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SPECIFIC SOIL CHEMICAL CHARACTERISTICS FOR RICE PRODUCTION IN ASIA

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- 2 -

SPECIFIC SOIL CHEMICAL CHARACTERISTICS FOR RICE PRODUCTION IN ASIA[1]

ABSTRACT

Evaluation of both current and potential rice lands is necessary to meet the pressing need for more rice in Asia. But because of the chemical changes caused by flooding soils, this evaluation cannot be based on criteria developed for dryland crops.

The chemical benefits of flooding can diminish the need for initial and recurrent financial inputs; but the opposite may also occur. Soils, which by dryland criteria may be placed in the unsuitable class, may shift into the suitable class or the conditionally suitable class and vice versa.

When formerly nonflooded soils are flooded, pH approaches 7 from both the acid and the alkaline sides, the electrolyte content increases, the availability of nitrogen, phosphorus, silicon, and molybdenum increases, the availability of zinc and copper decreases, and harmful concentrations of iron, hydrogen sulfide, and organic reduction products may build up.

The chemical changes brought about by flooding and inherent soils properties complicate the evaluation of saline, sodic and peat soils, and soils with nutritional problems.

There is promise that some of the chemical changes with implications for evaluation of land for use in wetland rice cultivation can be predicted, at least qualitatively, from such properties of the dry soil as pH, cation exchange capacity, exchangeable aluminum content, organic matter content, content and reactivity of the iron oxides, and content of and availability of macro and micro elements, considered with soil temperature and percolation rates.

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[1] by F. N. Ponnamperuma, principal soil chemist, International Rice Research Institute, Los Baños, Philippines. Submitted to the IRRI Research Paper Series Committee, 6 October 1976.

-3-

SPECIFIC SOIL CHEMICAL CHARACTERISTICS FOR RICE PRODUCTION IN ASIA

Rice is the most important crop in Asia, where more than 80% of the world's rice is grown and consumed and where pressure is mounting for an annual increase of from 7 to 8 million tons in rice production to keep pace with population growth. That increase can be achieved by increasing rice yield per hectare or by extending the area under rice cultivation. Either way soil problems are obstacles. This paper deals with soil chemical problems and their implications for land evaluation for wetland rice.

In many parts of the world the new high-yield-potential rice varieties are not doing well. Soil problems, which had gone undetected earlier because of the low yield potential -- and low demand on soils -- of the old varieties, and perhaps also because of their tolerance to adverse soil conditions, are now assuming more importance. Examples are iron toxicity on acid soils; phosphorus deficiency on ultisols, oxisols, vertisols, and andepts; zinc deficiency on sodic, calcareous, peat, and waterlogged soils; iron deficiency on high-pH soils and, regardless of pH, on aerobic soils; and manganese and aluminum toxicities on acid aerobic soils.

The extent of arable land in the densely populated countries of Asia is limited and any additional rice cultivation must move onto lands that are uncultivated largely because of soil problems such as salinity, alkalinity, strong acidity, severe nutrient deficiencies, or unknown toxicities.

To evaluate current and potential rice lands, an understanding of the peculiar properties of flooded soils and of the physiology of the rice plant is necessary because the chemical changes caused by soil submergence and the peculiarities of the rice plant drastically alter the criteria used for evaluating land for dryland crops.

The main chemical changes in flooded soils (Ponnamperuma, 1972) that have implications for land evaluation for wetland rice are

1. **depletion of molecular oxygen;**
2. **increase in pH of acid soils and decrease in pH of calcareous and sodic soils;**
3. **changes in electrical conductivity;**
4. **reduction of Fe(III) to Fe(II);**
5. **increase in supply and availability of nitrogen;**
6. **increase in availability of phosphorus, silicon, and molybdenum;**
7. **decrease in availability of zinc and copper;**
8. **generation of toxins such as organic reduction products, organic acids, ethylene, and hydrogen sulfide.**

The extent of these changes varies with chemical and physical properties of the soil, water regime, and temperature.

Depletion of oxygen

Within a few hours of soil submergence, microorganisms use up the oxygen present in soil air and water and render the soil virtually oxygen free except in a thin layer at the soil surface (Ponnamperuma, 1965). The exhaustion of oxygen causes reduction of the soil with its attendant benefits such as increase in pH, elimination of aluminum and manganese toxicities, and increased availability of nutrients. Rice is able to exploit the chemical benefits of soil submergence because its roots receive oxygen through aerenchyma in the shoot system and lysigenous channels in the roots (van Raalte, 1941). Thus not only can rice grow in oxygen-free soils but it can also protect its roots against anaerobic poisons by oxygen secretion. Waterlogging, a drawback for plants that need aerated soils, is an advantage for rice.

Change in pH

Within a few weeks of submergence the pH of acid soils increases and the pH of sodic and calcareous soils decreases (Ponnamperuma et al., 1966). Thus submergence causes the pH values of most acid and alkaline soils to converge between 6 and 7 (Fig. 1). The rate and degree of the pH changes depend on

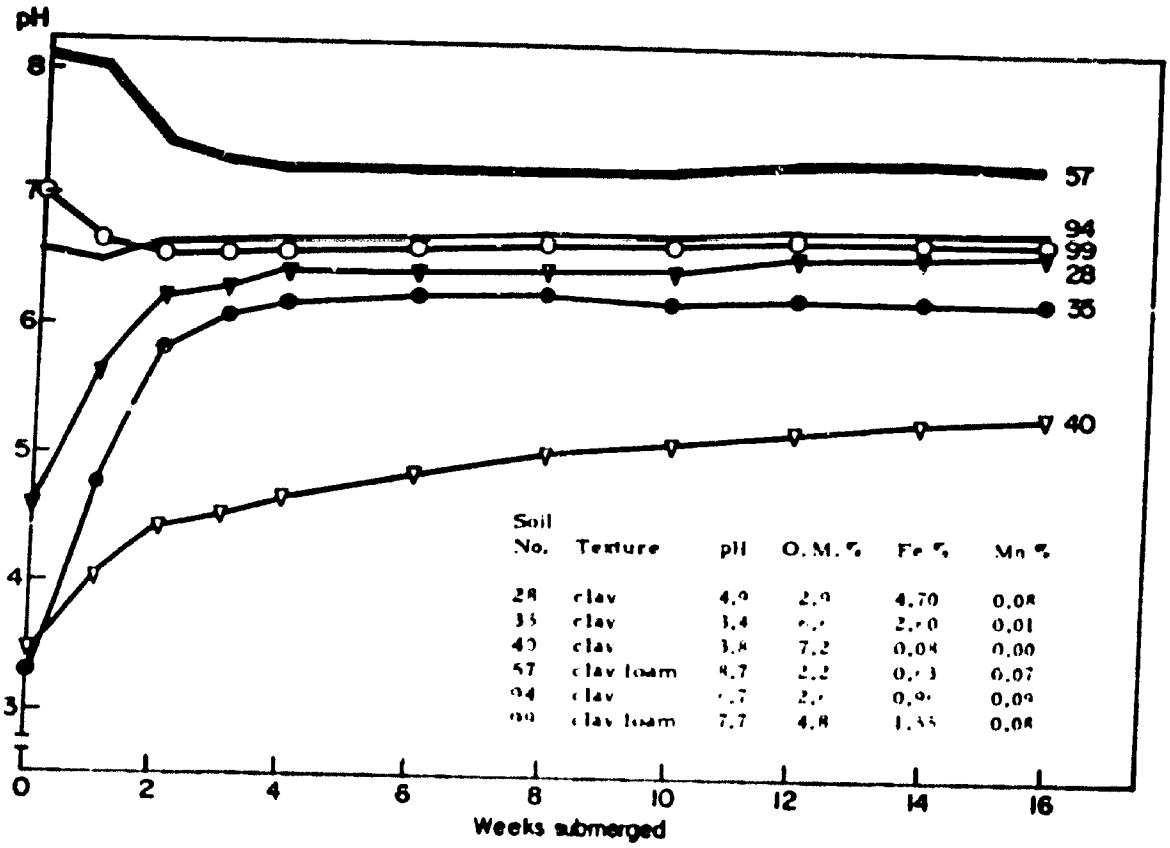

Fig. 1. Kinetics of the solution pH of six submerged soils.

soil properties and temperature. Soils that have adequate amounts of organic matter (>2%) and active iron (>1%) and are low in acid reserves attain a pH of about 6.5 within a few weeks of submergence. If acid soils are low in organic matter or in active iron, or are high in acid reserves, they may not attain a pH more than 5 even after months of submergence (Fig. 2). Organic matter magnifies the decrease in pH of sodic and calcareous soils through carbon dioxide effects. Low temperature retards pH changes in both acid and alkaline soils (Cho and Ponnamperuma, 1971). The pH values of submerged soils can be described by the equations:

$$pE = 17.87 - pFe^{2+} - 3\ pH$$

and $$pH = 6.1 - 0.58 \log P_{CO_2} \quad \text{(acid soils)}$$

$$pH = 6.1 - 2/3\ P_{CO_2} \quad \text{(calcareous soils)}$$

$$pH = 7.85 - \log HCO_3^- - \log P_{CO_2} \quad \text{(sodic soils)}$$

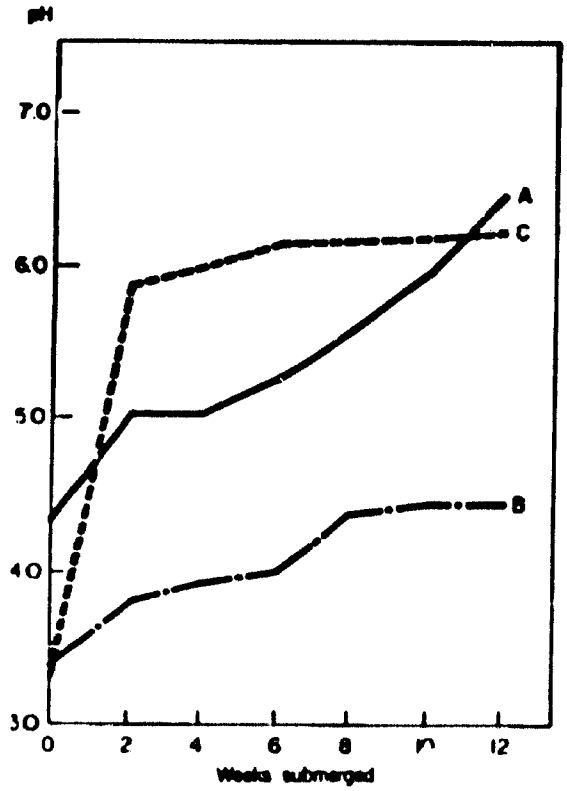

Fig. 2. Kinetics of pH in three acid sulfate soils.

The stabilization of the pH of submerged soils at about 7 has several favorable consequences.

1. Adverse effects of low or high pH per se are minimized.
2. Excess aluminum and manganese in acid soils are rendered harmless.
3. Iron toxicity in acid soils is lessened.
4. Availability of phosphorus, molybdenum, and silicon is increased.
5. Mineralization of organic nitrogen is favored.
6. Organic acids decompose.
7. Lime is unnecessary.

Thus, in evaluating land for rice production the pH of the dry soil may not be as important as the factors that influence pH kinetics on soil submergence.

Changes in electric conductance

The electrical conductivity of the soil solution after submergence increases with time, reaches a peak, and then decreases (Table 1). In 150 wetland rice soils whose conductivity at 25°C immediately after submergence ranged from

0.2 to 15.3 mmho/cm, the peak values ranged from 1.1 to 18.5 mmho/cm. Only six soils had peak values less than 2 mmho/cm. Naturally, the initial conductivities are highest in the saline soils and lowest in the leached ultisols and oxisols, but the kinetics, or the course of conductivity changes, varied markedly with the soil. The changes in conductivity were highly correlated with the concentration of bicarbonates, chiefly iron and manganese, in the soil solutions of acid soils and with the calcium and magnesium bicarbonate concentration in alkaline soils.

Table 1. Initial and peak electrical conductivities (EC) of the solutions of five submerged soils.

Soil	pH	O.M. (%)	Electrical conductivity (mmho/cm at 25°C)		
			Initial	Peak	ΔEC
Kalayaan clay loam	5.7	1.3	0.27	1.55	0.38
Luisiana clay	4.7	2.8	0.50	2.61	2.11
Maahas clay	6.6	2.0	1.37	2.47	2.10
Morong clay loam	7.7	4.8	5.80	8.91	3.11
Acid sulfate clay	3.6	9.5	4.95	10.30	6.65

Because most submerged soils, regardless of their initial conductivities, have conductivities exceeding 2 mmho/cm during a good part of the growing season (Ponnamperuma, 1972), are they to be regarded as saline soils as defined by the *Glossary of Soil Science Terms* (Soil Science Society of America, 1975)? If the EC_e (electrical conductivity of the saturation extract) of the dry soil is to be used as a criterion of salinity, what of soils that produce high concentrations of electrolyte after soil submergence?

The salinity hazard in flooded soils may be greater than the EC values of the soil immediately after submergence may indicate, because soil reduction and the solvent action of carbon dioxide release large amounts of ions into the soil solution, but due to dilution it may be less than the EC_e values may suggest.

Reduction of Fe(III) to Fe(II)

The most dramatic change that occurs when a soil is submerged and undergoes reduction is that Fe(III) oxide hydrates are reduced to Fe(II) compounds. Consequently, the soil color changes from brown to gray, and large amounts of Fe(II) enter the solution phase. The concentration of water-soluble iron, which at submergence rarely exceeds 0.1 ppm, may rise to 600 ppm within a few weeks after flooding and then declines or reaches a plateau (Ponnamperuma, 1972). In acid sulfate soils the peak values may be as high as 5,000 ppm (Ponnamperuma et al., 1972).

The rate of increase of the concentration of water-soluble iron is determined by the organic matter content of the soil, nature and content of the Fe(III) oxide hydrates, pH of the soil, and temperature (Fig. 3 and 4). Strongly acid soils with adequate amounts of organic matter and reactive iron oxides can build up toxic concentrations of ferrous iron (Ponnamperuma et al., 1955; Tanaka and Yosnida, 1970; Ponnamperuma et al., 1972). These concentrations are enhanced by the presence of salt (Fig. 5). Thus iron toxicity is common in submerged ultisols, oxisols, and acid sulfate soils in the tropics. It may also occur in acid sandy soils and in peat soils low in active iron, as in Akiochi soils. Low temperatures (<20°C), by bringing about late but high and persistent concentrations of water-soluble iron, may cause iron toxicity in soils in which, at 25° to 35°C, high concentrations are shortlived (Cho and Ponnamperuma, 1971). Criteria for the iron toxicity hazard are --

1. pH of the dry soil;
2. amount of reserve acidity;
3. reactivity and content of Fe(III) oxide hydrates;
4. soil temperature;
5. salt content;
6. percolation rate;
7. interflow from adjacent areas.

Iron toxicity may be a hazard for wetland rice on soils for which the main drawbacks for dryland crops are manganese and aluminum toxicities and a deficiency of the macro elements.

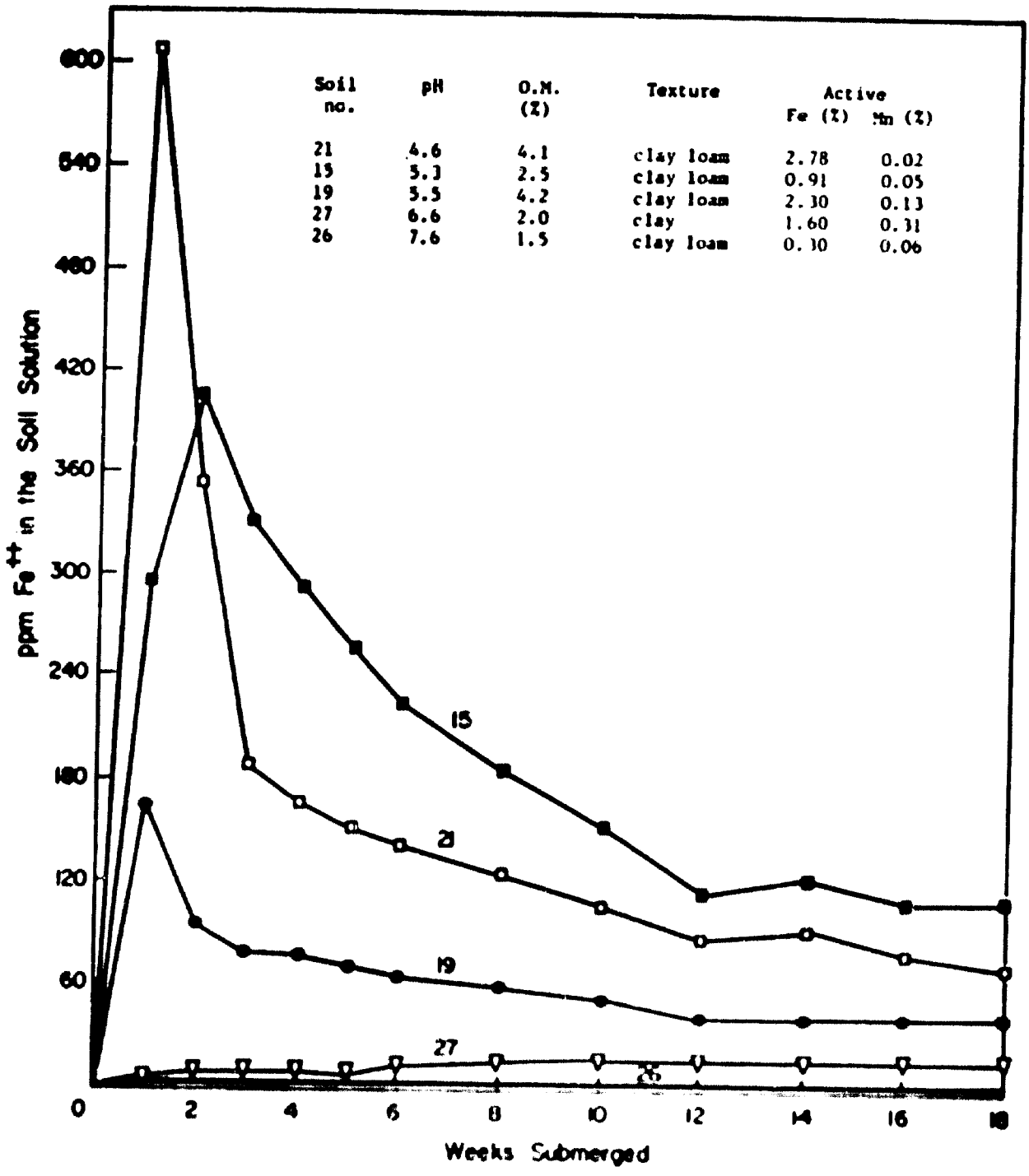

Fig. 3. Kinetics of Fe^{++} in the solutions of five flooded soils.

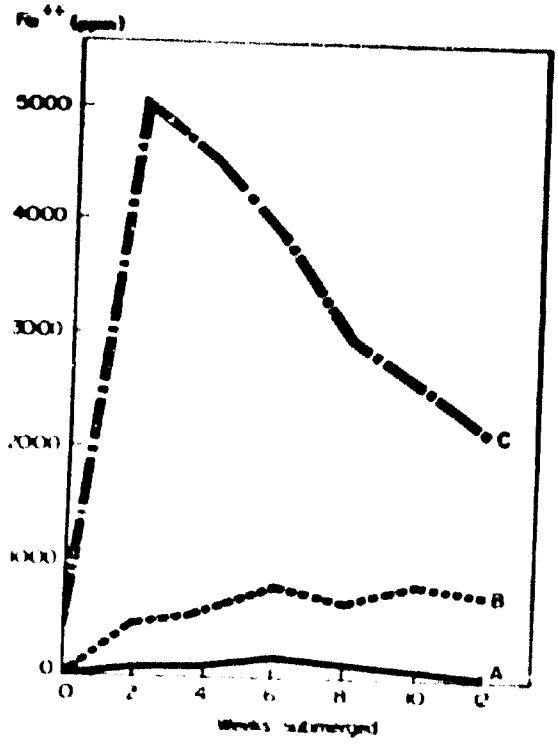

Fig. 4. Kinetics of water soluble Fe^{++} in three acid sulfate soils.

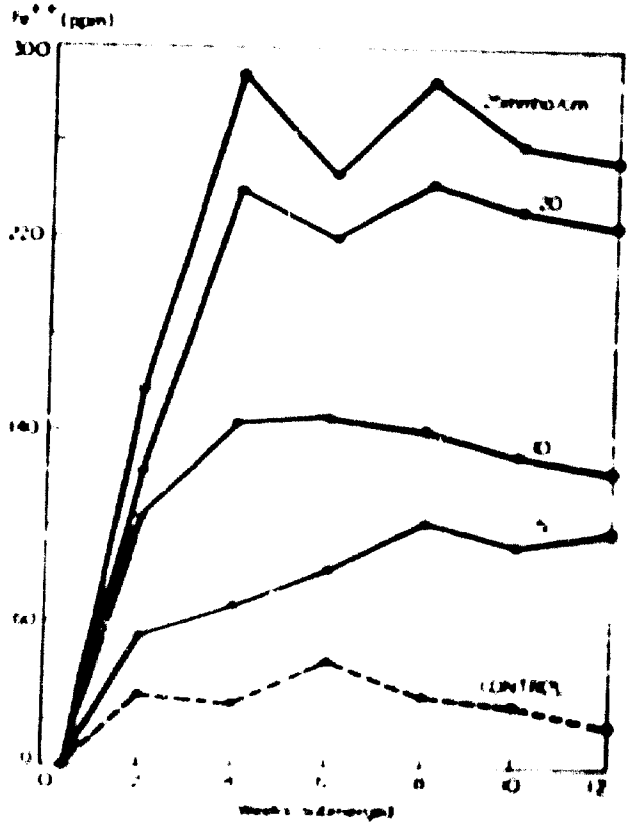

Fig. 5. Kinetics of water soluble Fe^{++} in a submerged salinized soil.

Increase in supply and availability of nitrogen

Rice has been grown for centuries in many parts of Asia without the use of nitrogenous manures or fertilizers. Nitrogen additions in rain water and irrigation water represent only a small part of the nitrogen removed by the crop or lost from the soil. There must be other sources of nitrogen. Nitrogen fixation by algae and anaerobic bacteria was once regarded as one of the main natural sources of soil nitrogen in flooded rice fields. Now there is evidence that aerobic bacteria living on the surface of rice roots in flooded soils fix about 50 kg N/ha per season (Yoshida and Ancajas, 1971).

The availability of nitrogen in flooded soils is higher than in nonflooded, aerobic soils. Although organic matter is mineralized at a slower rate in anaerobic soils than in aerobic soils, the net amount mineralized is greater because less is immobilized (Borthakur and Mazunda, 1968). Thus the A values of nitrogen in flooded soils are about twice as high as in nonflooded soils (Broadbent and Reyes, 1971). The availability of nitrogen in flooded soils increases with nitrogen content of the soil, soil pH, temperature, and previous desiccation of the soil (Ponnamperuma, 1965).

To obtain comparable yields, less nitrogen input is required for wetland rice than for other cereals. This observation could be considered in evaluating land for wetland rice.

Increase in availability of phosphorus, silicon, and molybdenum

The availability of phosphorus and silicon, whether judged by chemical methods or by plant uptake, increases on submerging a soil (Ponnamperuma, 1972). The increase in availability of these elements is often cited as one of the benefits of flooding rice soils. The increase in solubility of phosphorus, however, is low in ultisols and oxisols (Fig. 6 and 7).

The concentration of water-soluble molybdenum increases on flooding presumably as a result of desorption following reduction of ferric oxides. This may benefit nitrogen fixing algae at the surface, anaerobic bacteria in the reduced soil, and aerobic bacteria on the roots.

The phosphate input for wetland rice is less than that for other cereals.

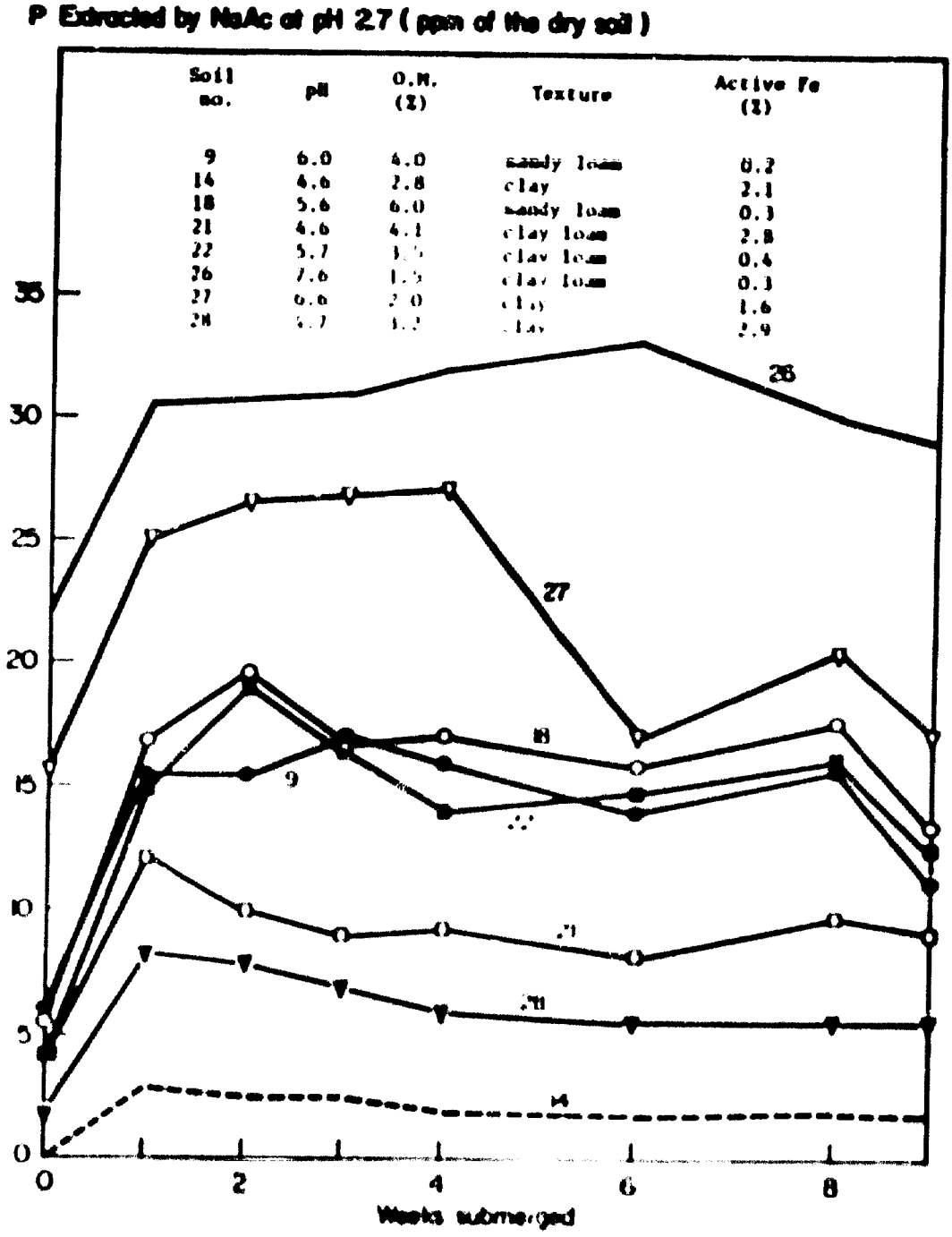

Fig. 6. Kinetics of P extractable in pH 2.7 NaAc in some flooded soils.

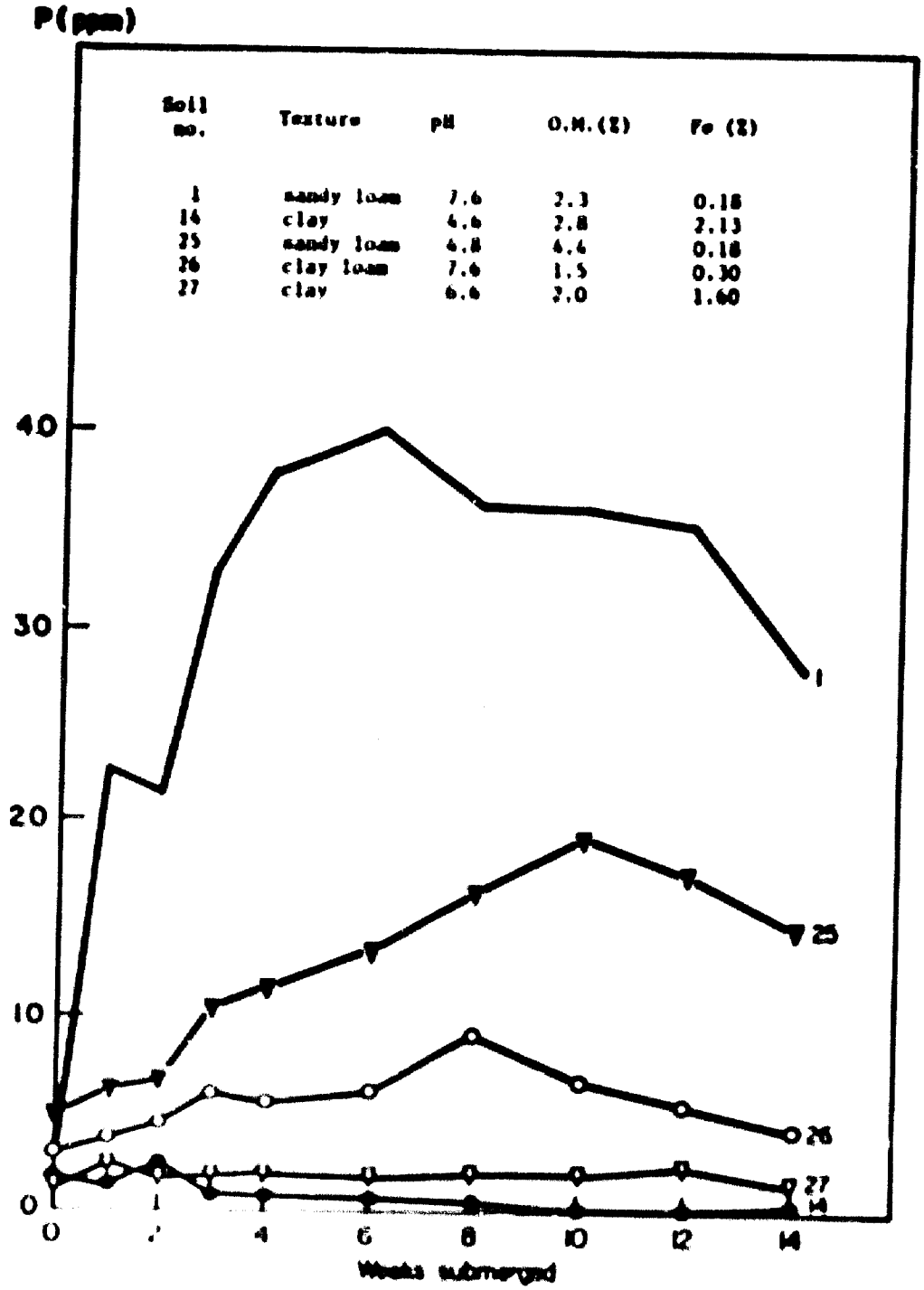

Fig. 7 Kinetics of water soluble phosphate in 5 submerged soils.

Decrease in concentrations of water-soluble zinc and copper

A decrease in concentrations of water-soluble zinc and copper is one of the few disadvantages of flooding soils for rice (Tables 2 and 3). Since 1966 zinc deficiency has been recognized as a widespread nutritional disorder of rice on sodic and calcareous soils. Recent work suggests that zinc deficiency (and perhaps copper deficiency) is a serious obstacle to the growth of rice on continuously wet soils and peat soils (Katyal and Ponnamperuma, 1974; IRRI*, 1974). The deficiencies may not be as acute for dryland crops grown on those soils after they are drained.

The possibility of zinc and copper deficiencies should be considered in evaluating land for wetland rice.

Table 2. Kinetics of water-soluble zinc in six submerged soils.

Soil	pH	O.M. (%)	Weeks submerged			
			1	2	4	6
			Zn (ppm)			
Acid sulfate soil (1)	3.4	5.6	1.90	0.28	0.14	0.10
Acid sulfate soil (2)	3.6	9.5	0.65	0.48	0.42	0.32
Luisiana clay	4.8	3.2	0.18	0.09	0.06	0.05
Silt loam (Korea)	4.9	2.8	0.18	0.14	0.05	0.04
Maahas clay	6.6	2.0	0.14	0.06	0.04	0.03
Pila clay loam	7.6	1.5	0.11	0.07	0.03	0.03

Table 3. Kinetics of water-soluble copper in six submerged soils.

Soil	pH	O.M. (%)	Weeks submerged			
			1	2	4	6
			Cu (ppb)			
Acid sulfate soil (1)	3.4	5.6	150	100	60	40
Acid sulfate soil (2)	3.6	9.5	80	80	40	30
Luisiana clay	4.8	3.2	60	40	30	30
Silt loam (Korea)	4.9	2.8	70	60	30	30
Maahas clay	6.6	2.0	60	40	30	30
Pila clay loam	7.6	1.5	60	40	30	30

*International Rice Research Institute

Production of toxins

Hydrogen sulfide is produced in submerged soils as a result of sulfate reduction and anaerobic decomposition of organic matter. In normal soils it is rendered harmless by precipitation as ferrous sulfide, but in soils high in sulfate and organic matter and low in iron, it may harm rice plants.

Organic acids, ethylene, and organic reduction products harm rice plants. They are produced and persist in anaerobic soils (Takijima, 1963). The toxicity of peat soils for wetland rice may be due to hydrogen sulfide and organic products of anaerobic metabolism. Thus a soil, which under dryland conditions may not be injurious to plants, may become toxic to rice when it is flooded.

Implications for land evaluation for wetland rice

The chemical changes brought about by soil submergence may alter drastically the category in which a soil is placed on the basis of criteria for dryland soil. Some soils may shift from suitable to unsuitable and vice versa. The same chemical changes, along with inherent soil properties, complicate enormously the evaluation of problem soils (Tables 4-8).

Table 4. Saline soils.

Kind of soil	Other growth limiting factors
Arid saline soils	Alkalinity, zinc deficiency, N and P deficiencies
Acid coastal saline soils	Iron toxicity, phosphorus deficiency, deep water
Neutral and alkaline coastal saline soils	Zinc deficiency, deep water
Deltaic and estuarine acid sulfate soils	Iron toxicity, phosphorus deficiency, deep water
Coastal histosols	Nutrient deficiencies, H_2S toxicity, toxicity of organic substances, deep water, Fe toxicity

Table 5. Acid sulfate soils.

Kind of soil	Other growth limiting factors
Coastal soils	Salinity, Fe toxicity, N and P deficiencies, deep water
Old inland soils	N and P deficiencies
Histosols	Fe toxicity, H_2S toxicity, nutrient deficiencies, deep water, salinity

Table 6. Iron-toxic soils.

Kind of soil	Other growth limiting factors
Acid sulfate soils	Salinity, N and P deficiencies, deep water
Acid oxisols and ultisols	P deficiency, low base status, low Si content
Histosols	H_2S toxicity, toxicity of organic substances, macronutrient deficiencies, Zn and Cu deficiencies, deep water

Table 7. Phosphorus deficiency in wetland rice.

Kind of soil	Other growth limiting factors
Acid sulfate soils	Strong acidity, iron toxicity, low nutrient status, base deficiency, salinity
Acid oxisols and ultisols	Iron toxicity, base deficiency
Vertisols	Zinc deficiency, iron deficiency, salinity, alkalinity

Table 8. Zinc-deficient soils.

Kind of soil	Other growth limiting factors
Saline-sodic and sodic soils	Salinity; N, P, and Fe deficiencies
Vertisols	P and Fe deficiencies, salinity, alkalinity
Calcareous soils	K deficiency
Wet soils	Cu deficiency?
Histosols	N, P, K, Si, Cu deficiencies; H_2S toxicity; deep water

Much work needs to be done before chemical criteria can be developed for a systematic evaluation of land for wetland rice. Multiple criteria may be more important for wetland rice than for dryland soils.

Progress in the development of rice varieties with resistance to adverse soil conditions will necessitate revision of land evaluation standards.

LITERATURE CITED

Borthakur, H. P., and N. N. Mazunda. 1968. Effect of lime on nitrogen availability in paddy soils. J. Indian Soil Sci. Soc. 16:143-147.

Broadbent, F. E., and O. C. Reyes. 1971. Uptake of soil and fertilizer nitrogen by rice in some Philippine soils. Soil Sci. 112:200-205.

Cho, D. Y., and F. N. Ponnamperuma. 1971. Influence of temperature regime on the chemical kinetics of flooded soils and the growth of rice. Soil Sci. 112:184-194.

International Rice Research Institute. 1975. Annual report for 1974. Los Baños, Philippines. 384 p.

Katyal, J. C., and F. N. Ponnamperuma. 1974. Zinc deficiency: A widespread nutritional disorder of rice in Agusan del Norte. Philipp. Agric. 58(3 & 4): 79-89.

Ponnamperuma, F. N. 1965. Dynamic aspects of flooded soils. Pages 295-328 *in* International Rice Research Institute, Mineral nutrition of the rice plant. Johns Hopkins Press, Baltimore, Maryland.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96.

Ponnamperuma, F. N., T. Attanandana, and G. Beye. 1972. Amelioration of three acid sulfate soils for lowland rice. *In* Proceedings of the International Symposium on Acid Sulfate Soils, August 13-20, 1972, Wageningen,

Ponnamperuma, F. N., R. Bradfield, and M. Peech. 1955. Physiological disease of rice attributable to iron toxicity. Nature 175:265.

Ponnamperuma, F. N., E. M. Martinez, and T. A. Loy. 1966. The influence of redox potential and the partial pressure of carbon dioxide on the pH values and the suspension effect of flooded soils. Soil Sci. 101:421-431.

Raalte, R.H. van. 1941. On the oxygen supply of rice roots. Ann. Bot. Gard. Buitenzorg, May 1944:13-34.

Soil Science Society of America. 1975. Glossary of soil science terms. Soil Sc. Soc. Am., Madison, Wisconsin, U. S. A.

Takijima, Y. 1963. Studies on behavior of the growth inhibiting substances in paddy soils with special reference to the occurrence of root damage in peaty paddy fields. Bull. Natl. Inst. Agric. Sci. Jpn. Ser. B, 13:117-252.

Tanaka, A., and S. Yoshida. 1970. Nutritional disorders of the rice plant in Asia. Int. Rice Res. Inst., Tech. Bull. 10. 51 pp.

Yoshida, T., and R. R. Ancajas. 1971. Nitrogen-fixing activity in upland and flooded rice fields. Soil Sci. Soc. Am. Proc. 37(1):42-46.

19

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