrients in soil may become more available, especially available nitrogen increased in the later stage through a fact that microbiological activitines were renewed by the treatment.

An application of organic matter to sandy soil may give a beneficial effect on grain yields. However, the drastic reduction will be caused by the application of organic matter to a weakly buffered soil such as the Surin soil. In this case, drainage treatment seems to be effective method for the romoval of harmful substances in the soil. But, it should be noted here that plant nutrients would be lost during the drainage because of its low holding capacity of nutrients.

One of the low productivity of rice in the Central Plain might probably due to poor drainage. A suitable drainage treatment may give a favorable effect on rice plant. The drainage practices taken in the experiments brought clearly the oxidized state to root zone as seen in the changes of redox potential and ferrous iron contents. Although the drainage practices in the experiments did not give a clear effect on rice yields, it is safely said that many soil characters affecting the growth of rice plant are in complicated relations to drainage which finally will give a favorable effect on increase in rice yield. Therefore, further studies are necessary to clarify the plant-water-soil relationship from such points of view.

Summary

This research was aimed to carry out on field experiments at two different Stations, Surin and Bank Khen, in order to clarify mainly on changes in physical and chemical properties of those distinctively different soils caused by the drainage treatments in relation to grain yield of rice. The results obtained are summarized as follows.

1) During the drainage treatment, solid phase generally increased in a proportion with decrement in liquid phase.

2) While wide cracks were observed in the Bang Khen soil within 3 to 4 days after drainage started, no cracks could be found to develope in the Surin soil during the drainage. It might probably be due to differences in shrinkage limit between both soils.

3) Ferrous iron content in soil fell rapidly in the Bang Khen Soil and slowly in the Surin soil, in parallel with the decrease of water contents in the upper layers of the soil.

4) Accerelated development of soil reduction was taken place by the application of organic matter, especially for the Surin soil.

5) The drainage treatment seemed to remove harmful substances formed under strongly reduced soils, which were promoted by organic matter applied.

6) Changes of redox potential and of ferrous iron contents in the soils may give a possible explanation that the intermittent drainage of this study will make a

favorable effect on refreshing rhizosphere by which rice yield may be advanced.

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Question and Answer

J. C. O'Toole, IRRI: The "shrinkage limit" seems to be a very important factor in your comparison of the two soil types. It is related to rate of soil moisture loss which inturn seems to relate to ferrous iron content and redox potentials. How is the "shrinkage limit" determined and could this be used to determine if mid season drainage is applicable or help to decide the length of tine between irrigations in water saving practices such as intermittent irrigation.

Answer: The shrinkage limit is expressed as the water content at which there is no further volume decrease with further evaporation of pore water.

Because there is little change in volume from the shrinkage limit after complete drying out, the shrinkage limit can determined from the volume of an oven dried specimen. If the total volume, the specific gravity of the solid, and the weight of the dry specimen are known, the shrinkage limit can be obtained by assuming the voids of the dry soil to be filled with water and determining the ratio of the weight of the dry solid.

S. Okabe, Japan: (1) You have mentioned about the effect of mid-season drainage of irrigation water. Could you give us any figures on balance sheet of the soil nutrients between loss of the nutrients by drainage treatment and supply of nutrients by irrigation water?

(2) Table 5 shows that the paddy field of the drained plot in the 1972 dry season were lower than those of the undrained plot. Do you think that those lower yields in the drained plot would have been partly caused by the drainage treatment in the previous two wet seasons?

Answer: (1) It is a very difficult to give on a balance sheet soil nitrogen, many losses of soil nitrogen such as denitrification, immobilization etc. The irrigation water contents about 1–2 ppm. of ammonium-nitrogen, 3–5 ppm. of potassium (K).

(2) The rice yield in Thailand is controlled by many factor such as 1) seasonal effect, 2) due to water management, 3) the losses of soil nitrogen by denitrification.

T. Saito, Japan: From engineering point of view, if wide cracks were created in the Bangkhen soil within 3 to 4 days after drainage started, that drainage project is fruitful.

If you plan the drainage project in that area, could you give me some information concerning the suitable distance of farm drainages there? If the open drainage system is not enough there, I would like to know the suitable undrainage system there.

Answer: I am a soil scientist. I have no idea about the drainage project will be fruitful in my country. Mr. Charin can answer this question.

Mr. Charin: I will answer this question in this afternoon.