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9. ABSTRACT

Mineral stresses of rice plants induced by soil conditions include salinity, alkalinity, strong acidity, iron toxicity, histosol problems, zinc deficiency, phosphorus deficiency in wetland soils, and iron deficiency and manganese and aluminum toxicities in dryland soils. Chemical amendments and water control can alleviate problems in rice cultivation caused by mineral stresses but they are both expensive. Breeding for tolerance to mineral stresses may be simpler and less expensive. To accomplish this, reliable, rapid, and convenient methods of screening rice for stress tolerance are necessary. Developing these techniques is complicated. A mineral stress in rice soil usually is compounded by the presence of other mineral stresses and by environmental problems. The magnitude of the stress varies in space and with time. The reactions of the rice plant vary with method of planting, age of seedling, and stage development of the plant. These problems and the methods of overcoming them are discussed under the various soil conditions.

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SCREENING RICE FOR TOLERANCE TO MINERAL STRESSES

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SCREENING RICE FOR TOLERANCE TO MINERAL STRESSES[1]

ABSTRACT

Stresses of rice plants caused by mineral conditions in soils are some of the main obstacles to the delivery of full potential by new rice varieties and to the use of marginal land for rice cultivation. These mineral stresses can be alleviated by breeding rices suited to the different adverse soil conditions. To accomplish this, reliable, rapid, and convenient screening methods are necessary.

To screen for salinity tolerance, 2-week-old rice seedlings are transplanted in a submerged, nearly neutral clay soil treated with 0.4% common salt in small trays, and scored visually after 4 weeks. Field screening is done in small replicated plots on an artificial saline soil at the International Rice Research Institute (IRRI) and through the International Rice Testing Program (IRTP) on natural saline soils. The annual screening capacities are 4,000 varieties on 100 sq m of greenhouse space and 1,200 varieties on 0.1 ha of artificial saline soil.

Varieties are screened for alkali tolerance in the greenhouse on a nearly neutral soil treated with 1.4% sodium carbonate. Field screening is done on an artificial alkali soil at IRRI. The screening capacities are the same as those for salinity.

Iron toxicity screening is by growing 2-week-old seedlings in a submerged strongly acid, red-yellow podzolic soil in 4-liter pots and scoring severity of symptoms 4 weeks later. Seven hundred varieties can be screened annually on 4 sq m of greenhouse space.

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[1]by F. N. Ponnamperuma, principal soil chemist, International Rice Research Institute, Los Baños, Philippines. Presented at the Workshop on Adaptation of Plants to Mineral Stress in Problem Soils, Beltsville, Maryland, November 22-23, 1976, and submitted to the IRRI Research Paper Series Committee 26 October 1976.

Screening for zinc deficiency tolerance is done in concrete beds and in the field on zinc-deficient soils. One thousand entries can be screened per year in a 27 x 2.5 x0.3-m screenhouse bed, and 8,000 entries screened on 1 ha in the field.

Varieties and lines resistant to phosphorus deficiency are selected by computing the relative tiller number of seedlings grown in phosphorus-deficient and phosphorus-sufficient culture solutions in the greenhouse. In the field, relative tiller number and relative yield of rice varieties grown on phosphorus-deficient soils with and without phosphate fertilizer serve as criteria for tolerance to phosphorus deficiency. On a 32 sq m bench space 1,400 varieties can be screened annually in the greenhouse. Field screening covers 1,000 varieties annually on 1 ha of a phosphorus-deficient soil.

Because acid sulfate soils and histosols vary widely in their properties and hydrology, screening for tolerance to them is best done through the IRTP in the environments in which they occur.

SCREENING RICE FOR TOLERANCE TO MINERAL STRESSES

The advent of rice varieties with high yield potential and the need to bring marginal land into rice production in the densely populated countries of the tropics and subtropics focus attention on mineral stresses in rice soils. Mineral stresses of rice plants induced by soil conditions are among the main obstacles to the delivery of full potential by new varieties and to the use of marginal land for rice cultivation. These stresses include salinity, alkalinity, strong acidity, iron toxicity, histosol problems, zinc deficiency, phosphorus deficiency in wetland soils, and iron deficiency, and manganese and aluminum toxicities in dryland soils.

Problems in rice cultivation caused by the mineral stresses can be alleviated by chemical amendments and water control, but both methods are costly and beyond the means of most developing countries. Breeding for tolerance to mineral stresses may be a simpler and less expensive method of overcoming the soil problems, especially where they are not severe. To accomplish that, reliable, rapid, and convenient methods of screening rice for stress tolerance are necessary.

Developing techniques for screening rice varieties for tolerance to mineral stresses is beset with difficulties. A mineral stress in rice soils rarely occurs in isolation; it is usually compounded by the presence of other mineral stresses and by environmental problems. The magnitude of the stress varies in space and with time. And the reactions of the rice plant vary with method of planting, age of seedling (if transplanted), and stage development of the plant. These problems and methods of overcoming them are discussed under the various soil conditions.

SALINITY

Salinity is the main obstacle to high rice yields on millions of hectares in deltas, estuaries, and coastal fringes in the humid tropics. It also seriously impedes the growth of irrigated rice in arid and semi-arid areas. As much as 150 million ha of current and potential rice land in the tropics and subtropics may be affected by salinity (Massoud, 1974).

Saline soils vary widely in their chemical, physical, and hydrological properties. The variables include content and nature of the salts, lateral and vertical distribution of salt, soil pH, nature and content of clay, organic matter, nutrients, water regime, relief, and temperature. The salt content of saline soils varies spatially, seasonally, and with the water regime. The dominant salts in areas of marine salinization are chlorides; in arid areas they may be sulphato-chlorides and chlorido-sulfates (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 status can vary from very low to moderately high, as gleaned from various sources. These variations present problems in devising universally applicable screening techniques.

Screening for salinity

During the past 2 decades, methods used for screening rice varieties for salt tolerance were

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 salinized 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 Murthy, 1970);
5. growing plants to maturity in salinized microplots (Janardhan and Murthy, 1972) or in replicated field trials (Purohit and Tripathi, 1972).

The maximum number of varieties tested at a time by any one of these methods was 18 (Bari et al., 1973). All those methods are unsuitable for mass screening a germ plasm collection or the progeny from a breeding program.

Problems in developing techniques. Salt tolerance in rice is influenced by the nature and content of salts, soil pH, water regime, method of planting, age of transplanted seedling, development stage of the plant, duration of exposure to salt, and temperature (IRRI, 1975). These factors, and the field problems discussed earlier, must be considered in devising salinity tolerance screening techniques that are rapid, reliable, and suited to large numbers of varieties.

Experimental studies of these factors at IRRI (1974, 1975) indicated

1. The discriminating level of salinity is 8-10 mmho/cm at 25°C.
2. At an EC (electrical conductivity) of 8-10 mmho/cm, seawater is less injurious than a solution of common salt.
3. Soil culture is better than solution culture.
4. Salinized Maahas clay (Table 1) behaves chemically and physiologically like a natural saline soil in the Philippines (IRRI, 1973).
5. Uneven distribution of salt can be minimized by using small amounts of soil (5 kg) in shallow trays and keeping them submerged to a depth of 1 cm.
6. Transplanting is better than direct seeding.
7. A 2-week-old seedling is better than a younger seedling.
8. Salt injury, as measured by the percentage of dead leaves (Table 2), is a good measure of varietal tolerance (IRRI, 1974).

Based on those findings greenhouse and field techniques were developed for screening large numbers of rices for salt tolerance (IRRI, 1975).

Table 1. Some properties of the soils used for screening for mineral stresses.

Property	Maahas clay	Shamping clay loam	Lipa clay loam	Luisiana clay
Color	Very dark brown	Reddish brown	Dark greyish brown	Yellowish brown
pH[a]	7.1	4.8	8.0	5.2
O.M. (%)	2.9	1.5	9.0	3.0
N (%)	0.16	0.09	0.48	0.16
CEC (meq/100 g)	43.8	9.7	40.3	32.3
Ex. bases (meq/100 g)	41.7	1.5	-	16.9
Reducible Fe[b] (%)	2.5	2.1	0.50	5.2
Reducible Mn[b] (%)	0.21	0.012	0.54	0.04
Available P[c] (ppm)	10	5	35	0.2
Available Zn[d] (ppm)	5.4	2.3	1.8	3.8

[a] 1:1 soil:water; [b] Asami and Kumada (1959); [c] Olsen et al. (1954); [d] Trierweiler and Lindsay (1969).

Table 2. Method of scoring salt injury in the greenhouse with some results.

Dead leaves (%)	Score	Rating	Example
0-20	1	Resistant	Nona Bokra
21-35	2	Resistant	Pokkali
36-50	3	Resistant	Kalarata
51-70	5	Moderately resistant	Damodar
71-90	7	Moderately susceptible	Peta
91-100	9	Susceptible	Ml-48

Screening techniques. To screen for salinity, 5 kg of Maahas clay is placed in plastic trays (35 x 27 x 11 cm). Four liters of a 0.5% common salt solution is added to the soil, the tray contents are thoroughly mixed, and the soil slurry is allowed to settle. The salt concentration (0.4% by weight) gives an EC_e (EC of the saturation extract) of 8-10 mmho/cm at 25°C. Three 2-week-old seedlings of each variety raised in solution culture (Table 3) are transplanted in each tray. One tray of a resistant variety and another of a susceptible variety are included as checks; they are placed after every 20 trays of test plants. Demineralized water is added daily to keep the soil submerged 1 cm. Four weeks after transplanting the plants are scored either according to the percentage of dead leaves (Table 2) or (more conveniently) visually (Table 4). The scores by the two methods were highly correlated:

$$y = 0.4 + 0.96\ x \qquad r = 0.86^{**}$$

where x is the score according to percent dead leaves and y is the visual score. About 4,000 varieties can be screened in 12 months on 104 sq m of greenhouse bench space (Fig. 1). Some results are in Table 2. IRRI uses this method for screening elite lines from its general breeding program and world germ plasm collection.

Table 3. Composition of culture solution.

Element	Source	Conc (ppm)
N	NH_4NO_3	40
P	$NaH_2PO_4 \cdot H_2O$	10
K	K_2SO_4	40
Ca	$CaCl_2$	40
Mg	$MgSO_4 \cdot 7H_2O$	40
Fe	FeEDTA	5.0
Mn	$MnCl_2 \cdot 4H_2O$	0.5
Zn	$ZnSO_4 \cdot 7H_2O$	0.01
Cu	$CuSO_4 \cdot 5H_2O$	0.01
B	H_3BO_3	0.2
Mo	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	0.05

Table 4. Method of scoring salt injury visually with results.

Observation	Score	Distribution[a]	
		Greenhouse	Field
Nearly normal growth and tillering, no leaf symptoms	1	0	12
Nearly normal growth and tillering, but leaf tips or upper halves of the leaves are white and rolled	2	86	53
Growth and tillering retarded; some rolled leaves	3	921	298
Growth and tillering severely retarded; most leaves are rolled; only a few are elongating	5	1353	879
Complete cessation of growth; most leaves are dry; some plants are dying	7	687	424
Almost all plants are dying	9	466	297

[a] In two different populations.

Salt-resistant varieties identified in the greenhouse are used by IRRI's Plant Breeding Department as parents in the hybridization program. Because plant breeders like to field-test progeny under insect, disease, and other stresses, progeny from the breeding program are screened for salt tolerance at IRRI in a 0.1-ha block of Maahas clay treated with common salt to give an EC_e of 8-10 mmho/cm at 25°C. After uniform application of the salt and its thorough incorporation in the puddled soil, the block is divided into eight plots, each surrounded by ridges and irrigation ditches. Each plot is subdivided into four subplots, also surrounded by ridges and ditches. Each subplot is irrigated simultaneously from the four surrounding ditches. Three-week-old seedlings of each entry, raised in unamended Maahas clay, are transplanted in rows replicated four times. The EC_e is measured at the start, the middle, and the end of each test. Salt is added from time to time to keep the EC_e at 8-10 mmho/cm at 25°C. The entries are scored according to the scale in Table 4. In a year 1,200 varieties can be screened. Table 4 shows some results.

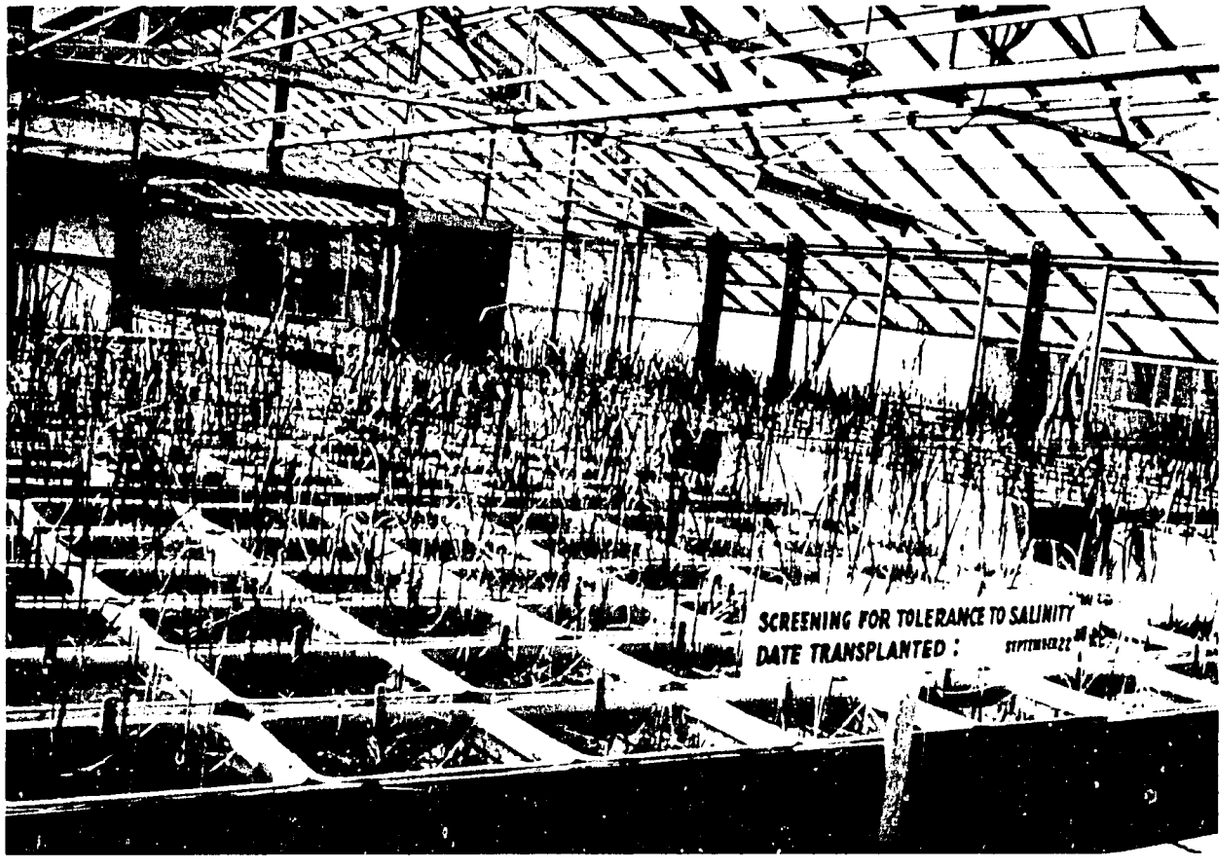

Fig. 1. Greenhouse screening of rice seedlings from IRRI elite breeding lines for salinity tolerance. IRRI, 1976.

Under natural saline conditions, a rice plant is exposed to many hazards other than salinity. Thus a line selected for high yield under IRRI conditions may fare poorly in a different environment. To sample other environments IRRI has the International Rice 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. The field plan is in Figure 2. Entries are rated according to Table 4 at 2 and at 4 weeks after transplanting. The second series of tests under this program -- in the Philippines, Thailand, India, and Pakistan -- was concluded during 1976.

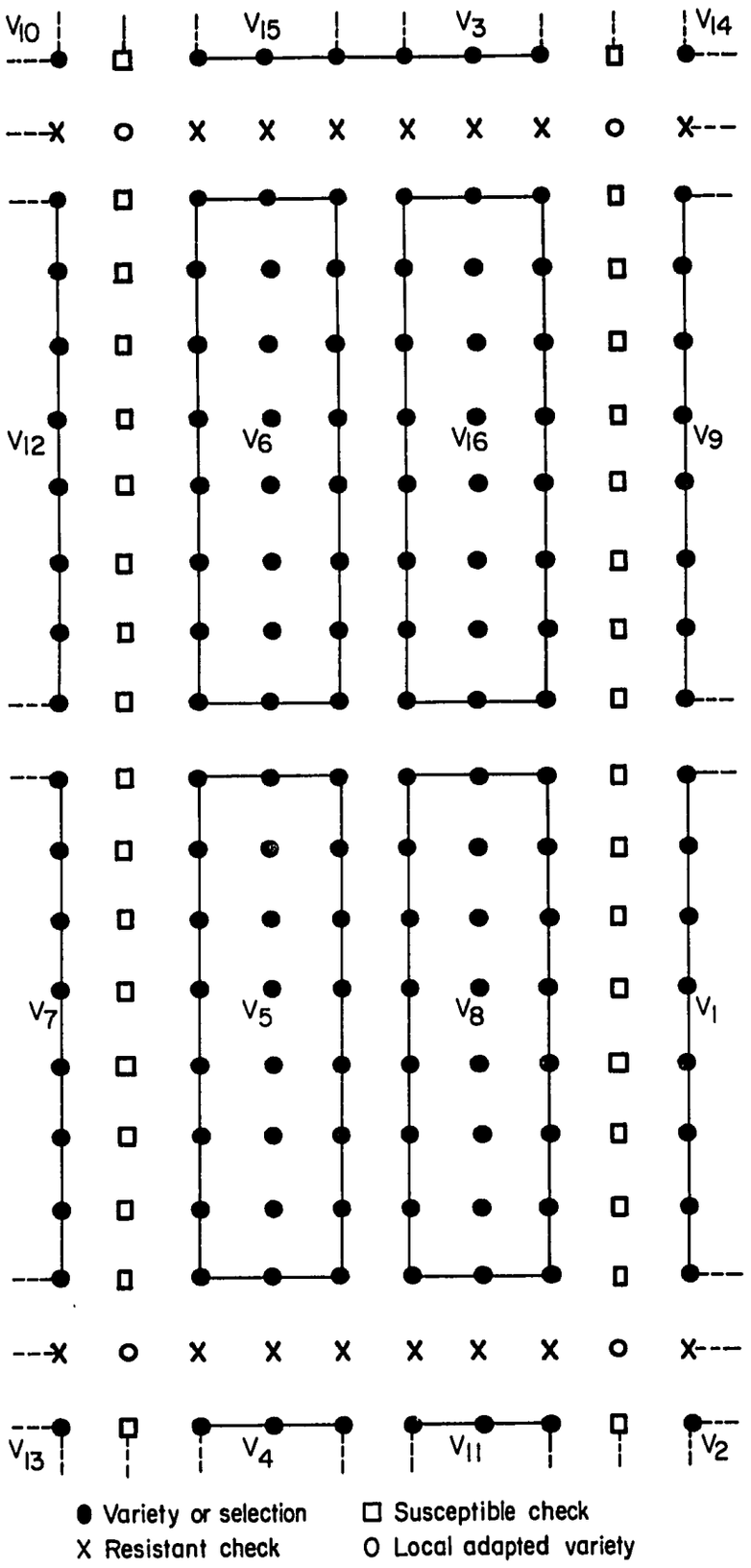

Fig. 2. Field plan for the International Rice Salt and Alkali Tolerance Observational Nursery (IRASTON).

ALKALINITY

Alkalinity, due to excess exchangeable sodium, limits the growth of rice on several million hectares of irrigated or irrigable land in the Indo-Gangetic plain in Pakistan and India, as well as on several hundred of thousands of hectares in the Near East and Africa. Because alkalinity often is associated with salinity, saline-alkali or saline-sodic soils are more common than straight sodic soils.

Screening for alkalinity

Studies on screening fc alkalinity tolerance are meager. Abdul Samad et al. (1960; cited by Srinivasan and Srinivasan, 1964) observed the field performance of 74 varieties of rice on a pH 8.9 alkali soil. Srinivasan and Srinivasan (1964) tested three varieties in a field experiment on soil with a pH of 8.7 and an EC of 2.3. The best variety (PVR-1) yielded 1.06 t/ha.

Problems in developing a technique. Solution or sand culture cannot be used for alkalinity screening because at pH values higher than 8.5 phosphate, iron, zinc, copper, and manganese precipitate and become unavailable. Bulk soil cultures in tanks in the greenhouse, or in the field lack precision because of uneven alkali distribution. So, small amounts of soil (Maahas clay) treated with 1.4% sodium carbonate were used. The pH of the air-dry soil after treatment was 8.5. The sodium absorption ratio (SAR) was 45 and the EC_e was 3.9 mmho/cm at 25°C. The chemical kinetics of this soil submergence was similar to that of a natural alkali soil from Cotabato, Philippines (IRRI, 1973).

Screening techniques. Four kilograms of soil is mixed with 5 liters of a 1.12% aqueous solution of sodium carbonate in shallow plastic trays as described earlier under salinity. Two-week-old seedlings, raised in solution culture, are transplanted in the trays. Alkali injury is scored 4 weeks after transplanting according to Table 5.

The screening capacity on 104 sq m of bench space is about 4,000 entries a year. The method is used for screening the IRRI germ plasm collection and elite lines from the general breeding program.

As for salinity tolerance, material identified in greenhouse screening is

used in the IRRI hybridization program for alkali tolerance. Field testing at IRRI is carried out on a 0.1-ha block that has been made alkali with sodium carbonate. The screening capacity is 1,200 entries a year.

To cover a wide range of environmental conditions, up to 100 promising selections and early generation breeding lines are tested annually in the IRSATON program, described under salinity.

Table 5. Method of scoring alkali injury visually with results.

Observation	Score	Distribution[a]	
		Greenhouse	Field
Nearly normal growth and tillering	1	0	2
Nearly normal growth and tillering, but leaf tips or upper halves of the leaves are discolored	2	267	5
Growth and tillering retarded; some discolored leaves	3	877	189
Growth and tillering severely retarded; most leaves are discolored, only a few are elongating	5	1218	513
Complete cessation of growth; most leaves are dry; some plants dying	7	591	1026
Almost all plants are dying	9	427	1354

[a] In two different populations.

IRON TOXICITY

Iron toxicity, a nutritional disorder of wetland rice, is associated with excess water-soluble iron (Ponnamperuma et al., 1955; Tanaka and Yoshida, 1970). The disorder is characterized by purple, reddish-brown, orange or yellow leaves, which later dry and give the plant a scorched appearance.

The roots are dark brown, scanty, and coarse. The disorder occurs in strongly acid ultisols, oxisols, and acid sulfate soils, often in association with other stresses such as salinity, phosphorus deficiency, and low base status. Iron toxicity of rice has been seen in Sri Lanka, India, Malaysia, Indonesia, Philippines, Senegal, Sierra Leone, Liberia, Nigeria, and Colombia.

Screening for iron toxicity

Field screening for iron toxicity tolerance has been in progress for several years in Sri Lanka (Gunewardena, 1975) and Liberia (Virmani and Tubman, 1974). The problems reported are variability of the severity of iron toxicity within a field, with time, and between seasons; other nutritional stresses, chiefly phosphorus and potassium deficiencies (Yamada, 1959; Tanaka and Yoshida, 1970); and climatic and biotic hazards.

At IRRI, to minimize the extraneous factors, rice was grown in an iron-toxic soil in small pots containing Shamping clay (a red-yellow podzolic soil from Taiwan) in the greenhouse. The characteristics of the soil are in Table 1. Within 2 weeks of submergence this soil built up a concentration of 400 ppm Fe^{2+} in the soil solution and maintained this concentration or higher ones for 8 weeks (IRRI, 1973). Shamping clay is one of the few strongly acid soils that maintain a high iron concentration for several months after submergence. Other acid soils attain peak concentrations which then decline to nontoxic levels.

Screening techniques. For iron toxicity screening, the soil is mixed with 50 ppm nitrogen, 25 ppm phosphorus, and 50 ppm potassium, and transferred to 3-liter pots. The soil is submerged to a depth of 1 cm and four 2-week-old seedlings (raised in culture solution) are transplanted. The symptoms are scored 4 weeks after. Seven hundred varieties can be screened annually on 4 sq m of bench space in a screenhouse with no protection from rain.

To sample other environments, 1,000 entries, including reputedly tolerant varieties, elite lines from the general breeding program, and materials from the breeding program are being mass screened in Sri Lanka. Those entries were direct seeded in rows replicated three times with resistant and susceptible checks in a 0.5-ha block in a field where iron toxicity occurs every season.

ZINC DEFICIENCY

Zinc deficiency is the third most important nutritional factor after nitrogen and phosphorus limiting the growth of wetland rice. The disorder occurs on histosols, sodic, calcareous, and sandy soils, and on soils wet for prolonged periods (IRRI, 1971, 1972). Zinc deficiency may be associated with alkalinity in sodic soils, with phosphorus and iron deficiencies in vertisols, with potassium deficiency in calcic soils, and with multiple nutritional deficiencies and multiple toxicities in histosols.

Screening for zinc deficiency

Reports on screening rice varieties for zinc deficiency are few (IRRI, 1972, 1973, 1974, 1975); they describe greenhouse tests in soil cultures and replicated trials in the field.

The greenhouse experiments limit the number of varieties that can be screened at a time. The disadvantages of field experiments are

1. Zinc deficiency symptoms frequently are absent in fields known to be zinc deficient if the fields dry out thoroughly as a result of prolonged dry weather before planting.
2. Flood damage may occur in the basins where zinc deficiency usually occurs.
3. Pest damage occurs.

These difficulties are overcome by growing rice on a zinc-deficient soil (Lipa clay loam) in screenhouse, concrete beds measuring 27 x 2.5 x 0.3 m. The properties of the soil are in Table 1.

Screening techniques. To screen for zinc deficiency, the soil is treated with nitrogen, phosphorus, and potassium, and is thoroughly puddled. Presoaked seeds are then sown directly in 1.2-m lines with a resistant and susceptible check after every 10 entries. They symptoms are scored 4 weeks after sowing (Table 6). One thousand entries can be screened in a year.

For mass screening of the world collection of germ plasm, IRRI uses 1,000 entries at a time. Three-week-old seedlings, raised in good soil, are planted in 5-m rows replicated three times on 1 ha of a zinc-deficient soil

in a farmer's field. The plants are scored 4 weeks after transplanting (Table 6). IRRI hopes to screen 8,000 varieties annually by this technique.

Table 6. Scoring zinc deficiency in screenhouse concrete beds.

Observation	Score	Distribution
Nearly normal healthy growth and tillering	1	231
Nearly normal growth and tillering, slight discoloration of basal leaves	2	41
Slight stunting, some tillering, some basal leaves are brown	3	458
Growth and tillering severely retarded, about half the number of leaves are brown	5	773
Cessation of growth and tillering, most leaves are brown	7	256
Almost all plants are dead or dying	9	9

PHOSPHORUS DEFICIENCY

Phosphorus deficiency limits rice yield on ultisols, oxisols, acid sulfate soils, ando soils, and some vertisols. These soils are low in available phosphorus and also fix considerable amounts of added phosphate fertilizer. Large amounts of added phosphorus may be required to produce a crop response. Because rice varieties vary in the capacity to extract soil phosphorus and metabolize it efficiently (IRRI, 1971), breeding may partially answer the problem of phosphorus deficiency.

In strongly acid soils phosphorus deficiency is associated with iron toxicity and base deficiency; on vertisols it is associated with zinc deficiency, iron deficiency, salinity, and alkalinity.

Screening for phosphorus deficiency

The first varietal differences in susceptibility to phosphorus deficiency were reported in 1971 (IRRI, 1971). Of 10 varieties, IR8 was severely injured by phosphorus deficiency while IR5 and H4 grew well on a phosphorus-deficient soil (Luisiana clay) in greenhouse pots. The characteristics of the soil are in Table 1.

The following year 52 varieties were screened on the same soil in outdoor concrete tanks. Their tolerance to phosphorus deficiency was assessed by comparing their grain yields with and without phosphate fertilizer (IRRI, 1972). Other methods reported were unreplicated (IRRI, 1972) and replicated experiments (IRRI, 1973, 1974, 1975), with and without phosphate fertilizer, on phosphorus-deficient farmers' fields.

Screening technique. Because pot and tank techniques are unsuitable for screening large numbers of plants from a breeding program, the possibility of using solution culture was investigated. After studying concentration of phosphorus, method of planting, and age of seedling at planting -- factors that affect the symptoms of phosphorus deficiency in culture solution -- the following method was developed (IRRI, 1975).

Four seeds of each variety are placed on nylon net screens floating on culture solution (Table 3) containing 1 ppm phosphorus in 5-liter porcelain pots. Four seeds of the same variety are placed on screens floating on a normal culture solution (10 ppm phosphorus). The pH of the culture solution is adjusted daily and the solution is changed weekly. Four weeks after sowing, the varieties are rated according to number of tillers at 1 ppm phosphorus relative to that at 10 ppm phosphorus (Table 7). On a bench space of 32 sq m, 100 varieties can be screened every 4 weeks.

Promising varieties from the greenhouse tests and from elite breeding lines are tested in phosphorus-deficient fields in replicated experiments. The rating of varieties in field plots is based on a combination of actual grain yield on phosphorus-deficient plots and grain yield relative to that on the phosphate-treated soils (IRRI, 1972, 1973, 1974). Thirty-two varieties are tested on Luisiana clay, each season, making a total of 64 for a year.

Table 7. Method of scoring phosphorus deficiency with results.

Relative tiller no.[a] (%)	Rating	Distribution
100-76	Tolerant	74
75-51	Moderately tolerant	154
50-26	Moderately susceptible	81
25-0	Susceptible	5

[a] $\frac{\text{No. of tillers in 1 ppm P culture solution}}{\text{No. of tillers in 10 ppm P culture solution}} \times 100$

IRRI has also started mass screening of the world's rice germ plasm collection in phosphorus-deficient fields using the procedure described under zinc. About 1,000 varieties can be screened each season on 1 ha of Luisiana clay.

AEROBIC SOILS: IRON DEFICIENCY, MANGANESE, AND ALUMINUM TOXICITIES

The poor yield of rice on dryland soils is usually attributed to drought and to weed competition. But it has been clearly shown that iron deficiency (regardless of soil pH) and manganese and aluminum toxicities on acid soils are important mineral stresses limiting the yield of rice on dryland, aerobic, or oxidized soils (IRRI, 1966, 1967, 1971, 1972; Ponnamperuma, 1975). Because there are no simple ways (apart from soil submergence) of ameliorating iron deficiency, and because correcting aluminum and manganese toxicities by liming is often not feasible, selecting and breeding for tolerance to these stresses have assumed increasing importance.

Screening for iron deficiency

Rice varieties were first screened for reaction to iron deficiency and to manganese and aluminum toxicities on aerobic soils on three soils in the IRRI greenhouse (IRRI, 1971). Preliminary work with 14 varieties indicated that the four dryland varieties in the group showed neither signs of iron deficiency on any of the soils nor manganese nor aluminum toxicity on an acid soil, while the typical wetland varieties showed varying degrees of injury on all three soils.

Screening technique. Screening for tolerance to iron deficiency and to manganese and aluminum toxicities requires exclusion of moisture stress, weed competition, other mineral stresses, and anaerobiosis. These conditions were achieved by growing rice on well-drained soils fertilized with nitrogen, phosphorus, potassium and kept at field capacity (IRRI, 1972).

Each variety to be screened was direct seeded in three rows on each of three soils (Luisiana clay, Maahas clay, and Maahas clay treated with 1% ground limestone) in concrete tanks provided with underground drainage. The soils were maintained at a moisture tension of < 200 millibars and a redox potential above + 0.5 V. Observations on plant growth and on the middle-row yield at harvest were used as indices of tolerance. Fifty varieties per season can be screened for tolerance to iron deficiency and to manganese and aluminum toxicities in three tanks, each measuring 10.8 x 8.7 m.

Promising varieties were later grown to maturity in IRRI-replicated field trials on Maahas clay and in a farmer's field on Luisiana clay (Table 1). The field tests confirmed the greenhouse and tank tests (IRRI, 1973).

MINERAL STRESSES IN ACID SULFATE SOILS, HISTOSOLS, AND COLD SOILS

Acid sulfate soils

Acid sulfate soils are extremely acid soils derived from marine sediments rich in sulfides. In the tropics, they cover about 15 million ha of flat land that is physiographically suited to rice. Much of that land is uncultivated because of such mineral stresses as salinity, aluminum and iron toxicities, and phosphorus deficiency.

Acid sulfate soils vary so widely in chemical properties and hydrology that screening rices on a single acid sulfate soil will have little practical value. It seems that the screening can best be done through the IRTP in acid sulfate soils in the countries where they occur -- Vietnam, Thailand, Malaysia, Indonesia, Senegal, Gambia, Sierra Leone, and Guyana, for example.

Histosols

Histosols occupy 20-30 million ha of flat land, chiefly in Indonesia. Rainfall and physiography permit rice cultivation. Because of population

pressure, these soils are being cultivated for rice. The main mineral stresses are deficiencies of nitrogen, phosphorus, potassium, zinc, copper, and molybdenum (IRRI, 1976). Salinity, strong acidity, and hydrogen sulfide toxicity are other possible stresses.

As with acid sulfate soils, histosols vary so widely in chemical properties, profile characteristics, and hydrology that screening is best done in the field in the regions where they occur. Again the IRTP provides a convenient screening system.

Cold soils

Rice is grown from the equator to 55°N and from sea level to altitudes of 2,500 m. At high latitudes and high elevations (even in the tropics) rice suffers cold injury. Part of the injury may be due to mineral stresses associated with the chemical kinetics of the soil at low temperature (Cho and Ponnamperuma, 1971). These stresses are more severe in acid soils than in neutral soils; they include phosphorus deficiency, iron toxicity, and carbon dioxide toxicity.

Screening for cold tolerance has been done for decades and continues to be done with no recognition of the mineral stress component of cold injury.

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