VARIETAL TOLERANCE FOR SALT IN RICE[1/]

F.N. Ponnamperuma[2/]

ABSTRACT

~~In~~ South and Southeast Asia 63 million hectares of land climatically and physiographically suited to rice lie uncultivated largely because of salinity. If salt tolerant non-lodging rices with disease and insect resistance are available, much of this area can be put under rice without coatly reclamation measures.

The International Rice Research Institute has developed techniques for the mass screening of the world's germ plasm collection and the progeny from its hybridization program for salt tolerance.

Of the nearly 14,000 rices screened in 1975-77, 109 have an acceptable degree of salt tolerance. They are being tested in saline tracts in the Philippines, Thailand, India, Pakistan, Sri Lanka, and Egypt.

Salt tolerance in rice appears to be associated with a high content of ions in the roots and the presence of malate dehydrogenase that is readily activated by NaCl. There is no clear-cut correlation between proline content and salt tolerance.

[1/] Paper to be presented at the seminar on "Plant Response to Salinity and Water Stress", in Mildura, Victoria, Australia, November 21-25, 1977.

[2/] Principal Soil Chemist, The International Rice Research Institute, Los Baños, Laguna, Philippines.

VARIETAL TOLERANCE FOR SALT IN RICE[1/]

F.N. Ponnamperuma[2/]

Asia needs 5 million tons of additional rice each year, even at the current inadequate per capita consumption rate, to meet the demand of population growth. The increase can come from increasing the yield per unit area or extending the rice acreage. Either way, soil problems are obstacles.

In many parts of Asia the modern rice varieties, which because of their good agronomic characteristics and resistance to pests have a high yield potential are not doing well. Soil problems that had gone undetected earlier because of the low yield potential of the old varieties and perhaps because of their tolerance for adverse soil conditions are now assuming importance. Salinity is one such adverse soil condition.

Extending the area under rice also faces soil problems. The extent of arable land in the world is limited. So to expand the cultivated area we have to move to marginal land or even poorer land lying uncultivated because of environmental stresses. Salinity is the commonest of these stresses.

Extent and distribution of saline soils

There are 381 million ha of saline soils on the earth's land surface. Of these, 240 million ha are not strongly saline (Massoud, 1974). About 100 million ha of the latter are in deltas, coastal fringes, and estuaries

---

[1/]Paper to be presented at the seminar on "Plant Response to Salinity and Water Stress", in Mildura, Victoria, Australia, November 21-25, 1977.

[2/]Principal Soil Chemist, The International Rice Research Institute, Los Baños, Laguna, Philippines.

in the humid tropics. Of this area, 63 m ha are in South and Southeast Asia (Fig. 1, Table 1).

The Philippine archipelago, with a coastline of 18,400 km, has 400,000 ha of coastal saline soils (Fig. 2) distributed as follows (Guerrero, 1977):

Region	Extent (ha)
Luzon	124,300
Visayas	173,200
Mindanao	103,300

Of this area, about 100,000 ha are still under mangrove forest and are likely to be preserved as such. Of the cleared area, about 175,000 ha are used for fish ponds with an average annual production of only 700 kg/ha. Over 225,000 ha are largely idle.

Although climatically and physiographically suited to rice, over 60 million ha of land in South and Southeast Asia are uncultivated largely because of salinity.

Breeding for salt tolerance

On some saline soils, farmers grow salt-tolerant varieties, but yields are about 1 t/ha because of lodging and susceptibility to pest injury. By combining salt tolerance with stiff straw and resistance to pests, the breeder can provide improved varieties suited to these soils. Such varieties can be grown on moderately saline soils without costly soil management inputs. But selecting and breeding rice for salt tolerance is beset with difficulties.

First, saline soils vary widely in their chemical, physical, and hydrological properties. The variables include salt source, the content and nature of salts, lateral and vertical distribution of salt, soil pH, content and nature of clay, organic matter content, nutrient status, water regime, relief, and temperature. The salt content of saline soils varies spatially, seasonally, and with the water regime. The dominant salts in coastal saline soils are chlorides; in arid areas they may be sulphato-chlorides and chlorido-sulphates (FAO/Unesco, 1973). The pH may vary from 2.5 to 8.5, the composition of the clay may vary from montmorillonite and illite to hydrous oxides of iron and aluminum, organic matter content may range from 1 to 50% and the nutrient content can vary from very low to moderately high, as gleaned from various sources. These differences have important implications for the management of saline soils and breeding rice varieties for salt tolerance (Ponnamperuma, 1977). Salt injury usually occurs with other mineral stresses. Some of them are listed below.

Kinds of saline soils	Accessory growth-limiting factors
Arid saline soils	High pH; deficiencies of zinc, nitrogen, and phosphorus
Acid saline soils	Iron toxicity, phosphorus deficiency
Deltaic and estuarine acid sulfate soils	Iron and aluminum toxicities, phosphorus deficiency, deep water
Neutral and alkaline coastal saline soils	Zinc deficiency, deep water
Coastal organic soils	Deficiencies of nitrogen, phosphorus, zinc, copper; toxicities of iron, hydrogen sulfide, and organic substances; deep water

Second, salt tolerance in rice is influenced by method of planting, age of seedling, development stage of the plant, duration of exposure to salt, humidity, and temperature (IRRI, 1975). Rice is more tolerant of salt during germination than in the one to two leaf stage. Beyond this, tolerance increases until panicle initiation. From panicle initiation to flowering, tolerance decreases (Ikehashi and Ponnamperuma, 1977).

The first requisite for a breeding program for salt tolerance in rice is the availability of simple, rapid, and reliable methods of screening tens of thousands of varieties from the germ plasm bank and thousands of lines from a hybridization program.

The methods used during the past 2 decades for screening rices for salt tolerance are summarized below.

1. germinating rice seeds in sodium chloride solutions (Shafi et al., 1970), in mixed salt solutions (Bari et al., 1973), in salt-treated sand cultures (Pearson et al., 1966), in soil cultures treated with sodium chloride and calcium chloride (Barakat et al., 1971), and in salinized soil at different water contents (Wahhab et al., 1959);
2. growing seedlings in culture solution treated with sodium chloride (IRRI, 1968) or in a mixture of sodium chloride and calcium chloride (Akbar and Yabuno, 1975);
3. transferring seedlings from soil culture to a 0.5% solution of sodium chloride and scoring injury (Sakai and Rodrigo, 1960) or measuring salt uptake (Janardhan, 1971);
4. growing seedlings to maturity in soil cultures in pots (Pearson, 1961; De Datta, 1972; Janardhan and Murty, 1970);
5. growing plants to maturity in salinized microplots (Janardhan and Murty, 1972) or in replicated field trials (Purohit and Tripathi, 1972).

None of these methods is suitable for mass screening a germ plasm collection or the progeny from a breeding program.

After studies on soil, plant, environmental, and logistic factors, IRRI workers and their international cooperators worked out a three-stage procedure:

1. Greenhouse screening under controlled soil, water, and salt conditions (Ponnamperuma, 1977);
2. Field testing in artificial saline soils with water and pest control (IRRI, 1976);

3. International field testing in replicated yield trials on natural saline soils with all hazards of the environment except insect injury.

The criteria used were visual scoring on the scale 1 to 9 in the greenhouse and field tests at IRRI. In the international tests, yield of grain was an additional criterion.

Of the nearly 14,000 rices screened in 1975-1977, 109 have an acceptable degree of salt tolerance. It is remarkable that one of them (IR2153-26-3) a dwarf IRRI breeding line, has a degree of salt tolerance only slightly inferior to that of Pokkali, a well known salt tolerant variety used as the resistant check in screening tests, without a planned effort to achieve it. Also 13 advanced breeding lines showed a level of salt tolerance only slightly inferior to that of IR2153-26-3. The presence of salt tolerance in some of the advanced breeding lines is encouraging because these lines have not only good agronomic characteristics but also resistance to diseases and insects.

Although emphasis in the breeding program at IRRI is on developing salt tolerant varieties with high yield potential, considerable attention was paid to breeding photoperiod-sensitive rices of intermediate stature, suited to coastal areas in monsoon climates. From this effort has come two promising experimental lines (IR4630-22-2 and IR4763-73-1), derived from Pokkali, with intermediate stature and a longer growth duration than the dwarf line IR2153-26-3. They are being tested in the Philippines and West Bengal.

Under natural saline conditions, rice is exposed to many hazards other than salinity. To sample other environments, IRRI has the International Salt and Alkali Tolerance Observational Nursery (IRSATON) within its International Rice Testing Program (IRTP). In the IRSATON program, promising varieties and selections, as well as material from the IRRI breeding program and its collaborators, are tested in different countries under field conditions. Such tests are under way in the Philippines, Egypt, Pakistan and India.

Basis of salt tolerance in rice

There is little information on the physiological basis of salt tolerance in rice. Janardhan and Murthy (1970) found a higher water content in the shoots of two salt tolerant varieties as compared with two susceptible ones. Unpublished IRRI data showed no significant correlation between sodium or cation content of the straw and salt tolerance in 50 varieties grown in pots in a soil with an EC_e of 10 mmho/cm. But the cation content of the straw of the five most resistant varieties was significantly lower than that of the four most susceptible ones (Table 2).

Salt injury may be partitioned into four main sources:

1. osmotic effects
2. specific ion toxicities
3. ionic antagonisms
4. effects of ionic strength on ion activities.

The reviews of Bernstein (1975) and of Maas and Nieman (1977) suggest that in non-woody plants the main adverse effect is osmotic. If so, varieties that adjust better to the external salt concentration should be more salt tolerant than others. Both shoots and roots adjust osmotically to increases in salt concentration of the root medium. The adjustment is accomplished by increasing the uptake of ions, chiefly Na^+ and Cl^-, and by generating water-soluble organic substances such as organic acids (chiefly malate and oxalate), amino acids, polyols (chiefly glycerol), sugars, proline, and betaine (Cram, 1974; Chu et al., 1976; Storey and Wyn Jones, 1975).

Osmotic adjustment in the roots is simpler than in the shoots and was surmised by C. A. Bower (personal communication) to be largely due Na^+ and Cl^- accumulation. To test this hypothesis Bower (unpublished), grew, at IRRI, nine rice varieties of varying salt tolerance in a complete nutrient solution having a total salt concentration of 15 meq/l and in the same solution with added NaCl and $CaCl_2$ at 24 meq/l and 12 meq/l, respectively, for the first 2 weeks and 34 meq/l and 24 meq/l for the next 2 weeks.

Dry weights of the 4-week-old shoots grown in saline solution as a fraction of the weights obtained in non-saline solution plotted against relative water contents of the fresh shoots (Fig. 3) show that in no case did the water content of the saline solution shoot exceed 0.9 of the water content of non-saline shoots. That clearly indicates that salt injury in rice involves water stress.

Root studies appear to confirm Bower's hypothesis of osmotic adjustment. Bower found that the dissolved salts in the roots were largely KCl and NaCl. Using EC of an extract of the roots, he calculated the salt content of the roots. He then plotted the difference between the salt content of the roots and culture solution against salt tolerance of the rice varieties expressed as relative shoot growth. Fig. 4 shows a good correlation between root salt content and salt tolerance.

Salt tolerance in the nine rice varieties studied appears to be associated with osmotic adjustment of the roots with the medium.

In an independent study of ^{22}Na uptake by six rice varieties, T.J. Flowers of Sussex University, England, found that the sodium content of the shoot was lowest and that of the roots highest in Pokkali, a salt tolerant variety. With the two susceptible varieties T26 and M1-48, the opposite was the case (Table 3).

Proline accumulates in plants in response to water stress (Hsio, 1973).

At IRRI we found that it accumulates in rice in response to mineral soil stresses including salinity, alkalinity, phosphorus deficiency, zinc deficiency, iron toxicity, toxicity of reduction products, and iron deficiency (IRRI, 1974).

In a separate study we found that the proline content varied with the variety both in salt-stressed and non-stressed soil (Table 4). Although the proline content of the tolerant varieties was higher than in the susceptible, there was no clear-cut association between proline content and salt tolerance.

In sharp contrast to our findings at IRRI, T.J. Flowers and his associates of Sussex University reported (personal communication):

"In none of the six rice varieties, however, was there any evidence of proline accumulation following a period of salinization."

In a study of malate dehydrogenase activity, T.J. Flowers observed that Pokkali, a salt tolerant variety, and IR20, a moderately tolerant variety, had enzymes that were more highly activated by sodium chloride than those of susceptible varieties (personal communication).

REFERENCES CITED

Akbar, M., and T. Yabuno. 1975. Breeeding of saline-resistant varieties for rice. III. Response of F_1 hybrids to salinity in reciprocal crosses between Thomas 347 and Magnolia. Jpn. J. Breed. 25(4):215-220.

Barakat, M.A., M.M. Khalid, and M.H. Atia. Effect of salinity on the germination of 17 rice varieties. Agric. Res. Rev., March 1971. Cairo, UAR.

Bari, G., A. Hamid, and M.A. Awan. 1973. 1973. Effect of salinity on germination and seedling growth of rice varieties. IRC Newsl. 22(3): 32-36.

Bernstein, L. 1975. Effects of salinity and sodicity on plant growth. Annual Rev. Phytopathology 13:295-312.

Chu, T.M., D. Aspinall, and L.G. Paleg. 1976. Stress metabolism. VII. Salinity and proline accumulation in barley. Aust. J. Plant Physiol. 3:219-228.

Cram, W.J. 1974. The regulation of concentration and hydrostatic pressure in cells in relation to growth, 183-189. In R.L. Bieleski, A.R. Ferguson, and M.M. Cresswell (ed.) Mechanisms of regulation of plant growth. Bull. 12, The Royal Soc. of New Zealand, Wellington.

FAO/Unesco. 1973. Irrigation, drainage and salinity. An international source book. Hutchinson, London.

Guerrero III, R.D. 1977. Utilization of mangrove swamps for aquaculture. Paper presented during the National Symposium Workshop on Mangrove Ecosystem and Management, Manila, July 28-30, 1977.

Hsiao, T.C. 1976. Plant responses to water stress. Annu. Rev. Plant Physiol. 24:519-570.

Ikehashi, H., and F.N. Ponnamperuma. 1977. Varietal tolerance of rice to adverse soils. Proceedings of the "Soils and Rice" Symposium, IRRI, Los Baños, Philippines, September 20-23, 1977. (In press).

International Rice Research Institute. 1968. Annual report for 1967. Los Baños, Philippines. 402 p.

International Rice Research Institute. 1974. Annual report for 1973. Los Baños, Philippines. 266 p.

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

International Rice Research Institute. 1976. Annual report for 1975. Los Baños, Philippines. 479 p.

Janardhan, K.V. 1971. Note on modified method for screening rice varieties for tolerance to saline conditions. Indian J. Agric. Sci. 41:504-507.

Janardhan, K.V., and K.S. Murty. 1970. Effect of sodium chloride on leaf injury and chloride uptake by young rice seedlings. Indian J. Plant Physiol. 13(2):225-232.

Janardhan, K.V., and K.S. Murty. 1972. Studies in salt tolerance in rice. III. Relative salt tolerance of some local and high yielding rice varieties. Oryza 9(1):24-34.

Maas, E.V., and G.J. Hoffman. 1977. Crop salt tolerance. J. Irrigation and Drainage Division. June 1977: 115-134.

Maas, E.V. and Nieman. 1977. Physiology of plant tolerance to salinity. Unpublished mimeographed report. 48 p.

Massoud, F.I. 1974. Salinity and alkalinity as soil degradation hazards. FAO/UNEP Expert Consultation on Soil Degradation, June 10-14, 1974. FAO, Rome.

Pearson, G.A., A.D. Ayers, and D.L. Eberhard. 1966. Relative salt tolerance of rice during germination and early seedling development. Soil Sci. 102:151-156.

Ponnamperuma, F.N. 1977. Screening rice for tolerance for mineral stresses. IRRI Research Paper Series No. 6.

Purohit, D.C., and R.S. Triphati. 1972. Performance of some salt-tolerant paddy varieties in Chambal commanded area of Rajasthan. Oryza 9(2): 19-20.

Shafi, M., A. Majid, and M. Ahmad. 1970. Some preliminary studies on salt tolerance of rice varieties. West Pak. J. Agric. Res. 8(2):117-123.

Storey, R., and R.G. Wyn Jones. 1975. Betaine and choline levels in plants and their relationships to NaCl stress. Plant Sci. Letts. 4:161-168.

Wahhab, A., A. Jabbar, and F. Muhammad. 1959. Salt tolerance of various varieties of agricultural crops at germination stage. Pak. J. Sci. Res. 11(2):71-80.

Table 1. Distribution of saline soils in South and Southeast Asia.

Country	Extent (m/ha)
Bangladesh	2.5
Burma	0.6
India	23.2
Indonesia	13.2
Khmer Republic	2.4
Malaysia	4.6
Pakistan	9.4
Philippines	0.3
Sri Lanka	0.2
Thailand	1.8
Vietnam	4.6
Total - - - - -	62.8

Table 2. Comparison of the cation content of the straw of the five most tolerant and the five most susceptible of 50 varieties grown in a soil with an EC_e of 10 mmho/cm in an unreplicated greenhouse experiment.

Variety	Salt[a/] tolerance	Relative[b/] grain yield	(Na + K + Ca + Mg) of straw (meq/100 g)
Pokkali	3	119	130
Doc Phung R-37	0	112	112
SML Awini	3	106	106
IR712-23-2	0	99	129
Doc Phung Lun AR-16	3	98	119
Mean		107	120
Bala	0	53	156
IR442-2-58	5	51	125
T26	7	45	145
RP5-3	5	32	146
M1-48	9	4	164
Mean		37	147

[a/] Based on an earlier rating on the scale: 0 = no information; 1 = almost normal plant; 9 = plant dead or dying.

[b/] $$\text{Relative yield} = \frac{\text{Yield in saline soil}}{\text{Yield in unsalinized soil}} \times 100$$

Table 3. Sodium contents of 14-day old rice plants after treatment for 24 hours with 100 mM sodium chloride labelled with ^{22}Na.

Variety	Salt[a/] tolerance	Sodium content meq/100 g dry wt	
		Tops	Roots
Pokkali	3	127	574
IR20	5	204	438
CAS 209	0	200	431
IR1008-14	7	395	545
T26	7	609	413
M1-48	9	300	433

[a/] Scale: 0 = no information; 1 = nearly normal plant; 9 = dying or dead plant.

Source: T.J. Flowers, Sussex University, England.

Table 4. Influence of salt on the proline content of six rice varieties, 6 weeks after transplanting in a submerged soil.

Variety	Rating[a/]	Proline µg/g	
		Normal soil	Normal soil + 0.4% NaCl
Pokkali	3	49	651
IR1008	5	140	378
IR20	5	87	1700
IR24	7	67	292
T26	7	55	209
M1-48	9	55	347

[a/] Scale: 1 = nearly normal growth; 9 = plants dead or dying.

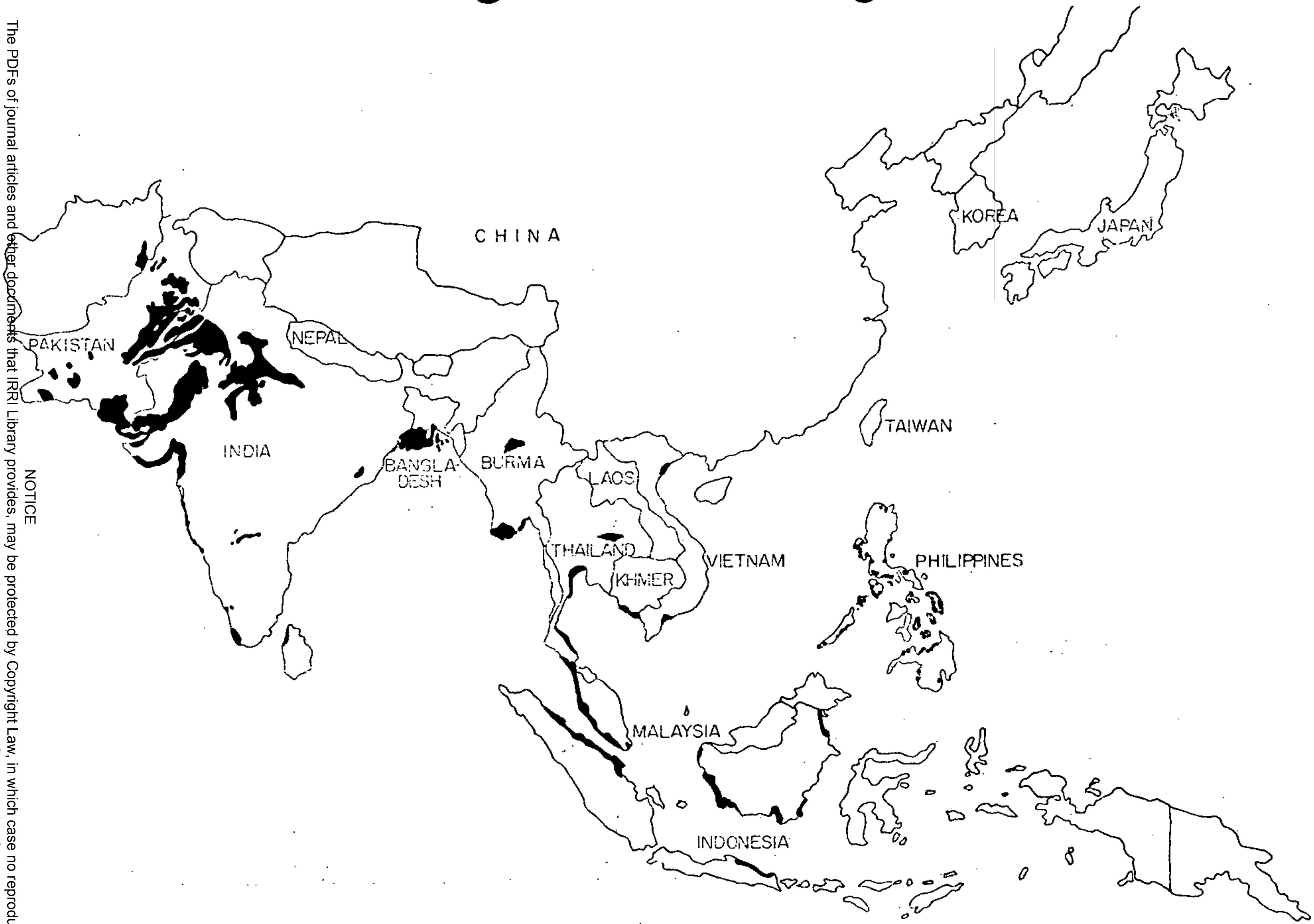

Fig. 1. Saline soils of South and Southeast Asia.

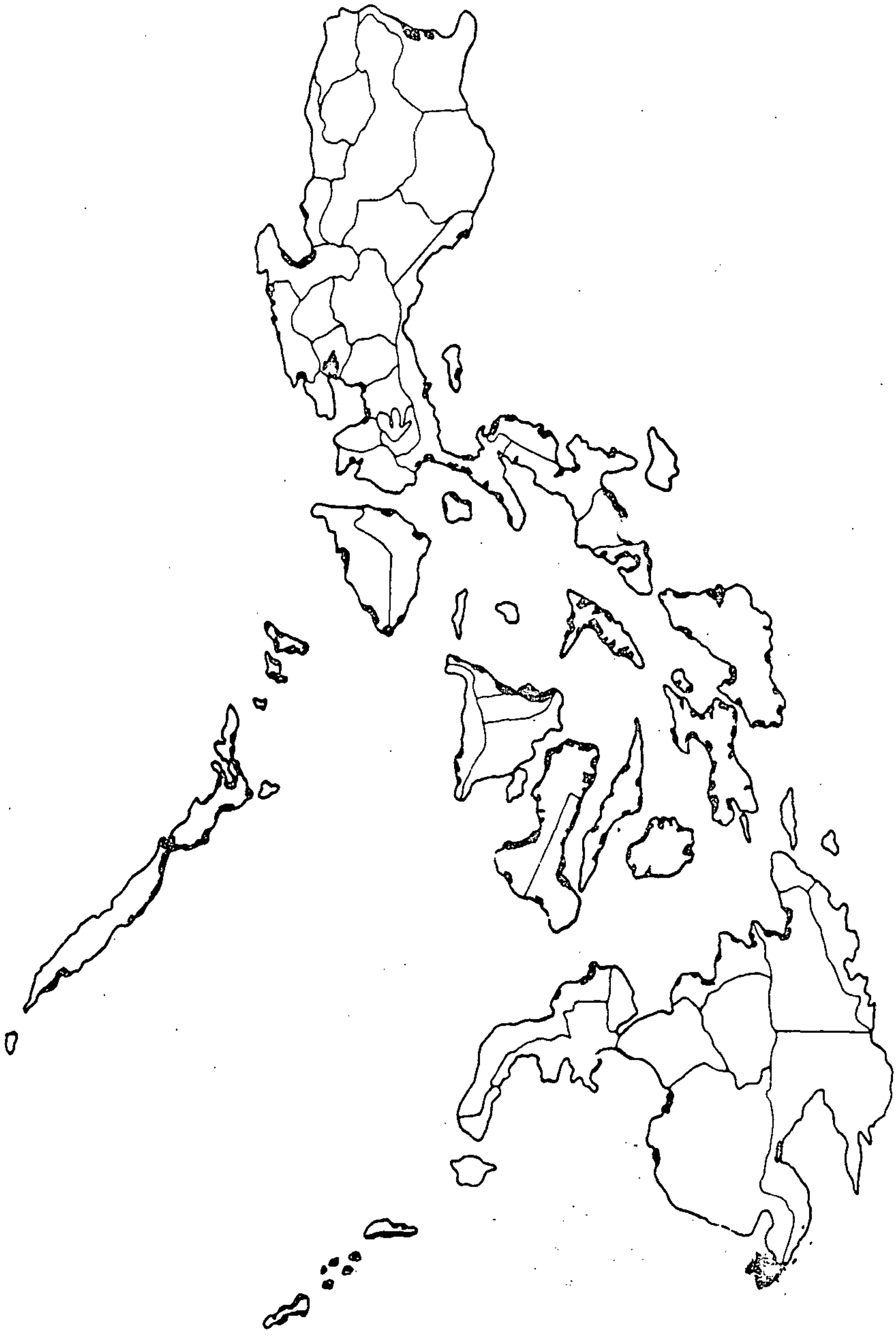

Fig. 2. Coastal saline soils of the Philippines.

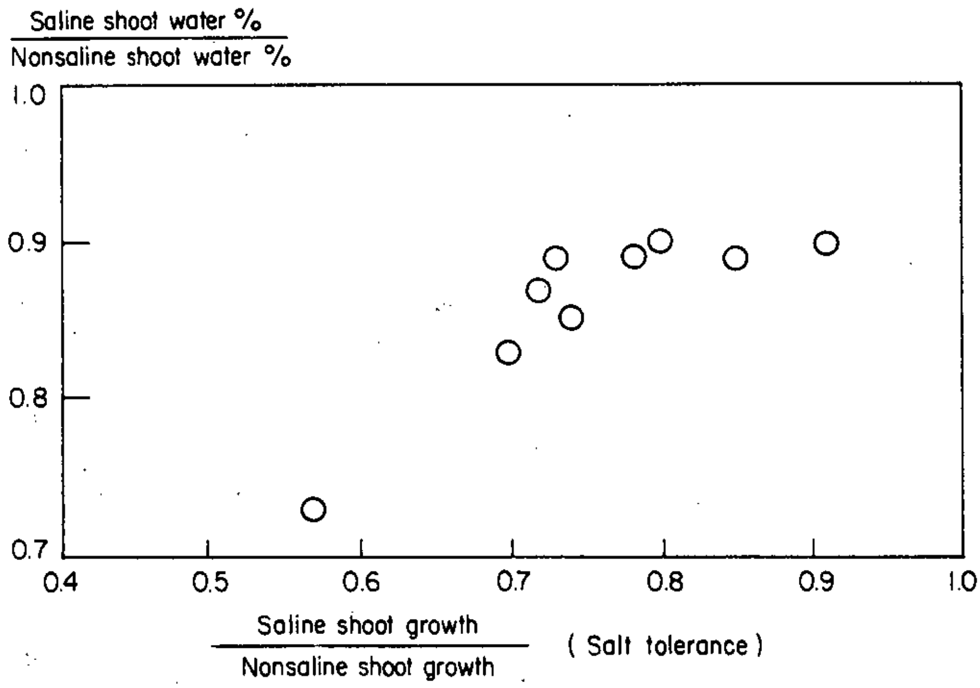

Fig. 3. Relation of shoot water content to shoot growth for rice cultivars grown on saline and nonsaline culture solutions (C.A. Bower, unpublished data).

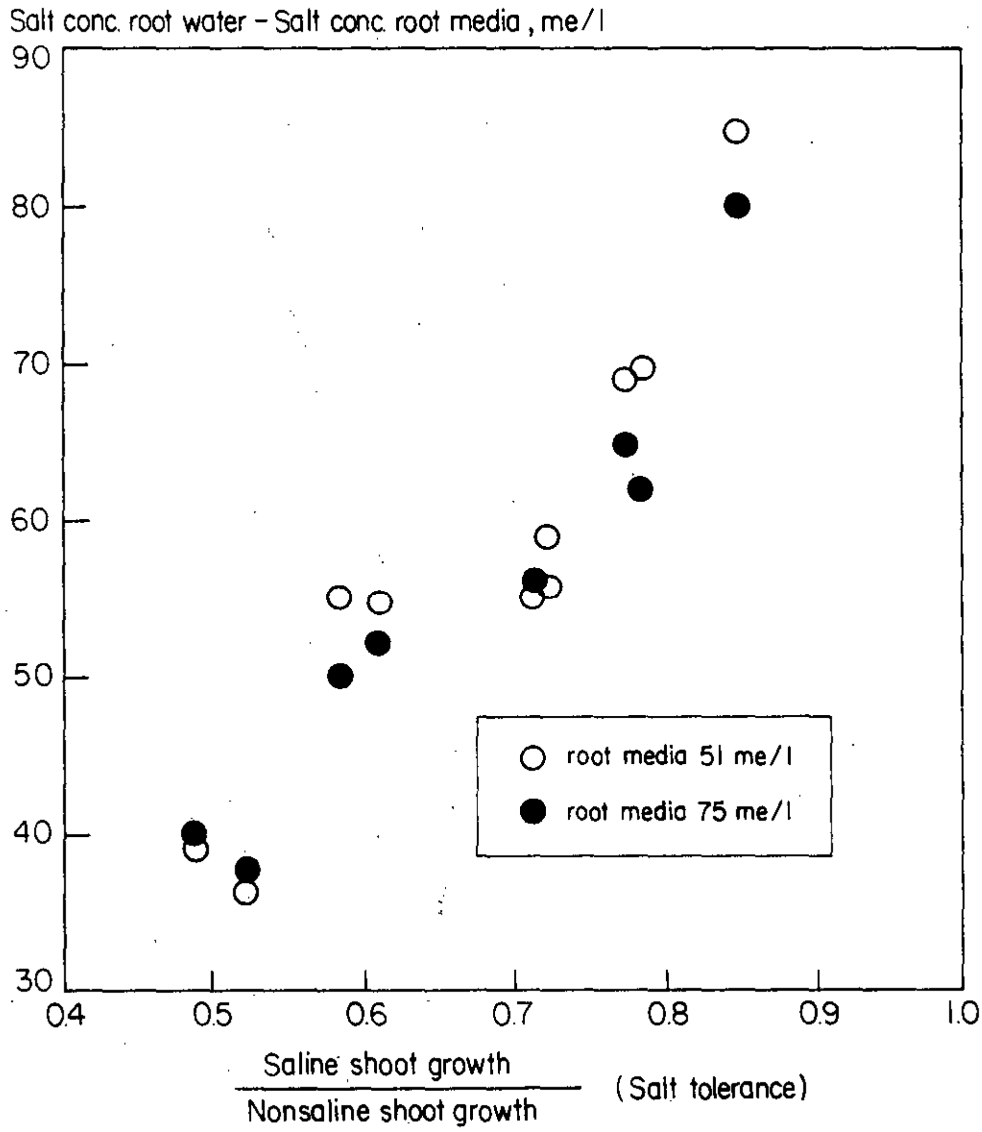

Fig. 4. Salt tolerance of rice cultivars as related to differences between salt concentrations of root water and root media (C.A. Bower, unpublished data).

Table 3. Varietal resistance to iron deficiency, manganese toxicity, and aluminum toxicity in aerobic soils.

Variety	Fe def.	Mn toxicity	Al toxicity
IR24	R	R	R
IR127-80-1	R	R	R
M1-48	R	MR	R
IR661-1-170	R	MR	MR
IR20	R	R	S
E 425	R	S	R
C 12	R	S	-
Peta	S	MR	-
IR5	S	S	S

R: resistant; MR: moderately resistant; S: susceptible.

Table 4. Kinetics of water-soluble Al in three acid sulfate soils.

Soil	Weeks submerged					
	0	2	4	6	8	10
	Al (ppm)					
Acid sulfate clay (A)	0.6	0.1	0.1	0.1	0.1	0.1
Acid sulfate clay (B)	156	25	9	5	6	6
Acid sulfate clay (C)	437	0.9	0.4	0.2	0.2	0.2

Table 5. Kinetics of water-soluble H_2S in two submerged soils.

Soil	Weeks submerged					
	1	2	4	6	8	10
	H_2S (parts per billion)					
Maahas clay	1	1	4	1	3	1
Acid sulfate clay (C)	964	237	124	18	16	1

Table 6. Kinetics of water-soluble Fe, Mn, and Zn in a submerged calcareous soil (San Manuel clay).

	Weeks submerged						
	0	2	4	6	8	10	12
Fe (ppm)	0.09	0.07	0.08	0.83	0.95	0.71	0.70
Mn (ppm)	0.02	0.10	0.23	4.4	15	15	12
Zn (ppm)	0.10	0.05	0.03	0.08	0.05	0.05	0.04

Table 7. Influence of soil properties on the mean content of mineral elements in the straw at harvest of 50 varieties of rice.

Soil	P	K	Ca	Mg	Si	Fe	Mn	Zn
	percent					ppm		
Maahas clay	0.17	2.51	0.17	0.28	7.6	145	507	26
Maahas clay + $CaCO_3$	0.16	2.48	0.18	0.28	7.1	141	512	27
Maahas clay + $NaHCO_3$[a]	0.17	0.30	0.07	0.26	5.8	114	264	28
Maahas clay + NaCl	0.12	1.17	0.24	0.29	6.1	174	814	25
Maahas clay (aerobic)	0.14	2.31	0.17	0.26	6.7	59	309	22
Ferralitic clay	0.14	1.94	0.27	0.20	2.9	2654	971	49
Luisiana clay	0.05	1.49	0.17	0.20	6.3	471	1136	25
Luisiana clay + P	0.10	1.58	0.21	0.24	6.4	544	1027	24

[a] Means for only the 14 varieties that survived.

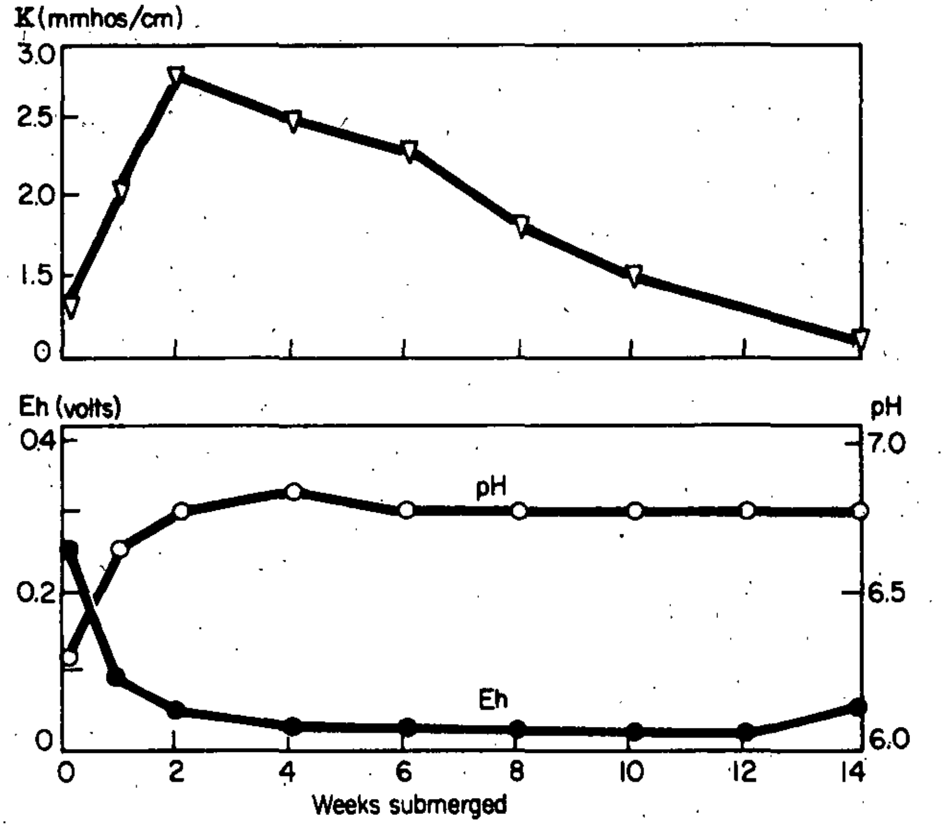

Fig. 1. Kinetics of Eh, pH, and K (sp. conductance) in submerged Maahas clay.

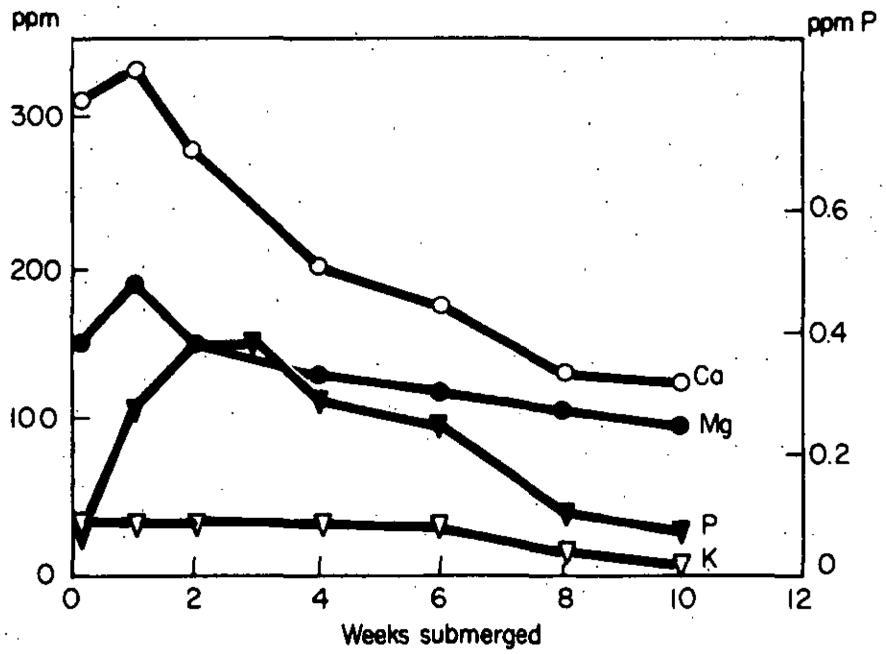

Fig. 2. Kinetics of water-soluble P, K, Ca, and Mg in submerged Maahas clay.

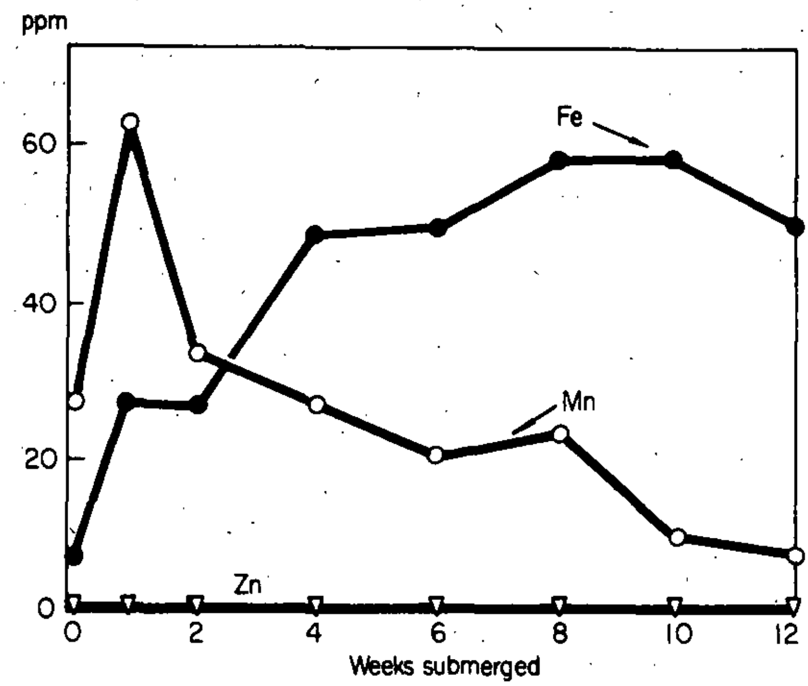

Fig. 3. Kinetics of water-soluble Fe, Mn, and Zn in submerged Maahas clay.

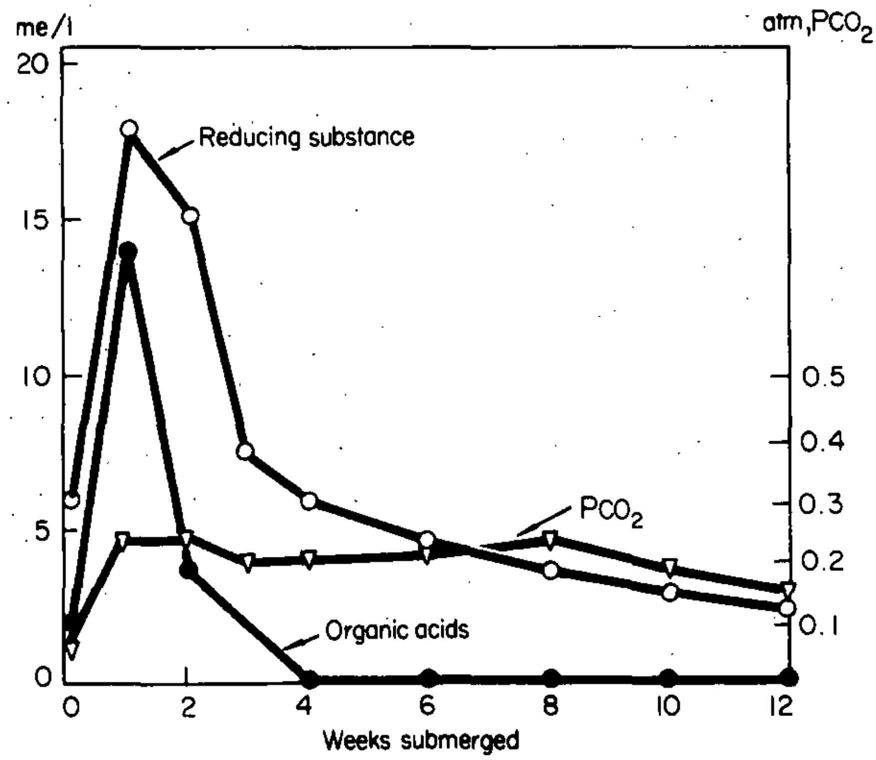

Fig. 4. Kinetics of reducing substances, volatile organic acids, and P_{CO_2} in submerged Maahas clay.

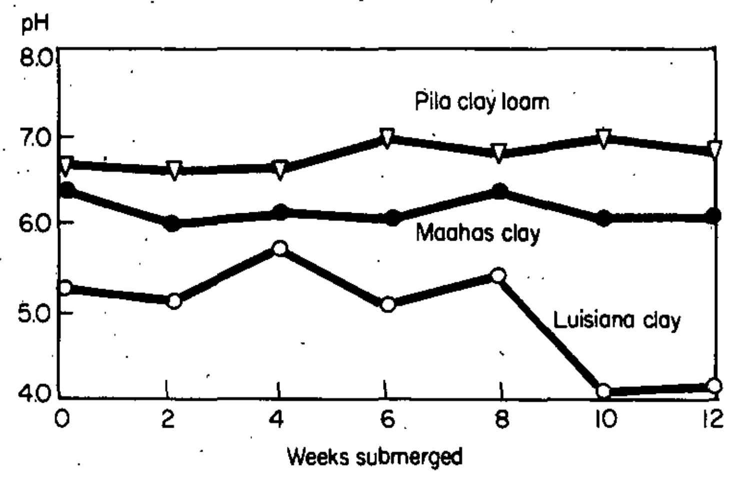

Fig. 5. Kinetics of pH of three aerobic soils.

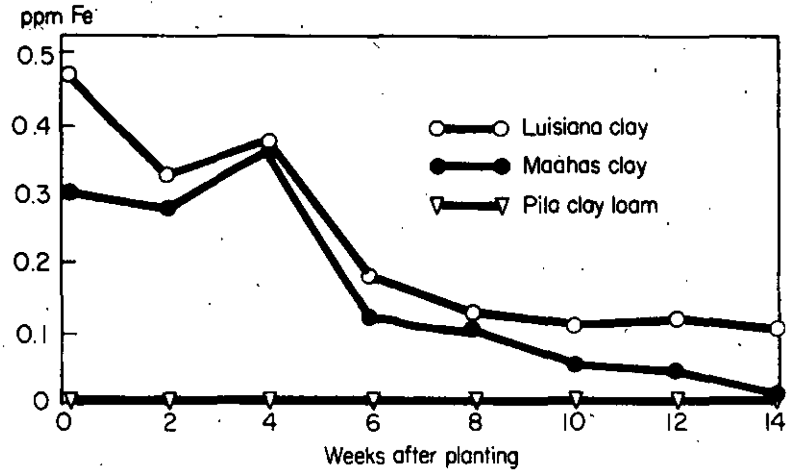

Fig. 6. Kinetics of water-soluble Fe in three aerobic soils.

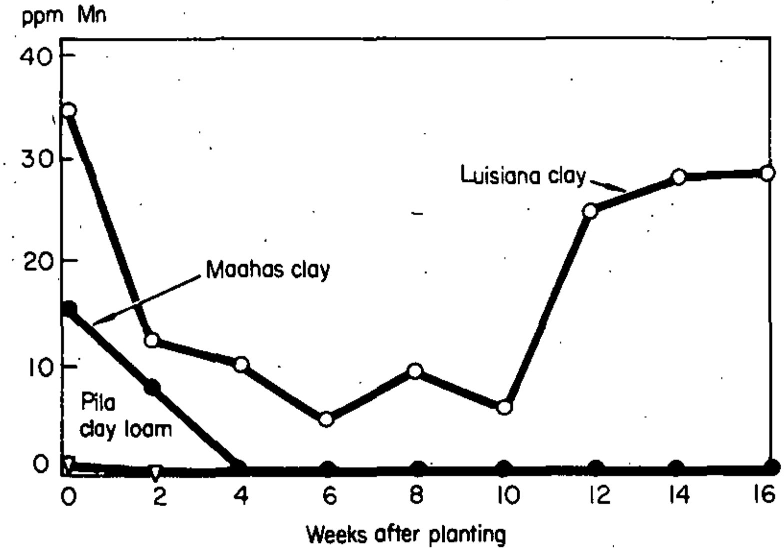

Fig. 7. Kinetics of water-soluble Mn in three aerobic soils.

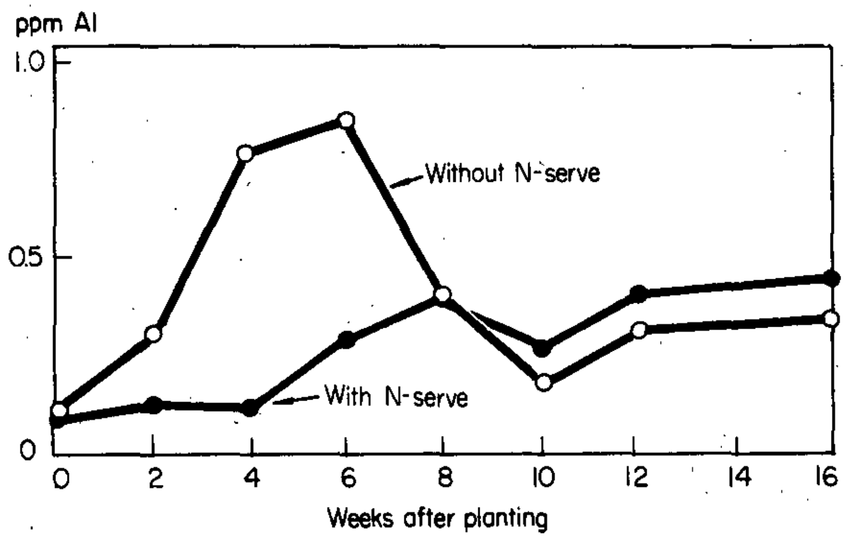

Fig. 8. Kinetics of water-soluble Al in an acid aerobic soil with and without N-serve.

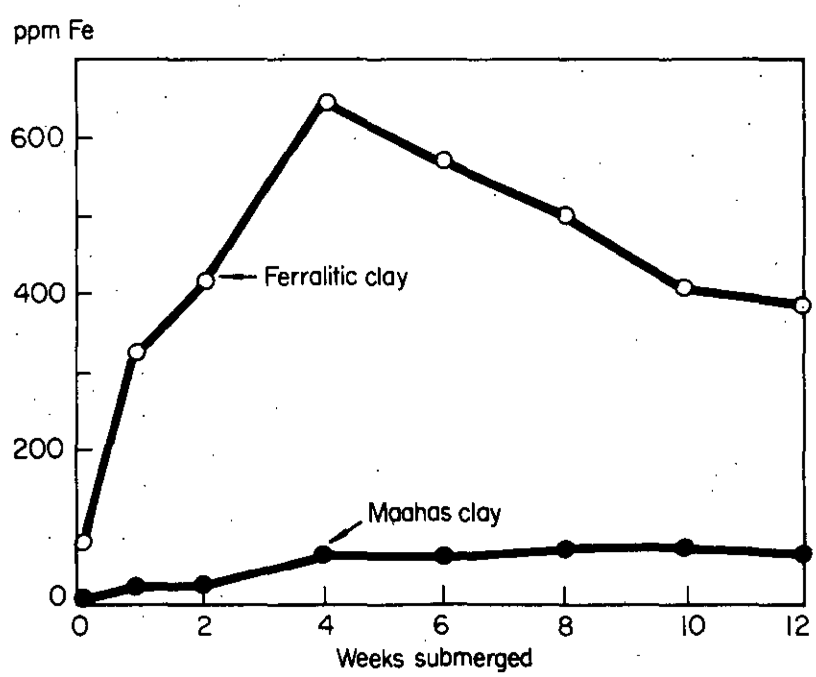

Fig. 9. Kinetics of water-soluble Fe in two submerged soils.

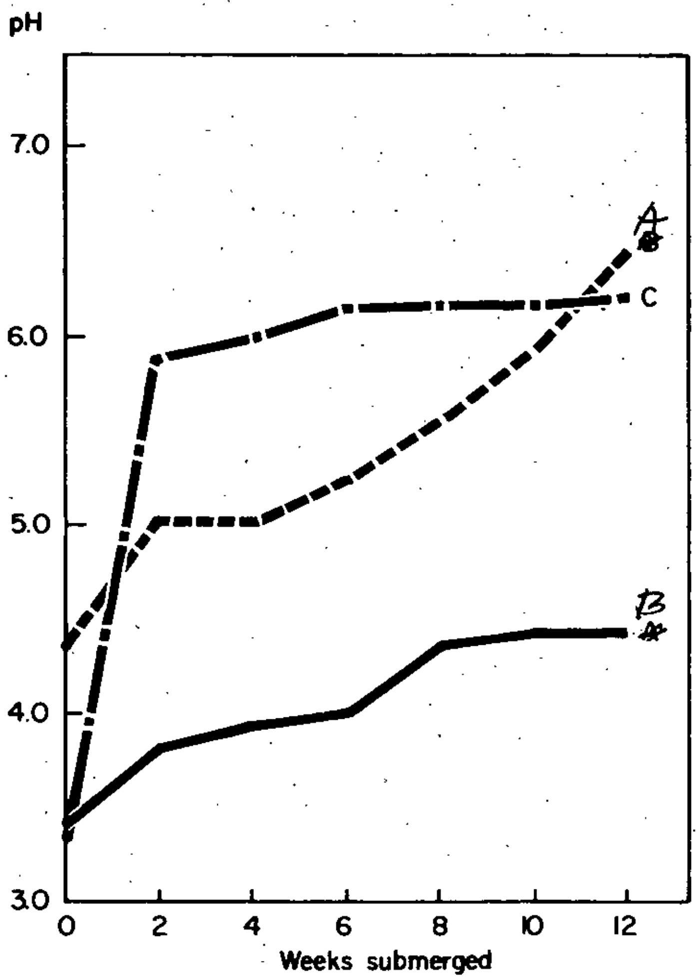

Fig. 10. Kinetics of pH in three acid sulfate soils.

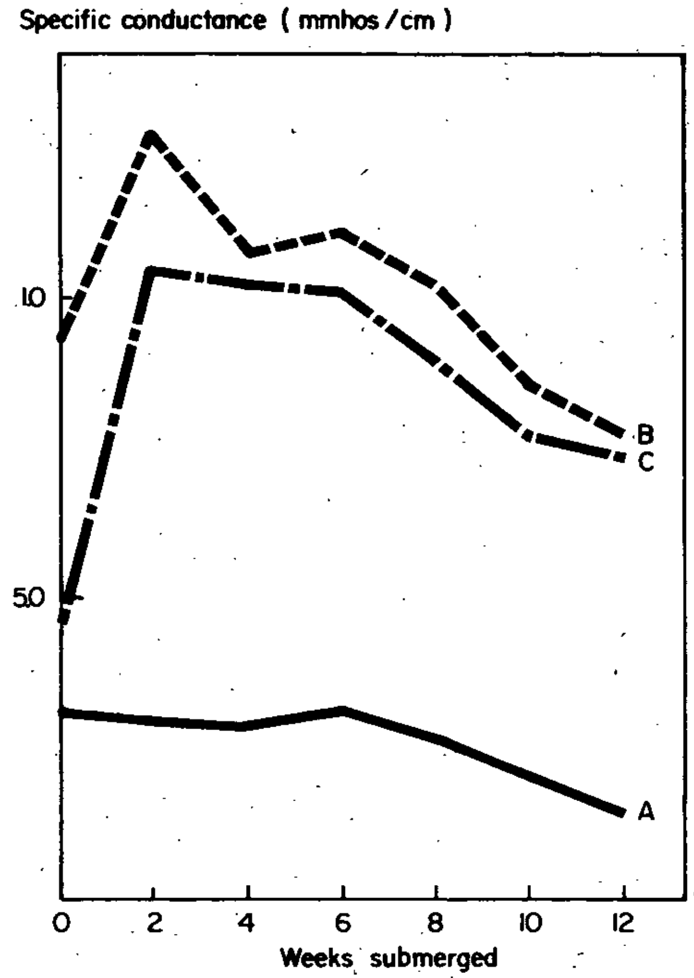

Fig. 11. Kinetics of sp. conductance (κ) in three acid sulfate soils.

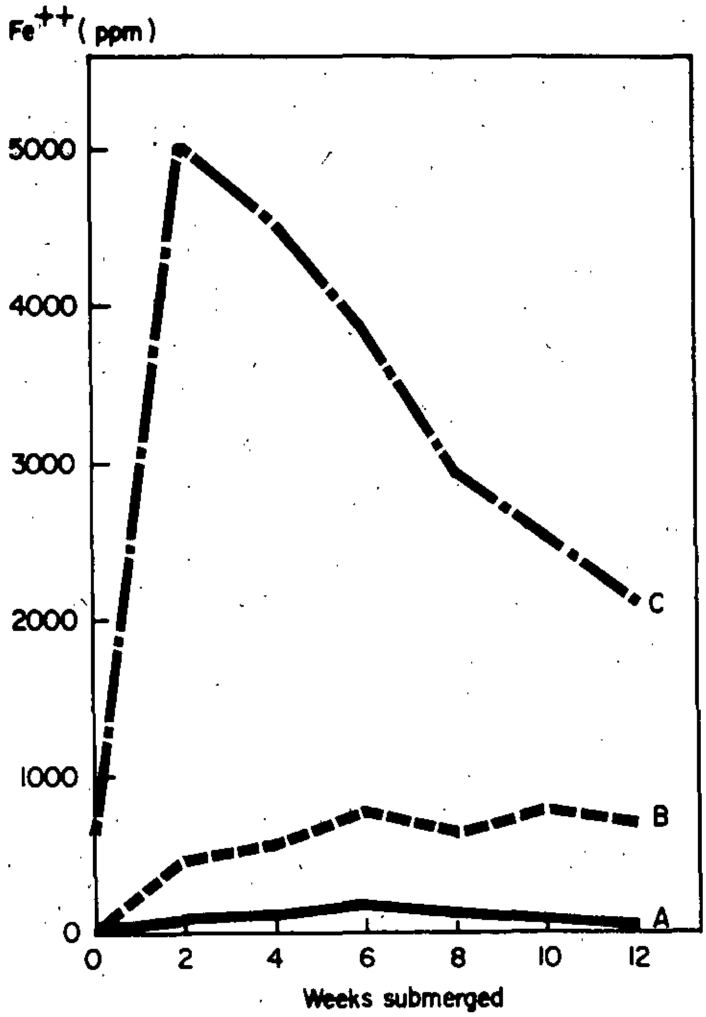

Fig. 12. Kinetics of water-soluble Fe in three acid sulfate soils.

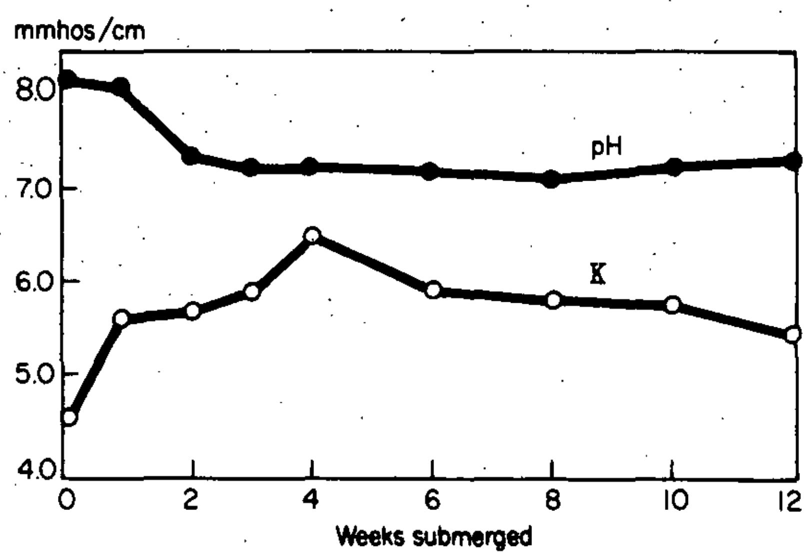

Fig. 13. Kinetics of pH and specific conductance (κ) in a submerged alkali soil (Cotabato clay loam).

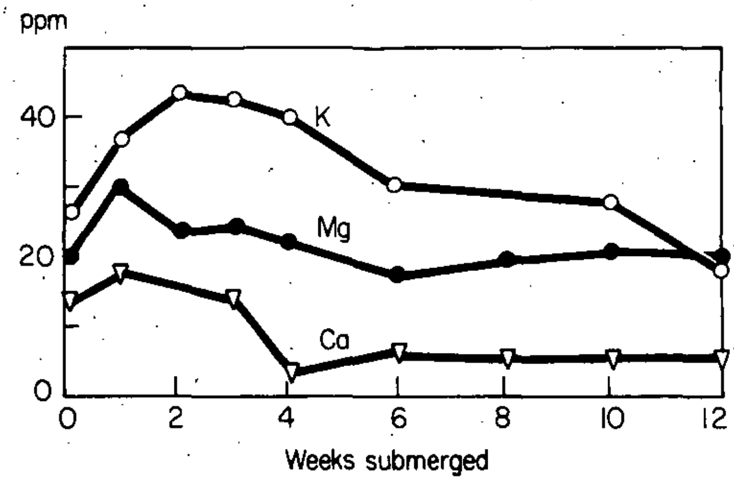

Fig. 14. Kinetics of water-soluble K, Mg, and Ca in a submerged alkali soil (Cotabato clay loam).

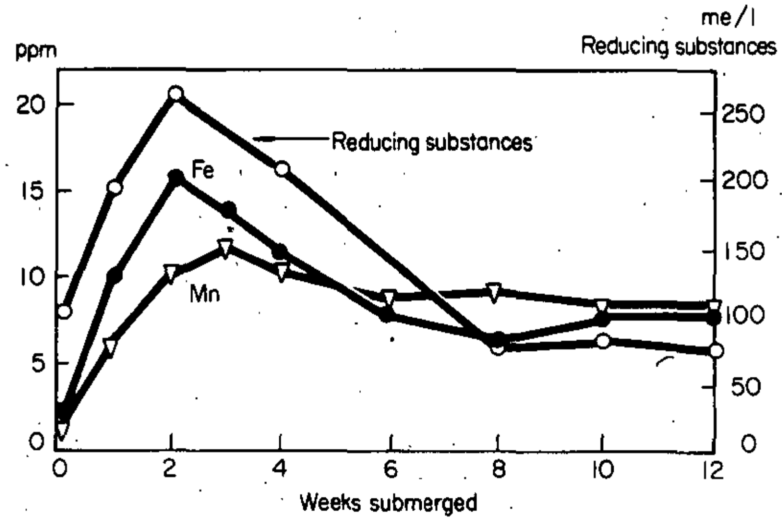

Fig. 15. Kinetics of water-soluble Fe, Mn, and reducing substances in a submerged alkali soil.

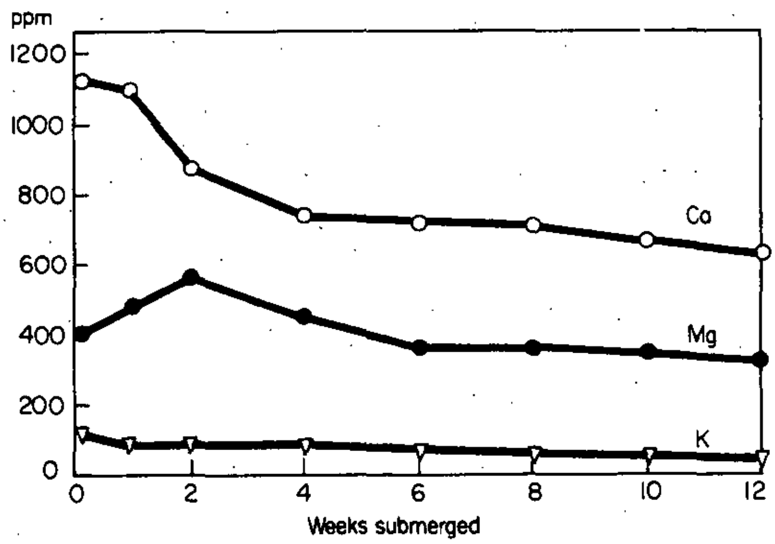

Fig. 16. Kinetics of water-soluble K, Ca, and Mg in a saline soil.

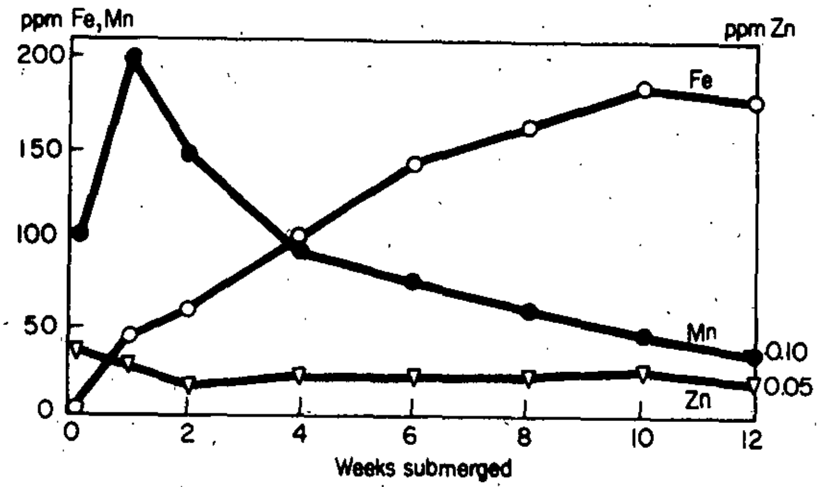

Fig. 17. Kinetics of Fe, Mn, and Zn in a saline soil.

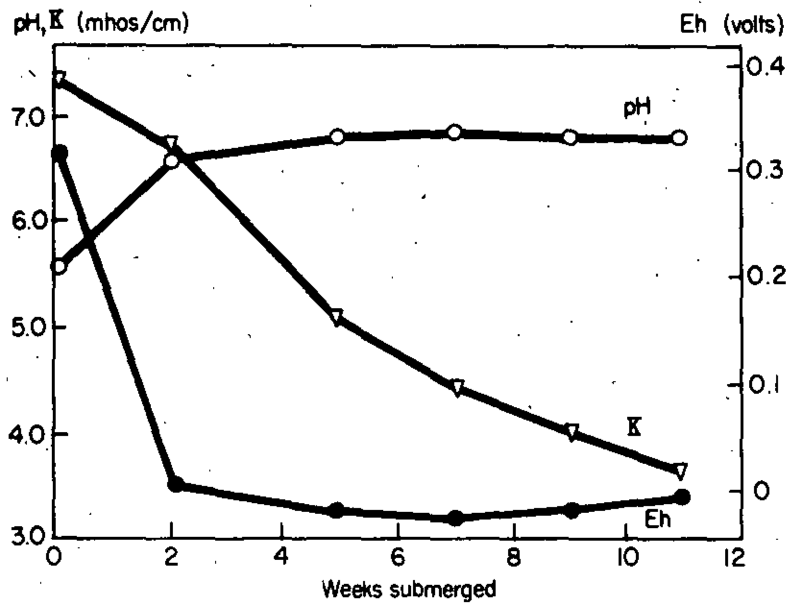

Fig. 18. Kinetics of Eh, pH, and κ (specific conductance) in a highly reduced soil.

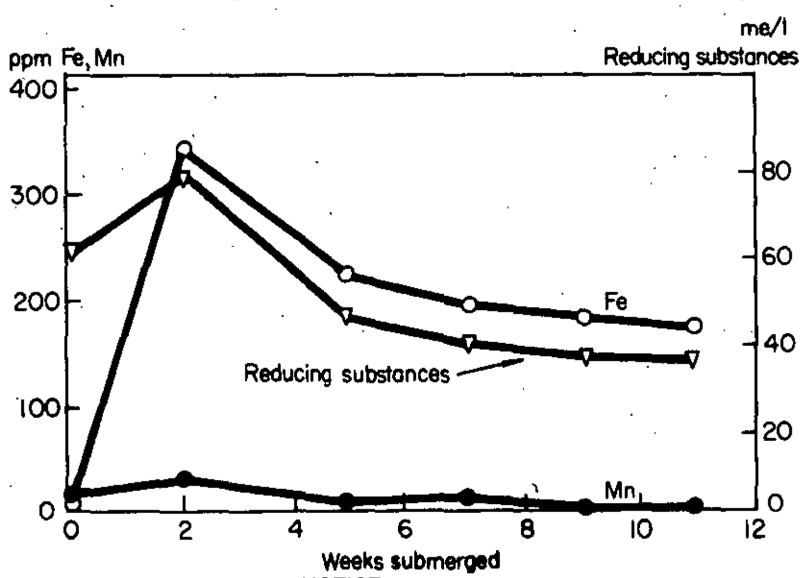

Fig. 19. Kinetics of Fe, Mn, and reducing substances in a highly reduced soil.

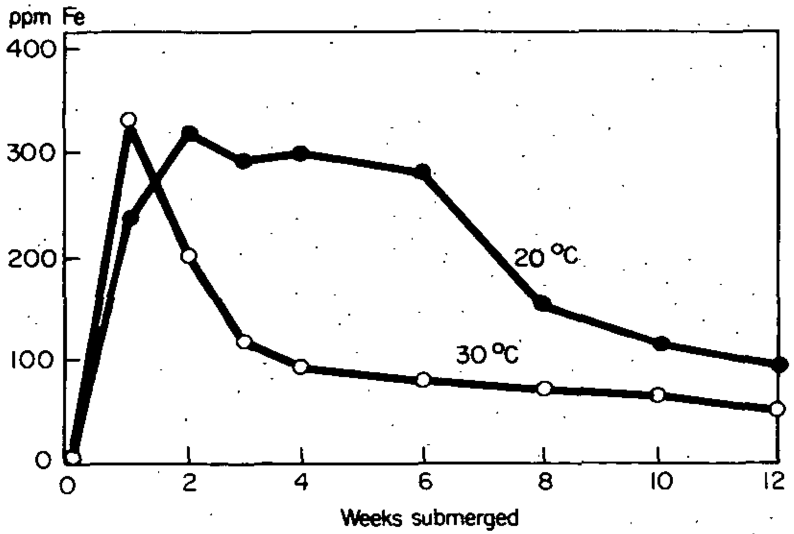

Fig. 20. Kinetics of water-soluble Fe in Casiguran sandy loam at two temperatures.

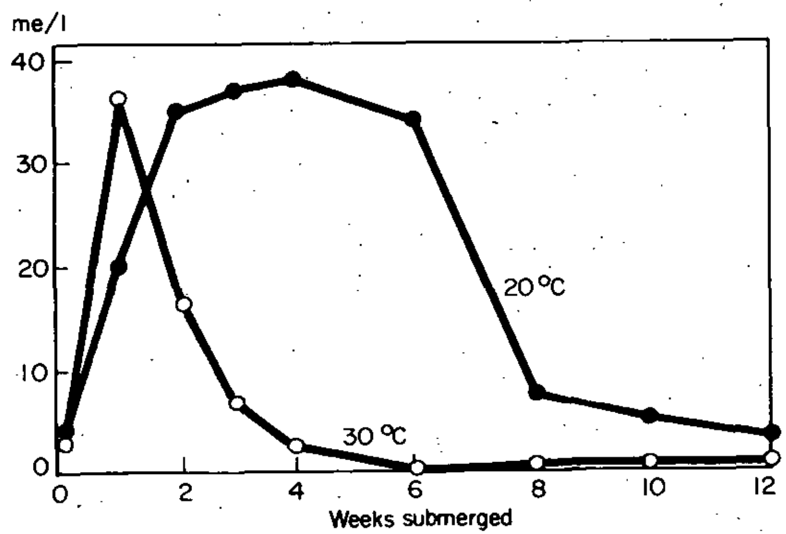

Fig. 21. Kinetics of volatile organic acids in Casiguran sandy loam.

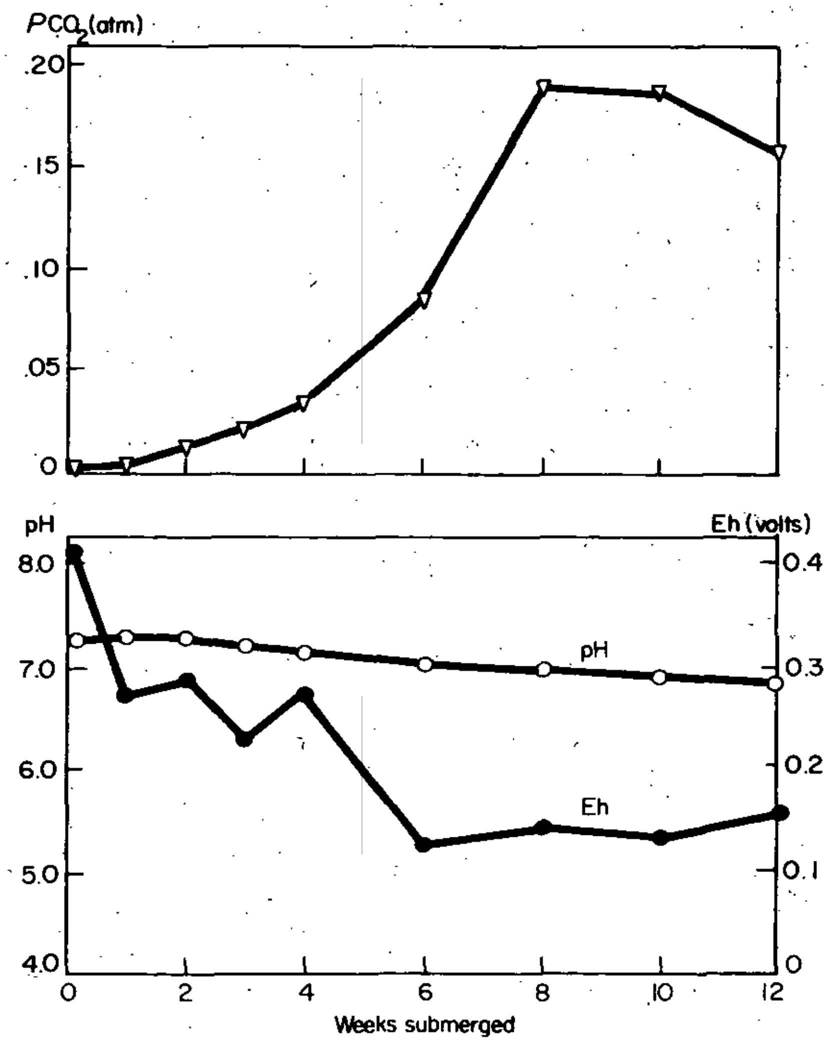

Fig. 22. Kinetics of pH, Eh, and P_{CO_2} in San Manuel clay.