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THE CONTRIBUTION OF VARIETAL TOLERANCE FOR PROBLEM SOILS TO YIELD STABILITY IN RICE

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THE CONTRIBUTION OF VARIETAL TOLERANCE FOR PROBLEM SOILS TO YIELD STABILITY IN RICE[1]

ABSTRACT

The erratic performance of the modern rice varieties in many countries has been attributed to physical and biological environmental stresses to which they are not adapted. Physical stresses include phosphorus deficiency, zinc deficiency, and iron toxicity in wetland rice and iron deficiency in dryland rice. To ascertain the contribution of varietal tolerance to yield stability under those mineral stresses, the performance of tolerant and sensitive genotypes of comparable yield potential was studied in the field in the 1978 dry and wet seasons and 1979 dry season. The tests were conducted, where possible, at three stress levels -- no stress, mild stress, and severe stress.

The results confirmed the existence of marked differences in varietal tolerance for mineral stresses, provided measures of the yield increase accruing from tolerance, indicated the value of initial mass screening followed by field tests in identifying stress-tolerant rices, and revealed a higher uptake of the deficient elements by tolerant rices compared with the sensitive ones.

Tolerance varied widely with the stress level and the genotype. Sensitive rices suffered severe yield losses even under mild stress, whereas tolerant rices resisted the yield decline until the stress became moderate. Under severe stress, both tolerant and sensitive genotypes perished.

The contribution of varietal tolerance to yield ranged from 0.5 to 0.8 t/ha for phosphorus deficiency, 0.5 to 1.5 t/ha for zinc deficiency, and 0.2 to 0.7 t/ha for iron deficiency at yield levels of 2.5 to 4.0 t/ha.

Ratings in mass screening at the seedling stage correlated closely with yield in the zinc and iron deficiencies tests. In the phosphorus deficiency and iron toxicity tests, the correlation was poor because of later recovery from the stress, especially by the late-maturing rices. That indicated the need for yield tests in the field.

The tolerant rices produced economic yields under mineral stresses common in rice lands and consistently maintained their superiority to the sensitive ones over locations and seasons.

[1]By M. Mahadevappa, senior research fellow; H. Ikehashi, former plant breeder; and F. N. Ponnamperuma, principal soil chemist, International Rice Research Institute, Los Baños, Laguna, Philippines. Submitted to the IRRI Research Paper Series Committee September 1979.

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THE CONTRIBUTION OF VARIETAL TOLERANCE FOR PROBLEM SOILS TO YIELD STABILITY IN RICE

The introduction of IR8 in 1966 marked the start of a technological revolution for rice farmers and promises of plenty for the people of the rice-growing areas of the world. But IR8 and its early successors did not fulfill its promise, largely because of adverse environmental factors that were beyond the control of the small farmers who constitute the bulk of the rice producers of Asia.

These factors include soil-based plant stresses such as salinity, alkalinity, iron and aluminum toxicities, and phosphorus, zinc, and iron deficiencies. Because of the widespread incidence of these stresses, the modern rice varieties have performed inconsistently over vast areas in Asia, Africa, and Latin America.

The stresses can be relieved by water control and chemical amendments but those are costly. Varietal tolerance may be a simpler solution, especially where the stresses are not severe (Ikehashi and Ponnamperuma 1978). Incorporating genetic tolerance for adverse soils in the modern varieties may ensure yield stability over a wide range of soil conditions and, in some mineral stresses, over several growing seasons.

Although thousands of rices have been screened for tolerance for various mineral stresses and many tolerant varieties identified (IRRI 1970, 1979; Virmani 1976; Howeler and Cadavid 1976; Ikehashi and Ponnamperuma 1978), information on the field performance of tolerant varieties is meager (IRRI 1973, 1979; Koyama et al 1973; Alluri and Buddenhagen 1977).

In this paper we compare the field performance of varieties on soils with three mineral stresses commonly encountered in wetland rice lands -- phosphorus deficiency, zinc deficiency, and iron toxicity -- and the most important mineral stress in dryland rice, viz., iron deficiency. We also evaluate the contribution of varietal tolerance to yield stability.

FIELD PERFORMANCE OF RICES ON ADVERSE SOILS

We tested rices for phosphorus deficiency, zinc deficiency, and iron toxicity in four Philippine provinces. Iron deficiency test was at IRRI. Tolerant and sensitive varieties were chosen on the basis of greenhouse tests. We elimi ed those with low yield potential as shown licated field trials at IRRI.

Phosphorus deficiency

During the 1978 dry and wet seasons we tested the performance of 12 tolerant and 12 sensitive lines on phosphorus-deficient soils (Luisiana clay, pH: 4.8, O.M.: 3.5%, total P: 1350 ppm, Olsen P: 2 ppm) at Pangil, Laguna, and Narra, Palawan (Bay clay loam, pH: 7.2, O.M.: 2.2%, Olsen P: 0 ppm). Half of the experimental site received a basal application of 25 kg P/ha as ordinary superphosphate (P_1) and the other half was not treated (P_0). All plots received 100 kg N/ha as urea and 50 kg K/ha as muriate. IRRI-grown seedlings were transplanted in a randomized complete block design replicated five times. Standard crop management practices were followed. The entries were scored 1-9 (Ponnamperuma 1977) for phosphorus deficiency injury twice before flowering. Number of tillers and straw and grain yield were recorded.

The test was repeated in the 1979 dry season with the following modifications: an additional treatment with 50 kg applied P/ha (P_2) was included, 20 genotypes were used, and a split-plot design was adopted. Straw and grain samples, or plant samples at the maximum vegetative growth stage, were analyzed for phosphorus content.

Tolerance for phosphorus deficiency. There were significant genotypic differences in grain yield at all levels (P_0, P_1, P_2) of the phosphorus stress. In the yield range from 2.5 to 3.9 t/ha, the mean yield depression in P_0 plots, as compared to phosphorus-amended plots, was 11% over 3 seasons (Tables 1 and 2). Five genotypes -- IR34, BR51-91-6, IR4427-58-5-2, IR4427-315-2-3, and IR4816-70-1 -- were consistently tolerant in all three seasons (Table 3); 8 entries were consistently sensitive and the rest were inconsistent.

In the 1978 dry season, panicle number per hill and straw weight were also studied. The overall reduction in panicle number in P_0 in relation to P_1 was 6%; straw weight reduction was 10%. Genotypes differed in the degree of depression of both panicle number and straw weight.

Growth was depressed in the P_0 treatment in all three seasons, with genotype differences in degree of depression. The differences were most pronounced at tillering, started diminishing soon after, and were at a minimum by flowering. Flowering of many entries was delayed 2-9 days in P_0 plots. Late-maturing entries had an advantage in recovering from the initial depression due to phosphorus deficiency, and their grain yield reduction was relatively low (Figs. 1 and 2). With acute phosphorus deficiency, however, all of the entries in the plots at Narra, Palawan barely survived during the 1978 wet season.

The ratings of phosphorus deficiency injury at the seedling stage ... ed ... rrel... on ... grain yield (r = -0.107 ns). However, the ratings at Pangil, Laguna, generally agreed with those at Narra, Palawan. The ratings at flowering stage differed from those at the seedling stage.

Phosphorus content in grain and straw. The phosphorus content in grain and straw revealed significant varietal differences (Fig. 3), but they did not indicate any trend in relation to reactions to phosphorus deficiency. Similarly, the phosphorus content in the plant at the maximum vegetative growth stage (1978 wet season) differed (in P_0 only) among varieties. Phosphorus absorption by 24 genotypes, as determined by grain and straw analysis at two levels of phosphorus deficiency (Fig. 4), indicated that phosphorus removed through the grain by tolerant varieties was high, whereas that removed through the straw was relatively low. The amount of phosphorus in the grain was highly correlated with yield (Table 4).

Zinc deficiency

Sixteen genotypes were tested on a zinc-deficient soil (Lipa clay loam, pH 7.9, O.M. 11.3%, Katyal and Ponnamperuma Zn: 0.04 ppm, total Zn 79 ppm) at Tiaong, Quezon, during three successive 1978-79 seasons. All plots received 25 kg N and 20 kg P/ha. A randomized complete block design, replicated 5 times, was used. Standard management practices were followed. The

Table 1. Performance of 20 genotypes in 3 seasons on a phosphorus-deficient soil at Pangil, Laguna, 1978-79.

	Grain yield (t/ha)[a]					
	1978 dry season		1978 wet season		1979 dry season	
	P_0	P_+	P_0	P_+	P_0	P_1
IR8	3.7	3.9	2.4	2.6	3.7	4.5
IR34	4.0	4.4	2.6	2.6	4.1	4.2
IR40	3.0	3.9	2.4	2.6	3.5	3.6
BR51-91-6	3.9	4.1	2.8	2.8	4.5	4.7
IR1632-93-2-2	3.1	3.8	2.8	2.9	3.6	4.0
IR5105-80-3-3-2	3.3	3.8	1.4	1.9	3.1	4.1
IR2307-84-2-1	3.3	4.0	2.1	2.6	3.5	3.3
IR2797-105-2-2-3	3.8	3.9	2.5	2.7	3.4	4.1
IR2823-103-5-1	3.7	4.2	2.1	2.4	3.5	3.9
IR2863-35-3-3	3.4	3.9	2.1	2.7	3.5	4.3
IR6115-1-1-1	-	-	2.5	2.7	2.4	2.6
IR4219-35-3	2.6	2.6	1.9	1.9	2.3	2.3
IR9439-20	-	-	2.4	3.1	4.6	4.5
IR4427-58-5-2	3.3	3.9	2.1	2.5	3.8	4.0
IR4427-315-2-3	3.5	3.8	2.4	2.5	3.8	4.1
IR4432-38-6-5-2	3.2	3.7	2.1	2.3	3.5	3.9
IR4432-52-6-4	-	-	2.7	2.8	4.1	4.2
IR4570-83-3-3-2	-	-	2.6	2.7	4.1	4.1
IR4707-123-3A	2.8	3.8	1.6	2.1	2.8	3.3
IR4816-70-1	3.4	4.1	2.6	2.8	3.5	3.2
F test (varieties)	**	**	**	**	**	**
CV (%)	9.7	6.9	23.7	19.9	14.6	14.6
LSD (5%)	0.4	0.3	0.6	0.7	0.9	0.9

[a]**Significant at the 1% level. P_0= no phosphorus added, P_+ = phosphorus-amended plots.

Table 2. Performance of tolerant and sensitive genotypes in a phosphorus-deficient soil at Pangil, Laguna, over three seasons.

Season	Mean yield (t/ha)	Yield depression due to phosphorus deficiency (%)				
		Overall	Tolerant		Sensitive	
			Range	Mean	Range	Mean
1978	3.9	15	0-17	8	7-27	17
1978	2.5	10	0-15	6	4-28	12
1979	3.9	9	0-8	2	2-32	15
Mean	3.4	11	0-17	5	2-32	15

entries were scored twice for zinc deficiency and data on panicle number, straw weight and grain yield were collected. Grain and straw samples or plant samples at maximum vegetative growth stage were analyzed for zinc content.

We attempted to establish mild and severe levels of deficiency during the first two seasons. In the first season, however, the *mild* level was actually severe and the *severe* level was lethal. The genotypes were scored for zinc deficiency injury when

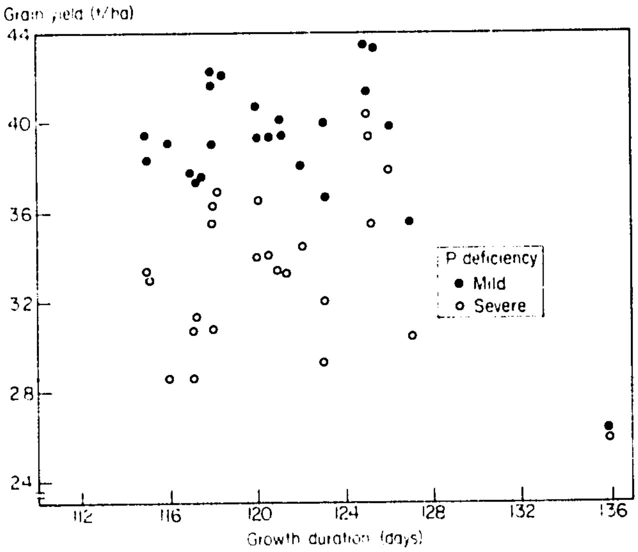

Fig. 1. Relationship between grain yield and growth duration in two levels of phosphorus deficiency, Pangil, Laguna, 1978 dry season.

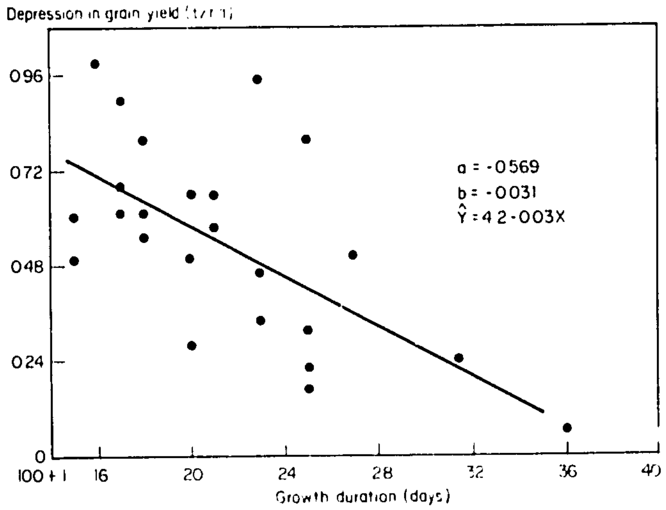

Fig. 2. Correlation between depression in grain yield due to phosphorus deficiency (P_1-P_2) and growth duration, Pangil, Laguna, 1978 dry season. **Significant at the 1% level.

Table 3. Range of varietal tolerance to phosphorus deficiency as measured by grain yield, Pangil, Laguna.

Season	Yield depression	Yield under stress (t/ha)			Reaction[a]	Designation
		Mild	Severe	Difference		
1978 dry	Min	4.3	4.0	0.32*	T	IR34
		4.1	3.9	0.22	T	BR51-91-6
	Max	3.9	2.8	1.1**	S	IR4427-51-6-3
		3.9	2.9	1.0**	S	IR1514A-E666
		4.3	3.5	0.8**	S	IR2797-105-2-2
1978 wet	Min	2.6	2.6	0.0	T	IR34
		2.8	2.8	0.0	T	BR51-91-6
		2.5	2.4	0.1	T	IR4427-315-2-3
	Max	2.6	1.9	0.7*	S	IR4427-51-6-3
		2.1	1.6	0.5*	S	IR4707-123-3A
		3.1	2.4	0.7*	S	IR9439-20
1979 dry[b]	Min	4.2	4.1	0.1	T	IR34
		3.6	3.5	0.1	T	IR40
		4.7	4.5	0.2	T	BR51-91-6
	Max	4.5	3.1	0.8**	S	IR8
		4.1	3.1	1.0**	S	IR5105-80-3-3-2
		4.1	3.4	0.7*	S	IR2797-105-2-2-3
		4.3	3.5	0.8*	S	IR2863-35-3-3

[a]T = tolerant, S = sensitive, * significant at the 1% level, ** significant at the 5% level. [b]*Mild* and *severe* in this case may be read as *normal* and *mild*.

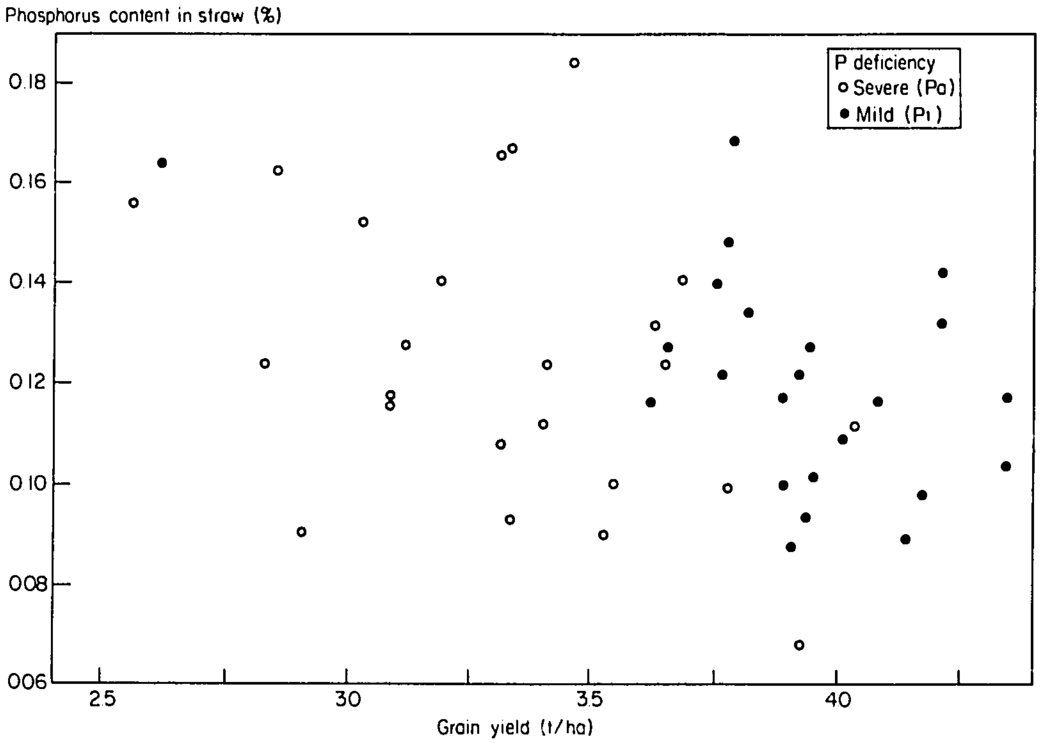

Fig. 3. Relationship between grain yield and phosphorus content in straw in 24 genotypes grown in 2 levels of phosphorus deficiency, Pangil, Laguna, 1978 dry season.

Table 4. Performance[a] of 16 tolerant and sensitive genotypes on zinc-deficient soil at Tiaong, Quezon, in three seasons.

Genotype	Grain yield (t/ha)[b]					
	1978 dry season	1978 wet season		1979 dry season		
	Z_0	Z_0	Z_1	Z_0	Z_1	Z_2
IR20	2.0 ab	1.3	3.7	2.3	2.9	3.3
IR34	2.7 a	1.3	3.2	2.7	2.8	3.3
IR36	-	0.4	1.5	0.5	1.0	0.9
IR38	2.7 a	1.5	2.2	3.0	3.4	3.6
IR2797-105-2-2-3	0.6 bcd	0.8	3.5	1.6	2.8	3.5
IR2153-26-3-5-6	10. abc	0.6	2.5	2.4	3.1	3.1
IR3464-126-1-3	1.8 abc	0.9	3.2	2.8	3.0	3.4
IR4432-103-6	3.4 a	1.7	3.1	2.5	2.8	2.9
IR4683-54-2	3.2 a	1.1	2.1	3.4	3.8	3.8
IR8	2.4 ab	1.2	2.5	1.8	3.5	3.5
IR2071-685-3-5-4-3	-	0.9	2.7	0.6	0.8	1.3
IR4432-52-6-4	-	1.5	3.5	2.3	3.3	3.6
IR4568-86-1-3-2	-	0.7	4.1	2.4	3.1	3.3
IR4568-225-3-2	1.8 abc	1.8	2.9	2.9	3.5	3.9
IR4707-123-3	1.2 abc	0.3	2.3	1.6	2.5	2.9
IR9439-20	-	1.7	3.8	2.8	2.9	3.5
F test	**	**	**			
Zn level					**	
Variety					**	
Zn x V					*	
CD (P = 0.05)	-	0.6	1.2			

[a]**Significant at the 1% level. Any two means followed by the same letter are not significantly different at the 5% level. [b]Z_0 = severe (2% ZnO dip), Z_1 = mild (4% ZnO dip), and Z_2 = nil (4% ZnO dip + $ZnSO_4$ spray).

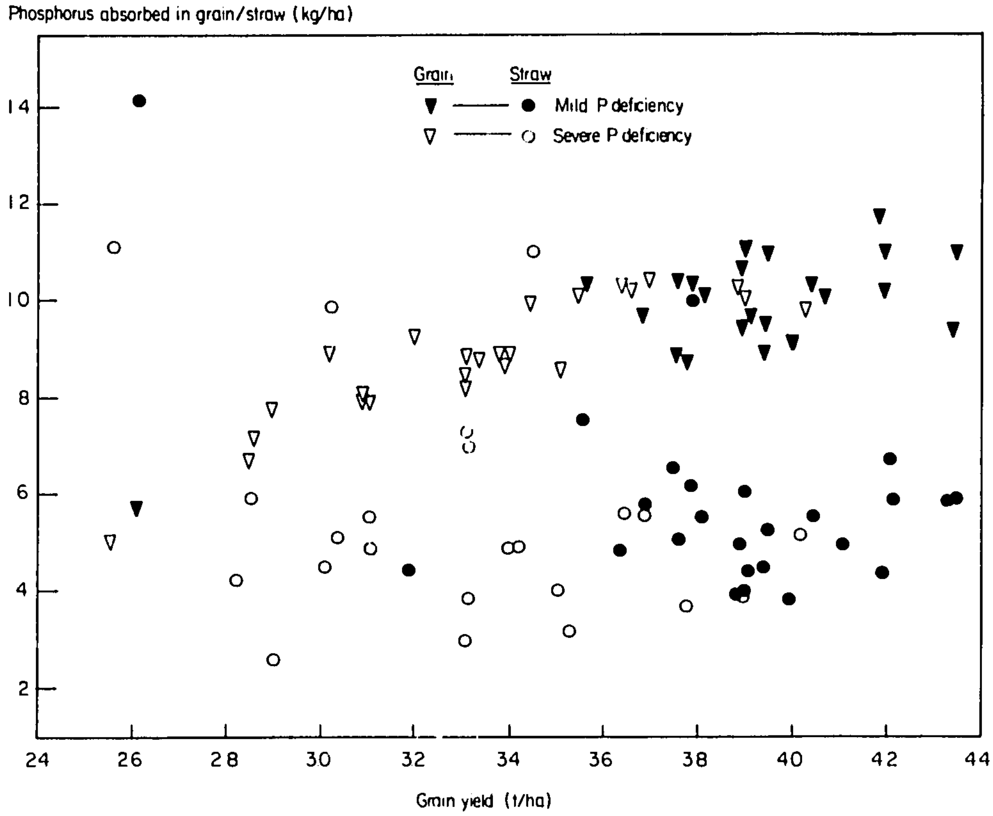

Fig. 4. Phosphorus absorption by 24 genotypes as present in grain and straw in 2 levels of phosphorus deficiency, Pangil, Laguna, 1978 dry season.

the seedlings started dying. In the two succeeding seasons, dipping seedlings in 2 and 4% aqueous zinc oxide suspensions was effective in establishing severe and mild deficiency levels. Spraying zinc sulfate in addition to dipping seedlings in the 4% suspension totally eliminated zinc deficiency symptoms.

During the 1979 dry season, a split-plot design was adopted with stress levels as main plots and entries as subplots. The stress levels were:

- nil (4% ZnO dip + $ZnSO_4$ spray),
- mild (4% ZnO dip), and
- severe (2% ZnO dip).

Zinc deficiency tolerance. Tolerant and sensitive genotypes grown with different degrees of zinc deficiency reacted differentially to mild and severe stresses in terms of grain yield (Tables 4-6). The tolerant genotypes had yield depressions ranging from 0 to 18% under mild deficiency, 10 to 31% under severe deficiency, and 32 to 72% under very severe stress. The sensitive genotypes showed greater depression than tolerant ones at all levels. As the severity of zinc deficiency increased, the yield depression increased in all entries but it was highest in the sensitive ones.

The ratings of zinc deficiency injury taken 3 weeks after transplanting showed a highly significant correlation with grain yield (0.70**).

On the basis of ratings and grain yield over three seasons, six entries -- IR20, IR34, IR38, IR3464-126-1-3, IR4432-103-6, and IR4683-54-2 -- appeared tolerant of zinc deficiency. IR8, IR2307-247-2-2-3, and IR5853-198-1-2 were tolerant of mild deficiency but very sensitive to severe deficiency.

Chemical analyses revealed marked differences in zinc content in the grain and straw of mature plants (1978 dry season) and in the plant at maximum vegetative growth stage (1978 wet season). However, both tolerant and sensitive rices absorbed more zinc from less deficient soils than from more deficient soils. The zinc deficiency levels were created through a zinc oxide seedling dip and results must be interpreted with this background.

Iron deficiency

Eighteen tolerant and 12 sensitive entries were tested for field performance in normal and iron-deficient soil at IRRI (upland) during three 1978-79 seasons. The normal soil was Maahas clay (pH 6.2, O.M. 2.0%, active Fe 1.6%). Iron deficiency was created artificially by liming the soil to pH 7.0-7.5. A randomized complete block design replicated five times

Table 5. Grain yield depressions in tolerant and sensitive rices due to different degrees of zinc deficiency tested over two seasons, Tiaong, Quezon.

Season	Degree of Zn deficiency	Mean grain yield (t/ha)	Yield depression due to zinc deficiency (%)				
			Overall	Tolerant		Sensitive	
				Range	Mean	Range	Mean
1979 dry	Fertile	3.1	-	-	-	-	-
1979 dry	Mild	2.5	9	0-18	9		9
1979 dry	Severe	2.2	29	10-31	19	26-54	41
1978 wet	Severe	2.6	-	-	-	-	-
1978 wet[a]	Very severe	1.0	61	32-72	49	67-87	72

[a]The depression in this case was computed in comparison with yields in severe zinc deficiency levels.

Table 6. Range of varietal tolerance to zinc deficiency as measured by grain yield, Tiaong, Quezon.

Season	Yield depression	Yield under stress (t/ha)			Reaction[a]	Designation
		Mild	Severe	Difference		
1978 wet	Min	3.2	1.3	1.9*	T	IR34
		2.1	1.1	1.0	T	IR4683-54-2
		2.9	1.8	1.1	S	IR4568-225-3-2
	Max	3.7	1.3	2.4**	T	IR20
		3.5	0.8	2.7**	S	IR2797-105-2-2-3
		4.1	0.7	3.4*	S	IR4568-86-1-312
1979 dry[b]	Min	3.3	2.9	0.4	T	IR20
		3.3	2.8	0.5	T	IR34
		3.6	3.4	0.2	T	IR38
		3.4	3.0	0.4	T	IR3464-126-1-3
		3.8	3.8	0	T	IR4683-54-2
	Max	3.5	2.8	0.7	S	IR2797-105-2-2-3
		3.5	2.7	0.6	S	IR9439-20
1979 dry[c]	Min	3.3	2.3	1.0**	T	IR20
		3.3	2.7	0.6*	T	IR34
		3.6	3.0	0.6*	T	IR38
		3.4	2.8	0.6*	T	IR3464-126-1-3
		3.8	3.4	0.4	T	IR4683-54-2
	Max	3.5	1.6	1.9**	S	IR2797-105-2-2-3
		3.5	1.8	1.7**	S	IR8
		3.9	1.6	1.3**	S	IR4707-123-3
1979 dry[d]	Min	2.8	2.7	0.1	T	IR34
		2.9	2.3	0.6*	T	IR20
		3.4	3.0	0.4	T	IR38
		3.0	2.8	0.2	T	IR3464-126-1-3
		3.8	3.4	0.4	T	IR4683-54-2
	Max	2.8	1.6	1.2**	S	IR2797-105-2-2-3
		3.5	1.8	1.7**	S	IR8
		3.3	2.3	1.0**	S	IR4432-52-6-4

[a]T = tolerant, S = sensitive. [b]Comparison between normal and mild stress. [c]Comparison between normal and severe stress. [d]Comparison between severe and mild stress.

on the limed and unlimed soils was used. Standard management practices were adopted, except that 200 kg N/ha and 20 kg Zn/ha were applied to avert deficiencies. The entries were scored twice for iron chlorosis. Data on grain yield were recorded and plant samples at maximum growth stage were analyzed for iron content.

Iron-deficiency tolerance. The statistical analysis of the grain yield data of three seasons (1978 wet and dry and 1979 dry) and that of ratings on iron chlorosis of the three seasons revealed significant varietal differences (Table 7). The overall yield depression due to iron chlorosis was 12% in the 1978 dry season, 34% in the following wet season, and 67% in the 1979 dry season (Table 8). Most entries rated as tolerant at vegetative growth stages showed the least depression whereas those rated as sensitive showed more (Table 9). The significant correlation between ratings on iron chlorosis and actual grain yield (r = 0.273*) indicated an association between rating based on iron chlorosis and yield depression.

In the 1978 dry season, clear chlorotic symptoms appeared only after the second application of lime at the late tillering period. M1-48, IR1754-F5B-22, and IR442-2-5-8 showed inconsistent behavior. Maturity of Kinandang Patong and IR5 was delayed. Hence, the yields of these varieties were not used in the computation. On the basis of ratings and grain yield, six entries -- IR22, IR24, IR36, IR661-1-170, IR1008-4-1, and IR760-4-8-2 -- were found tolerant of iron deficiency. The most sensitive ones were IR5, IR28, IR38, IR712-23-2, IR2153-96-1-5-3, and IR7805-22-3-1.

Iron uptake by tolerant and sensitive rices showed no definite trend in the 1978 dry season. However, the 1978 wet-season data indicated some difference. The genotypes included in this study differed significantly in their ability to absorb iron from normal and iron-deficient soil. Further, absorption of iron in general from iron-deficient soil was low compared to that from normal soil. But in some of the tolerant entries, iron absorption from deficient and normal soil did not differ significantly (Fig. 5).

Iron toxicity

Tests were made with 20-24 tolerant and sensitive genotypes on an iron-toxic soil (Malinao fine sandy loam, pH 3.4, O.M. 2.0%, active Fe 2.2%) at Malinao, Albay, over three 1978-79 seasons. A randomized complete block design replicated five times was used. The entries were scored for iron toxicity injury twice before flowering, adopting the same scale as for other mineral stresses. Plant and grain samples were analyzed for iron content.

Iron-toxicity tolerance. In the 1978 dry season, it was possible to establish the test at two levels of iron toxicity but the yields could not be measured in the higher toxicity plot damaged by animals. However, the plot with a high initial iron content appeared to improve considerably in the succeeding seasons (1978 wet and 1979 dry). Therefore, the data of the two sites were pooled under the low toxicity level and it was not possible to estimate yield depressions attributable to iron toxicity.

The analysis of variance of grain yield and ratings revealed significant differences in varietal performance on the iron-toxic soil. Yield data for two seasons revealed that Mahsuri, IR2797-105-2-2-3, IR2797-125-3-2-2-2, and IR36 consistently produced relatively high yields (2.1-2.8 t/ha), which were much above the experimental mean yields (Table 10). Mahsuri performed best. IR26 and IR4422-143-2-1 were consistently sensitive; the other genotypes behaved inconsistently.

The iron content in plant samples drawn at maximum tillering stage averaged 296 ppm for the severely toxic plots compared with 173 ppm for the mild-stress plots. However, in the straw samples harvested at maturity this difference was 35% less. The iron content in grain tended to be higher in tolerant (185-290 ppm) than in sensitive (144-218 ppm) genotypes.

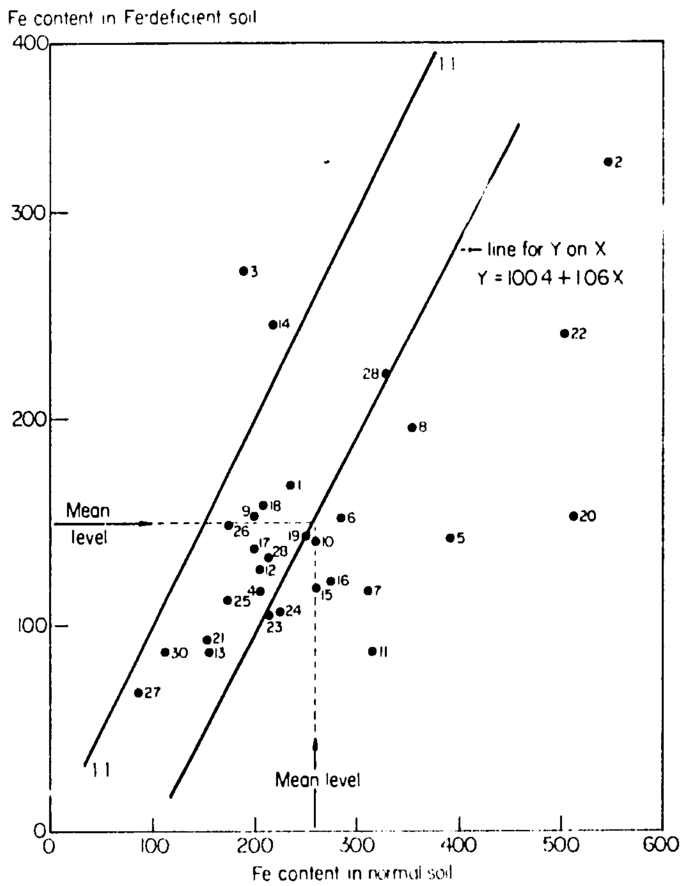

Fig. 5. Iron content in 30 genotypes on iron-deficient (x) and normal (y) soil, as present in plant samples drawn at maximum growth stage, International Rice Research Institute, 1978 wet season.

VARIETAL TOLERANCE AND YIELD STABILITY

Research on varietal tolerance for soil mineral stresses, at IRRI and elsewhere, has been reviewed by Ponnamperuma and Castro (1972) and Ikehashi and Ponnamperuma (1978). The contribution of varietal tolerance to yield in farmers' fields has been studied (IRRI 1973, 1979; Alluri and Buddenhagen 1977; Vose 1963; Gunawardena and Wijeratne 1978).

The contribution of varietal tolerance to grain yield stability is substantial, but other aspects must be considered before embarking on any project to breed varieties for problem soils. They include:

- need for varietal tolerance,
- range of varietal tolerance,
- yield differences near the level of economic production for tolerant and nontolerant rices,
- stability of differential yield over locations and seasons,
- feasibility of identifying tolerant rices without high inputs,
- impact of tolerant rices on soil nutritional status and fertilizer use, and
- tolerance vs amendments.

Need for varietal tolerance

In densely populated South and Southeast Asia, where both food and arable land are scarce, more than 100 million ha climatically and physiographically suited to rice are idle largely because of soil toxicities. There are also millions of hectares of current rice lands where iron toxicity and phosphorus and zinc deficiencies limit rice

Table 7. Performance of 20 tolerant and sensitive genotypes on iron-deficient soils in 3 seasons, IRRI upland.

Genotype	Grain yield (t/ha) 1978 dry season	Grain yield (t/ha) 1978 wet season	Grain yield (t/ha) 1979 dry season
IR5	0.2 k	1.2 bcdef	–
IR22	1.2 defgh	1.1 bcdef	0.28 cdef
IR24	1.2 defgh	1.2 bcdef	0.52 bc
IR36	1.9 abc	1.3 abcdef	0.66 ab
IR28	–	0.6 ghi	0.21 def
IR34	0.8 hij	1.3 abcd	0.02 ef
IR38	0.5 jk	0.9 cdefghi	0.17 def
IR661-1-170	1.4 cdefg	1.0 bcdefg	0.52 bc
IR1008-14-1	1.1 fgh	0.8 defghi	0.41 bcd
IR6115-1-1-1	0.8 hij	1.0 cdefgh	0.54 bc
IR7760-4-8-2	1.5 bcdef	1.1 bcdef	0.92 a
IET 1444	1.9 ab	1.1 bcdef	0.52 bc
IR3880-29	2.0 ab	0.9 cdefghi	0.54 bc
IR4422-164-3-6	1.2 defgh	0.9 cdefghi	0.00 f
IR7805-22-3-1	1.0 ghij	1.3 ab	0.11 ef
Cauvery	2.0 ab	0.8 defghi	0.20 de.
B9C-MD-3-3	1.6 bcdef	1.0 bcdefg	0.22 def
IR2153-96-1-5-3	0.6 ij	0.8 defghi	0.16 def
IR712-23-2	1.5 bcdef	0.9 cdefghi	0.34 cde
IR4417-177-1-4-1	1.0 ghi	0.5 i	0.32 cdef
F test	**	**	**

**Significant at the 1% level. Any two means in the same column followed by the same letter are not significantly different at the 5% level.

Table 8. Performance of tolerant and sensitive genotypes on iron-deficient soil in three seasons, IRRI upland.

Season	Mean yield (t/ha)	Yield depression due to iron deficiency (%) Overall	Tolerant Range	Tolerant Mean	Sensitive Range	Sensitive Mean
1978 dry	1.4	12	0-19	3	9-48	23
1978 wet	1.5	34	6-34	18	22-58	42
1979 dry	1.0	67	18-74	58	51-86	78

Table 9. Range of varietal tolerance for iron deficiency as measured by grain yield.

Season	Yield depression	Yield under stress (t/ha) Normal	Fe-deficient	Difference	Reaction	Designation
1978 dry	Min	1.72	1.25	0.47	T/S	IR1561-228-3-3
		2.25	2.20	0.05	T/S	IR4707-202-2-2
		1.42	1.48	0	T	M1-48
		1.88	1.96	0	T	Cauvery
		1.85	1.40	0.45*	T/S	IR442-2-58
	Max	2.09	1.48	0.61	T	IR7760-4-8-2
		3.18	1.91	1.27*	T	IET 1444
1978 wet	Min	1.69	1.25	0.44	T	IR36
		1.45	1.15	0.30	T	IR24
		1.66	1.29	0.37	S	IR34
		1.73	1.62	0.11	T/S	IR442-2-58
	Max	1.70	0.59	1.11**	T/S	IR1561-228-3-3
		2.42	1.18	1.24**	S	IR5
		1.74	0.90	0.84**	S	IR38
		2.00	1.08	0.92**	T/S	IET 1444
		1.74	0.94	0.80**	S	IR4422-164-3-6
1979 dry	Min	0.80	0.66	0.14	T	IR36
		1.83	0.92	0.91	T	IR7760-4-8-2
		1.29	0.52	0.77	T	IR24
		0.96	0.28	0.68	T	IR22
	Max	1.33	0.00	1.33	S	IR4422-164-3-6
		0.94	0.16	0.78	S	IR2153-96-1-5-3
		0.78	0.11	0.67	S	IR7805-22-3-1
		1.20	0.17	1.03	S	IR38

T = tolerant, S = sensitive (based on overall data). *Significant at the 5% level, ** significant at the 1% level. Note: Genotypes with yield level less than that of the grand mean of the experiment were ignored as they are basically low yielding and might not give a correct measure of the reaction to the stress under study.

Table 10. Performance of 20 tolerant and sensitive genotypes on iron-toxic soil at Malinao, Bicol, in 3 seasons.

Genotype	Grain yield (t/ha) 1978 dry season	1978 wet season[a]	1979 dry season	Mean
IR20	-	1.4	2.9 defg	2.2
IR32	-	1.1	3.4 bc	2.3
IR36	1.6 abcde	1.7	3.0 cdef	2.1
IR38	-	1.1	3.1 cde	2.2
IR42	1.8 abcde	1.1	3.8 ab	2.2
IR2031-124-2-3-2	-	0.8	2.2 h	1.5
IR2797-105-2-2-3	2.6 ab	1.4	3.0 cdef	2.3
IR2797-125-3-2-2-2	2.2 abcd	1.3	3.4 bc	2.3
IR3464-217-1-3	1.4 bcde	0.7	2.7 efg	1.6
IR3839-1	-	1.5	2.4 gh	2.0
IR4227-28-3	1.6 abcde	0.7	3.4 bcd	1.9
IR9129-136-2	-	1.5	2.7 efg	2.1
IR9209-26-2-3	1.3 hij	1.3	2.6 efg	1.7
Mahsuri	-	1.2	4.0 a	2.6
IR4422-143-2-1	2.1 abcd	0.7	2.7 efg	1.8
IR4427-51-6-3	1.7 abcde	1.2	2.7 efg	1.9
IR4707-123-3	0.8 de	1.7	3.0 cdef	1.8
IR26	1.0 de	1.2	3.0 cdef	1.7
IR5105-80-3-3-2	1.6 abcde	1.6	2.6 fgh	1.9
IR5853-162-1-2	1.5 bcde	1.9	2.6 fg	2.0
F test	*	-	**	-
LSD (0.5)	1.3	-	0.4	-

[a]Av of two toxicity levels. * Significant at the 5% level, ** significant at the 1% level. In a column any two means followed by the same letter are not significantly different at the 5% level.

yields (Ponnamperuma 1978). These lands can be made productive by soil amendments. Varieties with built-in tolerance for soil toxicities and nutrient deficiencies will enable small farmers to obtain reasonable, stable yields with management inputs that they can afford.

Range of varietal tolerance

Our results confirm the existence of varietal tolerance and provide a measure of its range for phosphorus, zinc, and iron deficiencies, as well as for iron toxicity.

The failure of all tolerant and sensitive rices under unamended conditions of acute phosphorus deficiency at Narra, Palawan, and zinc deficiencies at Tiaong, Quezon, and crop failure in a severely phosphorus-deficient soil in Sri Lanka (Gunawardena 1979) indicate that varietal tolerance alone is of no advantage where there are severe phosphorus and zinc deficiencies. But the existence of a distinct and wide range of varietal tolerance for the four mineral stresses of this study and the fact that a large proportion of rice soils probably produce only mild stresses amply justify exploiting varietal tolerance for stabilizing yields.

The genotypes, which were carefully chosen for their comparable yield potential in replicated yield trials, performed as expected on the basis of ratings taken in *mass screening* tests (IRRI unpublished data for 1975, 1976, 1977). The sensitive genotypes suffered severe yield losses even under mild stress, the tolerant ones resisted the yield decline until the stress became severe.

Our results are consistent with the earlier reports of tolerance of IR34 for phosphorus deficiency (Ponnamperuma 1977, IRRI 1978), of Mahsuri, IR2797-105-2-2-3, and IR2797-125-3-2-2-2 for iron toxicity (Virmani 1976, IRRI 1979), of IR36 for iron deficiency (Ikehashi and Ponnamperuma 1978, Gines et al 1977), and of IR20 and IR34 for zinc deficiency (IRRI 1977).

The contribution of varietal tolerance to yield of rice grown under unameliorated soil mineral stresses appears to range from 0.5 to 0.8 t/ha for phosphorus deficiency, 0.5 to 1.5 t/ha for zinc deficiency, and 0.2 to 0.7 t/ha for iron deficiency at yield levels ranging from 2.5 to 4.0 t/ha. The ranges for iron toxicity, however, cannot be given because of lack of yield data under normal soil conditions.

Yield difference near the level of economic production for tolerant and sensitive rices

Rice varieties exhibit a range of tolerance to a given level of a soil mineral stress but because no known variety can tolerate acute deficiency of an essential element, the use of varietal tolerance is limited to relatively less severe stresses. Nevertheless, adoption of tolerant varieties in vast areas of adverse soils, however mild their effect, should be reflected by significant increases in production. Therefore, for successful utilization of varietal tolerance it is important to consider the threshold of economic production for any given stress.

There is a definite range of any type of soil mineral stress under which tolerant varieties will grow normally and produce economic yields. Under the same conditions, sensitive varieties will fail to reach an economic production level. For instance, at the two levels of phosphorus deficiency that existed at Pangil, Laguna, during the 1978 dry and wet seasons, tolerant lines maintained yield levels at higher stresses that were on par with those of sensitive lines under very mild stresses. The performance of tolerant rices such as IR34 and BR51-91-6, with grain yields higher than 4 t/ha in the dry season and 2.5 t/ha in the wet season, presents a sharp contrast to that of sensitive lines such as IR4427-51-6-3 and IR4707-123-3A, with grain yields less than 3 t/ha in the dry season and 2 t/ha in the wet season. The depression of grain yield of nontolerant varieties is much greater than that of tolerant varieties. As a result, tolerant varieties probably maintain economic levels of production (2.6-4.3 t/ha) under mineral stresses common in rice lands, whereas sensitive varieties become uneconomic. More agro-economic studies are needed to determine the yield levels profitable to farmers with tolerant varieties. This will depend on the nature of the adverse soil, the degree of tolerance possessed by the variety, the cropping pattern, the cost of inputs, and the price of rice.

Stability of tolerant variety yield over seasons and locations

The yield advantage from tolerant varieties does not mean much to a farmer if the varieties do not possess the desired level of adaptability. The field performance of tolerant and sensitive rices on different adverse soils over three seasons has provided some indication of the stability of performance of the common entries.

A variety x season interaction analysis of the two dry-season and one wet-season experiments on the phosphorus-deficient soil at Pangil revealed significant differences due to both varieties and seasons (Table 11). Five lines were more depressed in grain yield in the dry season and two in the wet season. However, it is interesting that the two proven phosphorus-deficiency tolerant genotypes, IR34 and BR51-91-6, were highly consistent in their yield performance.

Fifteen lines tested on a zinc-deficient soil at Tiaong, Quezon, showed the same trend. Variances due to varieties and seasons were significant. The tolerant entries IR20, IR34, and IR4683-54-2 exhibited moderate stability.

Two seasons' yield data and ratings for iron deficiency injury of IR22, IR24, IR36, IR442-2-58, and IR1008-14-1 showed consistency. An adaptability analysis of these data of Finlay and Wilkinson's (1963) model by Mahadevappa et al (1979) revealed differential stability of varieties to iron-deficient and normal soil conditions. However, it must be noted that the variance due to seasons was statistically significant whereas that due to varieties was not (Table 9). The inconsistency of the varietal differences may be because the iron deficiency stress was not well established initially, but became clear only after the second liming.

The differential reactions to mineral stresses seemed consistent over seasons for tolerant rices.

Yield stability of IR34 under mild phosphorus deficiency and its tolerance to zinc deficiency may indicate that the stability of yield, or the adaptability to wide range of environmental stresses is partly explained by the varieties' tolerance for mineral stresses. In other words, the continued efforts by breeders to choose the cultivars with wide adaptability may have also enhanced the varietal tolerance for mineral stresses. Varietal adaptability may be an effective measure of suitability of varieties for cultivation on suboptimal soils. The report of Mahadevappa and Ikehashi (1979) that tolerance for different mineral stresses is independently controlled signifies that tests under different soil stresses are of interest, at least to reject lines that may be sensitive to mineral stress.

Feasibility of identifying tolerant varieties

Our data revealed that varietal tolerance was consistent over the different seasons and could increase yield significantly under marginal soil fertility. However, if identifying tolerant varieties takes time and resources beyond the reach of an ordinary varietal testing program, the benefit from such a tolerant variety may not be realized in practice. The soil chemist's approach to this has been the development of a series of mass screening methods (Ponnamperuma 1977). Such screening methods are concerned primarily with tolerance at the seedling stage. The steps required after mass screening need further consideration with regard to their value in predicting yield.

Our studies allowed us to observe the relevance of mass screening data to differential yields. At the seedling stage the correlation between ratings in the greenhouse and in the field showed very close agreement. However, the correlation between the rating of seedlings for adverse-soil injury and the actual grain yield realized on the same adverse soil revealed very close association under zinc- and iron-deficiency conditions but no significant association under phosphorus deficiency and iron-toxicity conditions. The discrepancy between the mass screening score at the seedling stage and the yield tests for phosphorus deficiency and iron toxicity probably arises from the longer growth duration of some entries, which enabled them to recover from the initial setback. As revealed by our data (Figs. 1 and 2) the yield depression due to phosphorus deficiency is negatively correlated to growth duration. Apparently, this is not detected in the mass screening tests. Thus, the rating in the greenhouse test seems to indicate yield stability to a certain extent, whereas the field test determines the actual tolerance. But the field test is time-consuming and expensive. Because the object of any mass screening program is to accommodate a large number of materials available for screening in the initial stages, some shortcomings in the mass screening test are acceptable.

Mass screening is an effective primary tool for choosing tolerant genotypes but additional field tests are necessary to select consistently stable lines. The best performer in such a test in a marginal soil would show its relative tolerance over seasons. Therefore, it is advisable to implement a system of preliminary mass screening followed by field tests to achieve reproducible results.

Impact of tolerant rices on soil nutritional status and fertilizer use

Two common objections to the use of varieties tolerant of mineral nutrient deficiencies are that the practice will deplete the soil of nutrients and that it will discourage the use of fertilizers.

The first objection is valid if the soil has a low total content of the element, e.g. sandy soils. But most soils where phosphorus, zinc, and iron deficiencies occur contain large amounts of the elements. The problem is one on availability. For example, a soil may contain 2,000 kg of total phosphorus/ha in the plowed layer but nearly all of it

Table 11. Analyses of variance in respect to three performance tests conducted on adverse soils during the 1978 dry and wet seasons and 1979 dry season.

Test	Entries common to 3 seasons (no.)	Variance	
		Variety	Season
Phosphorus-deficient soil at Pangil, Laguna	16	0.42**	7.59**
Zinc-deficient soil at Tiaong, Quezon	10	0.59**	2.74**
Iron-deficient soil, IRRI	29	0.18 ns	1.61**
Iron-toxic soil, Malinao, Albay	11	0.25**	8.96**

**Significant at the 1% level, ns = not significant.

may be in highly unavailable forms. Such soils also strongly fix phosphate fertilizers. Varieties that can absorb and metabolize both native and added phosphate may enable small farmers with little or no phosphate fertilizer to grow as many as 50 crops of rice at 4-5 t/ha, each removing about 20 kg P/ha from such soils.

Long-term experiments at experiment stations have shown that both yield and soil test phosphorus in unfertilized soil do not change appreciably over decades (Kawaguchi and Kyuma 1977). Most rice soils contain 100-200 kg of total zinc/ha but the available zinc content may be as low as 0.04 ppm. Because a single crop removes only 0.5 kg/ha it will be years before the soil can be even half-depleted.

The use of fertilizers where they are not required must be discouraged. First, because fertilizers will become scarce and expensive due to a growing energy shortage. Second, because the small farmer can divert his limited cash resources to the purchase of other materials needed for good husbandry. Third, where mineral stresses are not severe, farmers using modern, pest-tolerant varieties with resistance to mineral stresses and good husbandry can give 4-5 t/ha with small applications of fertilizer. Fourth, the foreign exchange saved can be substantial. The Philippines, for example, with a million hectares of zinc-deficient rice lands, could save US$2 million a year on zinc imports by using tolerant varieties.

Varietal tolerance vs soil amendments

Ideally, varietal tolerance should complement, not replace, soil amendments. But in practice, there are situations where the amendments may be too costly or impracticable and varietal tolerance may be the only solution. For example, iron toxicity, common on strongly acid wetland rice soils, can be corrected by liming or drainage. But liming is often uneconomic; draining flooded rice fields in the rainy season is difficult. Traditional varieties in iron-toxic areas have marked tolerance. By genetically transferring this tolerance to modern rices with pest resistance, varieties that will outyield the traditional ones on iron-toxic soils can be produced.

In the case of phosphorus and zinc deficiency, tolerance will enable varieties to yield well on marginal land without adding these elements and reduce the amount needed to obtain good yields on strongly deficient soils.

REFERENCES CITED

Alluri, K., and I. W. Buddenhagen. 1977. Evaluation of rice cultivars for their response to limiting nutrients. Int. Rice Res. Newsl. 2:3.

Finlay, K. W., and G. N. Wilkinson. 1963. The analysis of plant adaptation in a plant breeding program. Aust. J. Agric. Res. 14:742-754.

Gines, H., L. Lavapiez, R. L. Tinsley, S. N. Lohani, H. G. Zandstra, R. Toralba, and J. Manzon. 1977. Evaluation of alternate cropping patterns in Pangasinan. CY 1976-77. Paper presented at a Saturday seminar, 25 June 1977, International Rice Research Institute, Los Baños, Laguna, Philippines.

Gunawardena, I. 1979. Field screening for tolerance to iron toxicity and phosphorus deficiency. Paper presented at the International Rice Research Conference, 6-20 April 1979, International Rice Research Institute, Los Baños, Laguna, Philippines.

Gunawardena, S. D. I. E., and H. M. S. Wijeratne. 1978. Screening of rice under phosphorus-deficient soil in Sri Lanka. Paper presented at the International Rice Research Conference, 17-21 April 1978, International Rice Research Institute, Los Baños, Laguna, Philippines. (mimeo.)

Howeler, R. H., and L. F. Cadavid. 1976. Screening of rice cultivars for tolerance to Al toxicity in nutrient solutions as compared with a field screening method. Agron. J. 68:551-555.

Ikehashi, H., and F. N. Ponnamperuma. 1978. Varietal tolerance of rice for adverse soils. Pages 801-823 *in* International Rice Research Institute. Soils and rice. Los Baños, Philippines.

IRRI (International Rice Research Institute). 1970. Annual report 1969. Los Baños, Philippines. 266 p.

IRRI (International Rice Research Institute). 1973. Annual report for 1972. Los Baños, Philippines. 246 p.

IRRI (International Rice Research Institute). 1977. Annual report for 1976. Los Baños, Philippines. 418 p.

IRRI (International Rice Research Institute). 1978. Annual report for 1977. Los Baños, Philippines. 548 p.

IRRI (International Rice Research Institute). 1979. Annual report for 1978. Los Baños, Philippines. (in press)

Kawaguchi, K., and K. Kyuma. 1977. Paddy soils in tropical Asia. University of Hawaii Press, Honolulu. 258 p.

Koyama, T., C. Chammek, and P. Snitwongse. 1973. Varietal difference of Thai rice in the resistance to phosphorus deficiency. Tech. Bull. 4, Trop. Agric. Res. Cent. Jpn. 32 p.

Mahadevappa, M., H. Ikehashi, and F. N. Ponnamperuma. 1979. Testing for yield stability in problem soils. Paper presented at the International Rice Research Conference, 16-20 April 1979, International Rice Research Institute, Los Baños, Laguna, Philippines.

Mahadevappa, M., and H. Ikehashi. 1979. Screening rice genotypes against alkalinity and other related problems. Sabrao J. (in press)

Ponnamperuma, F. N. 1977. Screening rice for tolerance to mineral stresses. IRRI Res. Pap. Ser. 6. 21 p.

Ponnamperuma, F. N. 1978. Toxic rice soils. *In* Plant nutrition 1978. Vol. 2. Proceedings, 8th international colloquium, plant analysis and fertilizer problems, Auckland, New Zealand, August 28-September 1, 1978.

Ponnamperuma, F. N., and R. U. Castro. 1972. Varietal differences in resistance to adverse soil conditions. Pages 677-684 *in* International Rice Research Institute. Rice breeding. Los Baños, Philippines.

Virmani, S. S. 1976. Breeding rice for tolerance to iron toxicity. Paper presented at the WARDA Varietal Improvement Seminar, Bouake, Ivory Coast, September 13-17, 1976.

Vose, P. B. 1963. Varietal differences in plant nutrition. Herb. Abstr. 33:1-13.

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