Varietal differences in resistance to adverse soil conditions

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Nearly 150 varieties or selections were tested for resistance to four adverse soil conditions in pots and in outdoor tanks. IR20 and H 4 were the most widely adapted of the high yielding varieties. Of 52 varieties tested for adaptability to three aerobic soils, on the average, M1-48, E425, and IR661-1-170 performed best. Peta, a typical lowland indica, was the worst. M1-48 and the IR661 line did uniformly well, and Peta, uniformly badly on the acid, neutral, and alkaline soils; E425 fared relatively poorly on the acid soil. Among 80 varieties screened for resistance to iron toxicity, IR20, IR22, IR665-8-3, and H 4 were among the least susceptible; IR5, IR8, IR424-21-PK2, and IR878B4-220-3 were among the most susceptible. Of 52 varieties, IR20, IR22, IR1168-21-3, and H 4 were most resistant to phosphorus deficiency; IR498-12-1, IR626-1-112, IR878B4-220-3, and Dawn were the least resistant. Twenty-nine of 32 varieties grown on a zinc-deficient soil perished within 5 weeks of transplanting but IR5, IR20, and H 4 survived. IR20 and H 4 were the best of 92 varieties in resistance to reduction products; the upland varieties, along with IR5 and IR8, performed the worst.

INTRODUCTION

Rice is grown from the equator to 45°N, from sea level to 2,500 m. It thrives in the hot, wet valleys of Assam and the irrigated deserts in Pakistan. The soils on which rice is grown are as varied as the climatic conditions to which rice is exposed: texture ranges from sand to clay; pH, from 3 to 10; organic matter content, from 1 to 50 percent; salt content, from almost 0 to 1 percent; and nutrient availability, from acute deficiencies to surpluses. Besides, rice is grown on flooded and non-flooded soils, and even in 6 meters of flood water. Combinations of these varying soil and climatic factors produce innumerable environments. The 14,000 varieties of cultivated rice in the IRRI collection reflect natural or artificial selection of types suited to these diverse environments.

Rice breeders have used genetic variability to produce varieties that have the right plant type, and that can tolerate cold, disease, insects, drought, and even floods. But apart from testing and breeding rice varieties for resistance to the straighthead disease of rice (Atkins, Beachell, and Crane, 1957) and some selecting for resistance to salinity (Chalam, 1954; Rao and Reddy, 1966; Sakai and Rodrigo, 1960), little has been done to identify and breed varieties adapted to adverse soil conditions that cannot be easily corrected by manage-

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ment. Among such unfavorable soil conditions are strong acidity, alkalinity, salinity, iron deficiency, iron toxicity, phosphorus deficiency (in soils that fix P strongly), and certain effects of oxidation or reduction. If the natural genetic resistance that some varieties may have to these conditions can be combined with the right plant type and resistance to pests, it may be possible to produce improved varieties suited to these soil conditions. Our preliminary tests indicate that varietal differences exist in resistance to growth-limiting factors in aerobic soils, to iron toxicity, to phosphorus and zinc deficiency, and to reduction products.

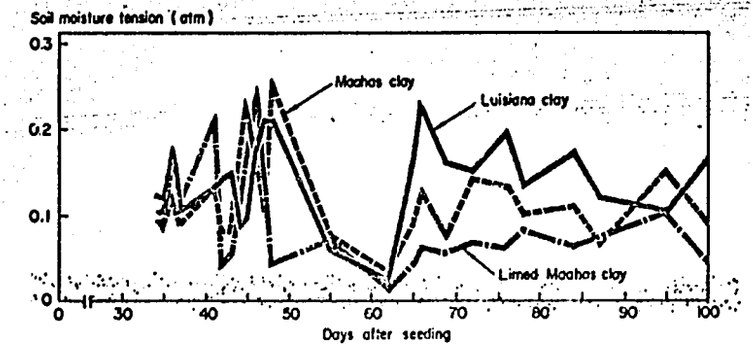
AEROBIC SOILS

The poor yield of rice on non-flooded fields is usually attributed to water stress and weed competition. But we found that even in the absence of water stress and weeds, rice yields less in aerobic than in anaerobic soils. We identified the main retarding factors in aerobic soils at field capacity as iron deficiency on neutral and alkaline soils and manganese and aluminum toxicity on acid soils fertilized with ammonium sulfate (IRRI, [1964], [1965], 1966, 1967*a*, 1967*b*, 1971). Since the severity of iron deficiency decreases while that of manganese toxicity increases as pH decreases, a calcareous soil, a neutral soil, and an acid soil, all at field capacity, were used to screen varieties for resistance to yield-limiting factors in aerobic soils.

Two common drawbacks of field experiments with upland rice are the absence of quantitative data on two important parameters—redox potential and soil moisture tension (redox potential reveals whether a soil is aerobic or anaerobic; soil moisture tension indicates the degree of moisture stress). In the absence of the control and the measurement of these two factors, yield differences among varieties depend on the rainfall pattern and cannot be related to resistance to the growth-limiting factors in aerobic soils. For this reason, we controlled and measured both factors.

We conducted a screening test in three concrete tanks, each 10.8 x 8.3 x 0.3 m, which were filled with air-dry Luisiana clay (pH 4.6, organic matter, 3.2%); Maahas clay (pH 6.9, organic matter, 2.4%); and Maahas clay limed to pH 7.6. To maintain the soils at field capacity, sprinklers were installed above the tanks and drainage pipes were fitted at the bottom. The seedbed was prepared and 100 kg/ha N, 50 kg/ha P, 50 kg/ha K were broadcast. Then pre-soaked seeds of 45 varieties were sown in furrows 20 cm apart. The tall varieties were grouped together and at later growth stages they were supported to prevent lodging. Eight tensiometers and eight platinum electrodes were set at a depth of 10 cm in each tank. The tensiometer readings were taken daily at 2 PM and redox potentials weekly. The soils were sprinkler-irrigated and the soil moisture tension was kept at 0.1 to 0.2 atm. The low soil moisture tension and the strongly positive redox potentials observed (fig. 1 and 2) showed that the soils were moist but aerobic.

The two top yielders were the upland varieties M1-48 and E425; the lowest was Peta, a typical lowland variety (Table 1). The variety IR5, which has been



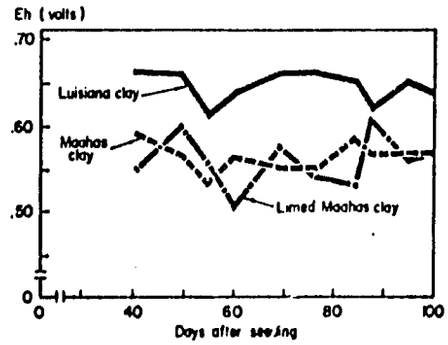
1. Changes in soil moisture tension of three soils at field capacity.

reported to yield well as an upland rice, was 34th in rank among the 45 varieties tested because it suffered severely from iron deficiency on limed Maahas clay and from manganese toxicity on Luisiana clay. On Maahas clay, however, it ranked as the fifth highest yielder. In spite of good vegetative growth, Peta, Dima, Texas Patna, M1-329, and IR332-2-10, on the average, produced little grain. The Philippine upland varieties, Azmil 26, Azucena, Palawan, and Dinalaga, produced moderate amounts of straw but little grain.

Most varieties roughly maintained their relative ranks on all three soils, but there were some variety-soil interactions (Table 2). On all three soils, M1-48 was the top yielder, IR22 was a moderate yielder, and Peta was the lowest yielder. But Taichung Native 1, E425, and IR661-1-140 fared badly on Luisiana clay compared with their performance on Maahas clay and limed Maahas clay. IR5 did much better on Maahas clay than on the other two soils.

The upland variety M1-48, in spite of its moderate height and poor tillering, produced the highest yield of grain on the acid, neutral, and calcareous soils. The Nigerian upland variety E425 yielded almost as much as M1-48 on the neutral soil, but had low yield on the acid soil. Of the IRRI lines, only IR661-1-170 approached M1-48 in yielding ability.

M1-48, E425, IR661-1-170, and IR424-21-PK2 were greener than the others and showed no signs of iron deficiency or manganese toxicity. A healthy green color may be a manifestation of adaptability to aerobic soils that are not under water stress.



2. Changes in redox potential of three soils at field capacity.

Table 1. Mean yields (per linear meter) on three aerobic soils.

Variety or selection	Yield (g/meter)	
	Grain	Straw
M1-48	151	247
E425	120	228
IR661-1-170	119	133
PI 215936	105	163
IR577-11-2	102	123
IR127-80-1	102	147
Taichung Native 1	101	156
CI 3094-1	99	257
IR12-178-2	99	143
IR24	94	126
IR305-3-17	92	122
IR140-136	90	133
IR159B3-1-1	89	195
IR424-21-PK2	89	161
IR305	88	109
IR759-53-5	88	137
IR773-112-2	88	113
CP231 x SLO-17	85	133
IR20	81	130
IR262-43-8	81	113
IR789-8-3	81	146
IR22	72	106
Azmil 26	70	170
IR790-5-1	70	135

Table 1 (Continued)

Variety or selection	Yield (g/meter)	
	Grain	Straw
IR648-2-8	69	124
Nira	69	171
Dickwee 328	68	243
IR8	68	151
Azucena	65	163
C4-63G	61	174
Palawan	60	165
Texas Patna	56	263
Milfor	55	182
IR5	53	284
Agbede	51	132
Dima	50	293
Pinulot 330	50	155
IR159B2-3-1	49	111
IR878B4-220-3	48	168
Dinalaga	47	165
M1-139	36	232
Original Century Patna	32	97
Century Patna 231	32	96
IR332-2-10	32	210
Peta	14	462

IRON TOXICITY

Iron toxicity is a widespread physiological disorder of paddy rice. It occurs on strongly acid ferrallitic (lateritic) soils in India, Ceylon, Thailand, Malaysia, and the Philippines (Tanaka and Yoshida, 1970). Iron toxicity is also one of the main impediments to the growth of rice on acid sulfate soils (Mai-thi-My-Nhung and Ponnamperuma, 1966; Tanaka and Navasero, 1966), of which there are more than 15 million hectares in Asia alone. Since liming, perhaps the best remedy, may not always be economic, the possibility of selecting and breeding resistant varieties was investigated.

In the dry season, we grew 54 varieties outdoors in pots containing a lateritic soil that built up water-soluble iron concentrations exceeding 400 ppm and induced iron toxicity even in the presence of adequate amounts of phosphorus and potassium (IRRI, 1971).

All plants showed signs of iron toxicity, but the degree and expression of the symptoms differed among varieties. The discoloration of the leaves ranged from light orange, through orange and brown to purple. Some varieties showed marked leaf rolling, others showed little. The symptoms varied even within lines from the same cross. For example, IR759-79-2 had light-orange leaves while

Table 2. Comparison of grain yields of 15 varieties on three aerobic soils at field capacity.

Variety	Luisiana clay		Maahas clay		Limed Maahas clay	
	(g/m)	Rank	(g/m)	Rank	(g/m)	Rank
M1-48	138	1	154	1	161	1
IR661-1-170	129	2	116	4	115	5
IR577-11-2	104	4	111	7	91	11
IR127-80-1	109	3	104	11	92	9
CP231 x SLO-17	82	15	91	20	83	17
IR22	69	25	77	28	71	26
C4-63G	52	33	74	30	58	30
M1-329	21	45	50	42	36	42
Original Century Patna	18	46	45	44	34	43
Peta	6	48	28	46	9	46
Taichung Native 1	82	16	118	3	104	6
E425	83	15	150	2	124	2
IR24	76	21	112	5	94	8
IR20	87	12	108	8	48	34
IR5	42	35	113	5	3	47

IR759-54-2 had purple leaves; IR790-28-5 showed severe leaf scorch while IR790-54-1 exhibited severe bronzing. Based on grain yield, the varieties least susceptible to iron toxicity were IR22, H 4, IR506-1-89, H 105, and RD 17-1-3. Among the susceptible varieties where RD 3, IR20, and IR24. Among the very susceptible varieties were IR661-1-170, Palawan, and RD 1. Among the highly susceptible varieties were IR8, E425, and IR5.

A better measure of resistance to iron toxicity would be the yield on the ferrallitic soil relative to the yield on a good soil like Maahas clay. So 56 varieties were grown side by side on the two soils in pots in the greenhouse. The yield of grain, both absolute and relative to Maahas clay, paralleled the visual symptoms of iron toxicity.

The eight least susceptible varieties were Dima, IR665-8-3, BG79, RD 1, IR506-1-89, IR22, Sigadis, and RD 17-1. On the ferrallitic soil these varieties gave 30 to 45 percent of their yield on Maahas clay. Five of the varieties were bred in countries where strongly acid ferrallitic soils are widespread.

The susceptible varieties included H 8, Tadukan, PI 215936, IR20, IR24, LD27, IR661-1-170, IR262-43-8, H 4, RD 3, IR790-5-1, IR400-5-12, and Taichung Native 1. On the ferrallitic soil, their yields were 15 to 30 percent of their yields on Maahas clay.

The following yielded less than 7 g of grain per pot or less than 8 percent of their yield on Maahas clay: CP231, Wagwag, IR790-28-2, IR8, IR589-66-2, IR759-53-5, PD46, IR790-28-5, IR878B4-220-3, and IR424-21-PK2. The IR424 line died on the ferrallitic soil 6 weeks after planting, but gave 99 g of grain per pot on Maahas clay. This group of varieties is highly susceptible to excess iron.

The fairly consistent behavior of the varieties that have been grown in several experiments makes possible their classification into two extreme groups according to susceptibility to iron toxicity—*least susceptible:* IR20, IR22,

IR262-43-8, IR506-1-89, IR665-8-3, H 4; *most susceptible:* IR5, IR8, IR424-21-PK2, IR759-79-2, IR790-28-1, IR878B4-220-3.

PHOSPHORUS DEFICIENCY

Phosphorus deficiency limits the growth of rice on vast areas of lateritic and acid sulfate soils, which not only are low in available P but also fix fertilizer phosphate as highly insoluble minerals. In these soils, the increase in availability of phosphorus brought about by soil submergence is slight (IRRI, 1967*b*; Kawaguchi and Kyuma, 1969). The phosphate fertilizer needs of such soils can be reduced if varieties that can extract phosphorus more efficiently can be developed. Since phosphorus deficiency and iron toxicity often go together but can occur independently, the soil used for screening should be deficient in phosphorus but should not induce iron toxicity. Fifty-two varieties of rice were grown outdoors on such a soil (Luisiana clay: pH 4.6; organic matter 3.2%) in pots fertilized with 100 ppm N and 50 ppm K.

The following varieties yielded at least 50 percent more grain than IR8: IR20, IR22, IR665-58-2, IR790-28-2, IR790-28-1, IR790-28-6, IR879-183-2, IR1168-21-3, H 105, and H 4. The selection IR878B4-220-3 gave only 50 percent of the yield of IR8. E425 gave practically no grain.

In a parallel experiment, 52 varieties were planted in rows on flooded Luisiana clay in outdoor concrete tanks in the dry season. Unseasonally heavy rains and several typhoons damaged some rows and depressed the yield of grain, in all varieties. Of the 37 varieties harvested, nine yielded more than IR8. One, IR1006-28-6, yielded nearly three times as much as IR8. Seven of the IRRI lines that outyielded IR8 had BPI-76 as one of the parents. None of the varieties that were inferior to IR8 had BPI-76 as a parent.

The results of the wet season experiments are reported elsewhere (IRRI, 1972).

REDUCTION PRODUCTS

When a soil is submerged and the oxygen supply is cut off, soil microorganisms use oxidized soil components such as nitrate, manganese dioxide, ferric oxide, sulfate, and even organic metabolites as electron acceptors in their respiration. As a result, nitrate is reduced to nitrogen gas, and manganic and ferric oxides are reduced to manganous and ferrous compounds which are highly soluble. Also, organic reduction products may accumulate and poison the rice plant or cause nutritional disorders. Since the obvious remedy of draining and reoxidizing the soil is not always feasible, selecting and breeding varieties that are resistant to these reduction products merits study.

We have in our collection of problem soils a soil (Tungshan silt loam) from Taiwan, on which a nutritional disorder known as "suffocation" disease occurs. The symptoms of the disease are stunting and a brownish discoloration of the leaves. The disease occurs only when the soil is submerged. It is corrected by the application of such retardants of soil reduction as nitrate and manganese dioxide (Yuan and Ponnamperuma, 1966). It is not caused by excess iron:

the symptoms differ from those of iron toxicity and the soil solution does not contain harmful levels of iron. Thus the disease appears to be due to unknown organic reduction products. Tungshan silt loam was therefore used for testing varieties for resistance to harmful reduction products.

The upland variety Palawan showed the most acute symptoms and yielded no grain at all. H 4 showed mild symptoms and produced the third highest yield of grain. The 10 most resistant varieties were IR20, IR22, IR95-43-13, IR400-5-12, IR661-1-140, IR937-76-2, IR874B2-121-3, IR790-28-1, H 4, and H 105. The least resistant varieties included IR5, IR8, IR879-183-2, IR878B4-220-3, E425, Azucena, and Palawan. In an earlier experiment (IRRI, 1970) the upland varieties Dinalaga, Azucena, and Palawan performed disastrously on the same soil although they gave high yields in aerobic, oxidized soils. Apparently, these upland varieties cannot tolerate the toxins that accumulate in reduced soils.

ZINC DEFICIENCY

Although zinc deficiency can be corrected by applying zinc to soil or to plant, resistance to zinc deficiency in improved varieties might help the small farmer. So the performance of 32 varieties was tested on a zinc-deficient soil (pH 6.2; organic matter 5.0%; total Zn, 73 ppm; available Zn, 0.8 ppm; and available P [Olsen], 78 ppm).

Two to three weeks after planting, all varieties showed zinc deficiency symptoms but IR5, IR20, and H 4 had the least. Five weeks after transplanting these three were the only varieties surviving in all plots; the lines, IR1561-189-3 and IR1561-284-3 survived in some replicates. The following were dead: IR8, IR22, IR24, one IR5 line, one IR262 line, three IR506 lines, two IR665 lines, one IR759 line, three IR790 lines, three IR878 lines, one IR1170 line, and one IR1561 line.

At 5 weeks after transplanting, the zinc content of all plants, including those that survived, was less than 13 ppm. But the surviving varieties had lower concentrations of manganese and magnesium.

IR20 and H 4 appear to combine resistance to four soil problems: iron toxicity, phosphorus deficiency, zinc deficiency and injury due to reduction products. These varieties should do well on strongly acid soils and continuously wet soils. IR20, in addition, should yield well on neutral and acid upland soils.

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Discussion: Varietal differences in resistance to adverse soil conditions

J. H. Cock: Peta gave a large straw weight but very low grain yield in Table 1. Why?

F. N. Ponnamperuma: Peta suffered a setback at the later growth stages. Peta showed high spikelet sterility.

A. C. McClung: How do you explain the low yield of IR5 in Table 1 which seems to differ from other IRRI experiments?

F. N. Ponnamperuma: IR5 yielded moderately well on Maahas clay (Table 2). But its poor performance on limed Maahas clay and on Luisiana clay depressed the average yield for the three soils.

Y. L. Wu: How do you differentiate iron deficiency and zinc deficiency in rice plants?

F. N. Ponnamperuma: The main symptom of iron deficiency is interveinal chlorosis of the younger leaves; that of zinc deficiency is slight interveinal chlorosis of the youngest leaf followed by brown spots in the older leaves.

Y. L. Wu: Do you think it is possible to raise rice yield by planting upland varieties or using direct seeding method in soils high in reduction products?

F. N. Ponnamperuma: The best way to prevent injury by reduction products is to direct seed, grow the crop in dry soil, and flood about a week before panicle primordia initiation.

P. R. Jennings: Which soil problem do you consider the most important?

F. N. Ponnamperuma: Iron deficiency.