RICE BREEDING FOR TOLERANCE TO PROBLEM SOILS

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ABSTRACT

Increasing population pressure, specially in Asia where 90% of global rice is produced and consumed, could neccessitate an extension of the cultivation of high-yielding varieties to problem soils, presently unsuitable because of stresses caused by an excess or deficiency of certain minerals. These soils have been identified and described, together with the different screening procedures and breeding methods adopted at IRRI to develop acceptably tolerant varieties of high production potential. Future strategies are also discussed.

WORLD RICE EXTENTS AND PRODUCTION

The world's cultivated extent to rice approximates 144 m ha and present world production of rice approximates 367 m tons (Table 1). Total production of rice has increased steadily in recent years but per capita production has remained fairly constant (Fig. 1). The reason for this is the population increase which is expected to reach the 6 billion mark at the turn of this century. Food shortages, particularly of cereals, are predicted for the present decade and none questions the need to produce more food. Among the cereals, rice is the most important as this continues to be the staple food of more than 70% of the world's population. Today, nearly 90% of rice produced and consumed globally is in Asia and this position is not expected to change in the foreseable future as population density continues to increase in this region.

If increasing demands for rice are to be met, there are two obvious courses of action. The first is to increase the area cultivated to rice; the second is to increase production per unit of arable land. New lands for rice are still available particularly in tropical South America and in Africa but these regions lack the infrastructure for rice cultivation and, even if they do, are specially remote from the Asian region where the demand will be highest. Thus Asia has no alternative but to increase rice production and this will have to come from increased yields on lands already growing rice and by bringing under command any lands where climate, physiography and hydrology permit rice culture but which remain uncultivated today. The most serious limitation in these attempts will be soil problems which do not permit the delivery of the full potential of most modern rice varieties when grown in these soils.

In the tropics and sub-tropics nearly 40 m ha are unsuited for modern rice varieties because of soil problems and if potential rice lands are also considered Asia alone has over 80 m ha of rice lands with problem soils where rice cannot be profitably grown due to stresses caused either by excesses or deficiencies of minerals (Table 2). Among these the most serious for rice are stresses due to salinity, alkalinity, iron-toxicity, phosphorus deficiency and zinc deficiency in lowland culture and in upland culture, iron deficiency on all soils and aluminium and manganese toxicity on strongly acid soils.

CHARACTERISTICS OF PROBLEM SOILS

Saline Soils. Asia alone has more than 50 m ha of saline soils but in the tropics and sub-tropics current and potential rice land affected by salinity is estimated around 150 m ha. A saline soil is characterized by having excess salts. Sodium constitutes the predominant cation in these salts while calcium and magnesium together generally constitute less than 50% of the total soluble cations in the exchange complex. The anions are predominantly chlorides and sulfates. The pH of the saturated soil paste is lower than 8.5 and electrical conductivity of the saturated soil extract, which is a measure of the salt content, is more than 4 m mhos/cm at 25°C. The exchangeable sodium percentage is less than 15.

There are two kinds of saline soils: arid and humid. Arid saline soils are found in regions where drainage is poor and evaporation exceeds precipitation. The source of salt is weathered rock and irrigation water. Salts accumulate in the surface soil. Humid saline soils are the alluvial soils of deltas, estuaries and low-lying coastal areas subject to inundation by sea water. There are more than 9 million ha of arid saline soils in India and Pakistan alone and more than 23 million ha of humid saline soils in the tropics. Climatically and physiographically these soils are suited to rice but the vast bulk of the area remains uncultivated.

Saline soils vary widely in their physical, chemical and hydrological properties. The variables include nature and content of salts, lateral and vertical distribution of salt, soil pH, nature and content of clay, organic matter content, nutrients, water regime, relief and temperature. The salt content of saline soils varies spatially, seasonally and with the water regime. Soil pH may vary from 2.5 to 8.5; clay composition may vary from montmorillenite and illite to hydrous oxides of iron and aluminum; organic matter ranges from 1 to 50% and nutrient content can be very low to moderately high.

Alkali or Sodic Soils. In these soils plant growth is impaired by the presence of sodium carbonate and bicarbonate. The pH of air dried soil suspended in water exceeds 8.5, the exchangeable sodium percentage is >15 and electrical conductivity is less than 4 mhos/cm at 25 °C. Soluble Ca and Mg are precipitated in these soils and the exchange complex is dominated by exchangeable Na. The high soil pH affects transformation and availability of several essential nutrients.

Saline/Sodic Soils. Both salinity and alkalinity occur together in these soils. The soil has a high ESP and high electrical conductivity. Poor plant growth is not due mainly to osmotic effects resulting in lowered availability of water but also to lack of Ca, toxicity of carbonate and high pH. The high soil pH affects transformation and availability of several essential nutrients.

Acid Sulfate Soils. There are two types: potential and actual. Potential acid sulfate soils occur in tidal swamps, They are poorly drained, have high levels of pyrite, low levels of bases and produce strongly acid sulfate soils when pyrite oxidizes to sulfuric acid after drainage. Otherwise pH is slightly acid to neutral. In young acid sulfate soils the adverse effects on plants are due to excess Al and Fe and low phosphorus. Al toxicity is acute when rice is started as a dry seeded crop to be followed by deep water in later growth.

Millions of hectares of low-lying coastal land in the tropics are low in productivity or unsuited for agriculture because the soils are acid sulfate or potentially acid sulfate.

Acid sulfate soils have a pH in the range 3.5 to 4 within the 50 cm depth of the soil profile caused by oxidation of iron pyrite. Despite the high acidity and associated adverse effects on plant growth these soils are topographically and hydrologically suitable for wetland rice. They are often well supplied with plant nutrients from appreciable amounts of 2:1 clay minerals and organic matter: pH increases on flooding from soil reduction which is favourable for rice.

Most of the acid sulfate soils are found in Indonesia, Thailand and Vietnam. Other areas are India, Bangladesh, Burma, West Africa, East Africa, Australia and tropical South America.

Iron pyrite forms 2-10% of the soil mass. Pyrite formation involves bacterial reduction of SO_4 to sulfide, partial oxidation of sulfide to elemental sulfur and interaction of ferrous and ferric iron with sulphide and elemental sulfur. The essential ingredients for pyrite formation are sulfate, iron, metabolizable organic matter, sulfate reducing bacteria, and anaerobiosis alternated with limited oxidation. These conditions are satisfied in mangrove swamps where tidal influence effects temporary aeration.

The following changes occur on flooding acid sulfate soils:

* pH increases slowly (compared to normal soils) and rarely exceeds 6.
* The decrease in redox potential is slow.
* Dissolved Fe + + increases to peak values between several hundred to several thousand ppm. Except when pH is increased to near neutral by liming, Fe + + shows little tendency to decrease to non-toxic levels (<400 ppm) as in most normal soils.
* Addition of fertilizer (except NO_3) enhances formation of Fe + +; leaching, liming and addition of MnO_2 reduce Fe + + levels.
* Dissolved Al decreases as pH rises, regardless of whether it is due to soil reduction, liming or leaching.

Iron Toxic Soils. These are strongly acid ultisols, oxisols of acid sulfate soils. Iron toxicity in these soils is often associated with other stresses such as salinity, phosphorus deficiency and low base status. Iron toxic soils are found in Sri Lanka, India, Malaysia, Indonesia, Philippines, Senegal, Sierra Leone, Liberia, Nigeria and Colombia.

Rice grown on iron toxic soils suffers from the nutritional disease called bronzing.

Phosphorus–deficient Soils. These soils are low in available phosphorus and also fix large amounts of added phosphate fertilizer. Phosphorus deficient soils are ultisols, oxisols, acid sulfate soils, ando soils, and some vertisols.

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

Zinc-deficient Soils. Zn-deficient soils generally contain less than 1–1.5 ppm available zinc. Zn deficiency is a limiting factor on calcareous soils and on continuously wet soils, regardless of pH. Thus most water-logged soils may be Zn-deficient.

Aerobic Soils. Drought and weed competition are well recognised yield limiting factors in dryland soils, but iron deficiency (regardless of pH) and Mn and Al toxicities on acid soils are important mineral stresses limiting rice yields on these soils.

Mineral Stresses in Problem Soils. Stresses caused by excesses or deficiencies of minerals in problem soils are listed in Table 3. In many instances there can be more than one mineral stress in a problem soil. Additionally there are other growth limiting factors associated with problem soils as shown in tables 4–7.

Reclamation of Problem Soils. In general reclamation of problem soils is expensive. Some of the recommended measures are listed in table 8.

VARIETAL IMPROVEMENT

It is clear from the foregoing that stresses in problem soils include salinity. alkalinity, strong acidity, iron toxicity, Histosol problems, zinc deficiency, phosphorus deficiency, and (in aerobic soils) iron deficiency and manganese and aluminum toxicities. These stresses can be alleviated to some extent by chemical amendments and management practices, particularly those involving water control, but these methods are prohibitive in cost. Thus, instead of attempting to alter soils to suit plant growth an alternative would be to breed plants to overcome these soil problems. In some instances where stress levels are high a combination of both approaches may prove useful.

Breeding for tolerance to problem soils is not new. For example in India many of the breeding programs in different states have had salinity tolerance as a specified objective. A number of varietal releases have been made and these still serve as useful donors for salinity tolerance. Varieties tolerant to salinity identified in India are shown in table 9. However, it is only recently that explanations of varietal tolerance to a wide range of adverse soils has been conceived and implemented. In these effors IRRI has played a key role. There are national rice programs, no doubt, that breed for tolerance to one or a few adverse soil conditions but it is only at IRRI that a concerted effort is being made to generate breeding materials with tolerance to the entire range of adverse soil conditions.

Breeding for adverse soils tolerance involves the following:

1. The use of known sources of tolerance in hybridization with the objective of transferring tolerance to high yielding plant types with acceptable levels of pest and disease resistance and preferred quality characteristics.

2. To attempt increasing the levels of tolerance by resorting to different approaches such as:

a. Accumulation of tolerance genes from diverse sources.

b. Exploitation of tolerance from wild and other cultivated species of rice.

c. Use of mutation induction with chemical and physical mutagens.

d. Use of cell and tissue methods.

An *a priori* requirement in breeding for adverse soils tolerance is evidently the availability of reliable, rapid and convenient methods of screening varieties or segregating populations for tolerance to different soil stresses. Greenhouse and field screening methods are now available for the different soil stresses as described below.

Screening Methods

Suitable greenhouse and field screening methods have been developed at IRRI and elsewhere for most of the stresses encountered in problems soils. The methods described are those in use at IRRI.

Salinity and Alkalinity

Greenhouse Screening:

Steps	*Key points*
1 Prepare soil and ingredients	* Air-dry and crush soil * Grind rice straw * Dry and grind *Glyricidia sepium*
2 Mix soil	* Mix 5 kg of crushed soil with: — 1.6 g ammonium sulfate — 0.75 g concentrated superphosphate — 0.25 muriate of potash — 3.8 g ground straw — 0.75 g *Glyricidia sepium* * Place soil in plastic trays. The wet soil in the trays can be used continuously if adjusted with sodium cloride after every third test. * Add 4 liters of a 0.5% solution of common salt (Na_2CO_3 for alkalinity) and thoroughly mix the soil. This level of salt solution gives an EC of 8–10 mmho/cm at 25°C.
3 Prepare seedlings	* Prepare culture solution — 40 ppm each of nitrogen, potassium, calcium, and magnesium — 10 ppm of phosphorus — 0.5 ppm of manganese — 0.55 ppm of molybdenum — 0.2 ppm boron — 0.01 ppm each of zinc and copper — 5 ppm of iron as Fe EDTA — adjust to pH of 6.0 * Two weeks before transplanting soak 20 seeds of each variety in 1/10 th strength culture solution. * Three days later replace with 1/4 strength solution * Six days later replace with full strength solution

4 Transplant and maintain	* Select 6 healthy seedlings and transplant in tray 2 days after the trays are prepared * Use one tray of resistant check (Pokkali) and one of susceptible check (MI 48 for salinity and Palman 579 for alkalinity) for every 20 trays.
5 Evaluate	* At 4 weeks after transplanting (3 weeks for alkalinity) score the plants according to the Standard Evaluation System for Rice. The 4-week score correlates highly with that of plants grown to maturity.

Field Screening:

1 Prepare field	* Plow, puddle, fertilize, and thoroughly level the field. Add some zinc to prevent zinc deficiency in the alkaline screening plots
2 Prepare seedlings	* Sow pregerminated seed in the seedbed in best available soil * Add optimum amount of fertilizer to get good growth
3 Transplant	* Select uniform seedlings at 3 weeks for inland areas and 4–6 weeks for coastal saline areas * Transplant I seedling/hill at 25x25 cm * Because of the spotty occurrence of salinity and alkalinity in fields replications are advisable
4 Manage nursery	* Separate experimental lots from water inlets with border strips of 3–4 rows at right angles to the water flow. * Maintain several centimeters of water on the plots at all times
5 Score	* Score only those plots where the susceptible check indicates the presence of salt * At scoring time measure the electrical conductivity (EC) of the soil and supernatant water of a convenient number of saline spots as indicated by plant stress * At scoring time take soil samples at a convenient number of saline spots and measure pH of the dried soil. Also take EC of the saturation extract if not done in the field. * Score rest of plants and resistant and susceptible check by the Standard Evaluation System for Rice

Iron Toxicity

Greenhouse Screening:

Screening for tolerance for iron toxicity involves growing rice in a submerged acid soil that builds up and maintains a high concentration of ferrous iron in the soil solution. The soil used is an acid sulfate soil from Malinao with characteristics as shown in table 10.

This soil is mixed with 50 ppm N, 25 ppm P, and 40 ppm K and transferred to 3 litre pots. The soil is submerged to a depth of 1 cm and four 2-week old seedlings raised in solution culture are transplanted. The symptoms are scored 4 weeks later on a 1–9 scale (Table 11).

Field Screening:

This is done in Malinao, Albay on an acid sulfate soil. Two types of tests are conducted : mass screening tests and yield tests.

a. Mass Screening:

This is a preliminary step in selecting rices and a large number are accommodated. The field is plowed, harrowed, and levelled. Fertilizers N, P, and K are braodcast just before transplanting. Three week old seedlings, raised on a "normal" wet seedbed, of each entry are transplanted in three 3 m rows at 20x20 cm spacing, with 2 seedlings per hill. Standard insect and weed control measures are adopted. A resistant (R) check is randomized along with the entries. A susceptible check is planted at regular intervals to monitor Fe toxicity.

The experimental design is an RCB with S–checks planted at regular intervals throughout the plot.

At 4 and 8 weeks after transplanting, each variety is scored on the scale 1–9 (Table 11) for tolerance for Fe toxicity. Other relevant observations such as insect or disease damage are noted.

The final score given to an entry is from the rating period when entry differences are most discriminating. The entries are scored relative to the score of the nearest S-check.

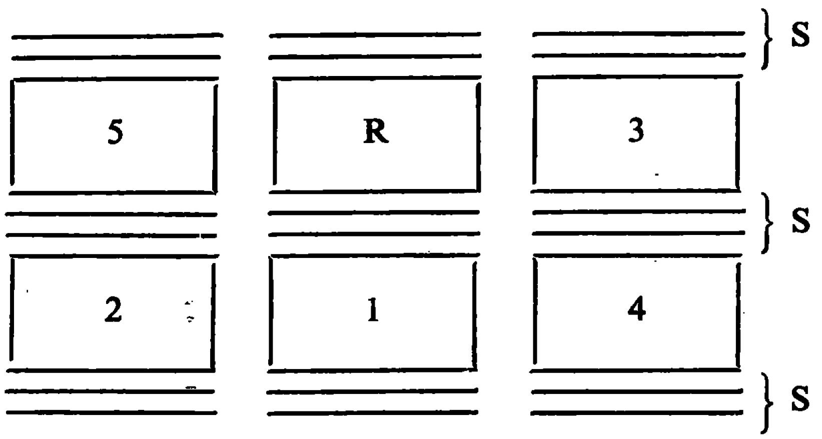
Yield (grain) is not considered in this test but may be taken for future reference.

b. Yield trial:

This test usually follows mass screening. Varieties and breeding lines found tolerant in mass screening are tested for their yield performance.

Land preparation is similar to that for mass screening. Each entry is planted in plots measuring at least 3x5 sq m. and grain yield is determined at harvest from a harvest area of at least 5 sq m

The experimental design is an RCB with the R-check randomized along with the entries while the S-check is planted in 2 or 3 rows between plots.



S — susceptible check

R — resistant check

1-5 — test materials

Phosphorus Deficiency

Greenhouse Screening:

Steps	*Key points*
1 Prepare culture solution	* 05 ppm of phosphorus 10 ppm of phosphorus and N, 40 ppm; K, 40 ppm, Ca, 40 ppm; Mg, 4.0 ppm; Fe, 5.0 ppm; Mn, 0.5 ppm; Mo, 0.05 ppm; Zn, 0.01 ppm; B, 0.02 ppm; and Cu, 0.01 ppm.
2 Seed	* Pregerminate seeds * Arrange 4 seeds in a square of 7.5 cm on nylon net floats placed in the culture solutions in 4-liter pots.
3 Maintain	* Check and maintain pH of culture solutions daily * Change culture solutions weekly
4 Score	* After 4 weeks count the tillers of each variety at the two concentrations of P and express tolerance as a relationship of tillers present (table 12)

Field Screening:

Steps	*Key points*
1 Field preparation	* Plant in phosphorus–deficient field
2 Management	* For a check, add 25 kg of phosphorus and compare the yields under both conditions

Zinc Deficiency

Screening is done with a zinc-deficient soil in concrete beds measuring 27x2.5x0.3 m in a screenhouse. Properties of this soil are in table 10.

The soil is treated with N P K fertilizers and thoroughly puddled. Presoaked seeds are next direct sown in lines 1.2 m long with a resistant and susceptible check after every 10 entries. Symptoms are scored four weeks after sowing on a 1–9 scale (Table 13).

Field screening can be done but is not reliable due to:

1. frequent absence of Zn deficiency 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 in basins where zinc deficiency usually occurs.
3. pest and disease damage.

Peat Soils

At present, only field screening is done. The field is prepared thoroughly and N, P. K fertilizers are added just before transplanting at the rate of 50–25–50 kg per ha. Three week old seedlings, raised on the same soil, are transplanted in three 5m rows, spaced 20 cm apart with 2-3 seedlings per hill. IR34, the resistant check, is randomised with the entries while the susceptible check E 425 is planted in two 5 m rows after every 10th entry. Standard insect, disease and weed control measures are adopted.

At 4 and 8 weeks after transplanting the entries are scored on the 1–9 scale (1 is normal and 9 is dead or almost dead) for tolerance. The final score of each entry is taken from the rating when entry differences are most discriminating. The entries are scored relative to that of the nearest susceptible check.

Aerobic soils: iron deficiency, manganese and aluminum toxicities.

To screen for tolerance to iron deficiency and manganese and aluminum toxicities, it is necessary to exclude water stress, weed competition, other mineral stresses, and anaerobiosis. Such conditions can be achieved by growing rice on well-drained soils fertilized with N, P, and K and kept at field capacity.

Three soils (Luisiana clay, Maahas clay, and Maahas clay treated with 1% ground limestone) are used in concrete tanks provided with underground drainage. Rice is direct seeded in three rows per entry. The soils are watered to maintain soil moisture tension at 200 millibars but the redox potential above 0.5V. Plant observations and the yield of the middle row are used as indices of tolerance.

Progress in Screening

Using the greenhouse and field screening procedures described earlier, a large number of rices have been screened at IRRI beginning 1969 (Table 14). The materials screened have originated from the germplasm collection and IRRI's breeding program. Those identified as tolerant to different problem soil stresses are given in table 25.

Breeding Methods

The pedigree method is most commonly used in breeding for adverse soils tolerance. Tolerance donors are hybridized with parents of superior characteristics and progeny selection is effected based on greenhouse and field screening data for adverse soils tolerance. Improved lines with tolerance are re-used in hybridization to generate new breeding materials. In the absence of greenhouse facilities screening of progenies is confined to the field. Selection for Fe-toxicity tolerance and P deficiency tolerance is based on field screening only, in some national rice programs.

Other methods of breeding such as bulk, derived line, backcross and population improvement can be resorted to in developing varieties tolerant to adverse soils. Mutation breeding and use of cell and tissue cultures are alternative methods that offer promise. Mutation induction with physical and chemical mutagens can be used either alone or in combination with cell and tissue culture methods. Use of cell and tissue culture methods has been successful in developing salt tolerant tobacco. Such methods are being explored in other crops such as wheat, corn, oat, sugar beet and soybean. IRRI has recently initiated such work in rice. In tobacco, for instance, tolerance at cellular level has been increased from 800 to 8200 NaCI and plants have been regenerated from these tolerant cells.

Population improvement methods utilizing genetic male sterility which facilitates recurrent selection in normally inbred populations is a new approach being attempted in breeding for tolerance to adverse soils. By growing such populations under increasing levels of stress, either man-made or natural, selection can be effected over stress intensities ranging from none to the upper limit of tolerance. With male sterility incorporated in these populations to facilitate continuous recombination, the probability of recovering rare combinations with stability of performance over a range of stress intensities can be increased, besides increasing the level of tolerance *per se*. This method of selection also overcomes the drawback in the conventional method of selection where a predetermined level of stress is used either in soil or solution culture tests which hampers the enhancement of the genetic potential for tolerance.

FUTURE STRATEGIES

1. Search for donors of diverse origin

Screening the world collection needs to be continued to identify new donors. All tolerance donors should be screened to identify those with high levels of tolerance. Because tolerance for a given stress can vary during growth, screening procedures should be devised to enable detection of such differences. If differential tolerance can be found in donors, attempts can be made to generate new donors with enhanced tolerance levels during ontogeny.

2. Selection from existing tolerant breeding lines for high yield and biological stress tolerance

Selection for high yield and biological stress tolerance from existing tolerant breeding lines needs more attention. Lines so identified must next be evaluated for adaptability and stability of performance by multilocation testing. Superior lines, aside from being released as varieties, must be further utilized in the breeding process to generate new genotypes.

3. Multiple stress tolerance

Because generally more than one soil stress is encountered under field conditions, multiple stress tolerance is desirable. The use of donors with tolerance for the common soil stresses must be continued in hybridization and these traits must be rigorously monitored through generation advance in progenies. Tolerance for several stresses can be combined as shown in Figure 2. This has been achieved by emphasizing salinity and alkalinity tolerance initially and recently iron toxicity, phosphorus deficiency, and zinc deficiency tolerance. In future, incorporation of tolerance for peat soils, acid sulfate soils, and aluminium toxicity is considered necessary. No serious genetic barriers seem to exist in combining tolerance for different soil stress, as is evident from the near independence of tolerance for five adverse soil stresses demonstrated using 44 genotypes (Table 16).

Breeding for high levels of tolerance Tolerance for a given stress observed in present varieties or breeding lines can often be traced to one or a few donors. For example, salt tolerance in IR4595–4–1, IR4619–54–3, IR4630–22–2 or IR9884–54–3, can be traced either to Pokkali or Nona Bokra, and zinc deficiency tolerance in IR20 has been traced to TKM–6 and its parents, GEB 24 and Co 18 Fig (3). There are others, however, in whose ancestry such donors are absent (Table 17). This suggests that the use of population breeding methods aimed at gene accumulation from diverse sources in attaining higher levels of stress tolerance is promising.

There is evidence that tolerance levels for salinity and zinc deficiency can be enhanced by combining diverse tolerance sources. First, zinc-deficiency tolerance is under polygenic control (Table 18). Secondly, salt tolerance can be enhanced by combining different tolerance sources. Thus, in two crosses one of which was between two moderately tolerant parents (IR 36/IET 1444) and the other between two tolerant parents (IR 2153–26–3–5–6/IR2071–88–8–10) F_4 progenies with higher levels of tolerance than either of the parents were recovered from both crosses, although their frequency was higher in the tolerant x tolerant cross than in the moderately tolerant x moderately tolerant cross. Also, a higher frequency of tolerant progenies was recovered in the F_4 generation from tolerant F_3 lines than from susceptible F_3 lines in both crosses (Fig. 4). Enhancement of tolerance levels may be similarly expected for other adverse soils.

In attempts to increase tolerance levels by combining diverse tolerance sources, the breeding method is important. Currently multiple crosses and convergent breeding procedures are in use, but population breeding methods using composites incorporating male sterility to facilitate recurrent selection need to be attempted. Such a procedure has already been proposed (Fig. 5) and establishment of such composites is now underway. What needs consideration is the manner of handling these composites. For rapid genetic advance in intermating composite populations two conditions are imperative. The first is increased genetic variability and the second is high selection pressure. Increased genetic variability can be achieved by including diverse tolerance sources in establishing the composite, and high selection pressure can be imposed by either subjecting the population to increasing levels of stress with every cycle of selection, or by exposure of the intermating population to stress gradients which are man made or found in nature. Gridded mass selection can be practised on these populations which might favour the combination or traits that will confer stability of performance over a range of stress intensities in extractions from these composites.

Differential behaviour of genotypes to increasing stress is documented for some crops (Fig. 6, 7). This is illustrated in Figure 8, What needs emphasis is that the breeding method employed should facilitate recombinations that eventually lead to genotypes with superiority of performance over a range of stress intensities. To search for stable genotypes in materials once homozygosity has been achieved is commendable but it would be more so if the breeding system and the selection procedure used is specifically designed to generate such genotypes. Population breeding procedures with intermating composites subjected to selection along stress gradients may be a possible means of achieving such an objective.

4. Studies on mineral deficiency tolerant varieties.

The continued culture of mineral deficiency tolerant varieties may be undesirable as such varieties will progressively mine the soil and result in aggravation of the problem. Nevertheless, it may still be possible to identify varieties/lines which show a higher efficiency in absorbing the element from applied fertilizer. In the case of phosphorus deficiency considerable differences have been observed in varieties/lines in yielding ability without P and in response to applied fertilizer phosphorus (Table 19) and similarly for zinc (Table 20). The search for varieties/lines high in mineral use efficiency may be a useful approach when confronted with element deficiencies.

5. Studies on genetics and mechanisms of tolerance for mineral stresses

Tolerance for mineral stresses is governed by many complex physiological, biochemical and perhaps morphological features. Better understanding of different tolerance mechanisms and genetics of these mechanisms should prove to be useful in developing genoptypes with multiple stress and enhanced stress tolerance.

6. Use of cell and tissue culture

These methods could be used to obtain homozygous lines from heterozygous materials. Somatic cell culture could be used in combination with mutation induction to generate materials hopefully with higher levels of stress tolerance. As large numbers of cells can be screened by these means, continued selection at progressively higher levels of stress could lead to enhanced levels of tolerance. Plant material used in such work should be obtained from varieties/lines having good agronomic features and high levels of stress tolerance so that any gains achieved will lead to cultivars superior to those produced by conventional methods.

Tolerance from exotic germplasm Wild and other cultivated species of rice may serve as useful sources of tolerance for adverse soils. Among wild species the search for tolerance should be confined to those with the A genome for ease of subsequent utilization in crosses with *Oryza sativa*. The use of exotic germplasm in enhancing tolerance to salinity is documented for tomato. Salinity tolerance of *Lycopersicum cheesmanii* has successfully been transferred to *L. esculentum*.

7. Exploitation of hybrid vigour

In some instances, as for example salinity, F_1 hybrids are known to have higher tolerance than their parents. Higher levels of tolerance to other stresses may similarly by expected in hybrid rice. This is plausible because of the better developed and physiologically more efficient root systems of hybrid rice.

8. Expanded scope of international testing in adverse soils

Up to now, the only adverse soil factors studied in the International Rice Testing Program were salinity and alkalinity. In view of the keen interest shown by South and Southeast Asian governments in using problem lands for rice production and the recognition of iron toxicity as a widespread yield-limiting factor on highly weathered tropical rice soils, special screening sets for acid sulfate soils, peat soils, and iron-toxic soils have been added to the International Rice Testing Program. Collaborative research on adverse soils testing is envisaged to be expanded during the 1981–1985 period. These collaborative projects are planned for the problem areas involving salinity (inland and coastal), alkalinity, acid sulfate soils, peat soils (inland and coastal) and iron toxicity. Eight countries in South and Southeast Asia have tentatively been identified for these collaborative projects (Table 21).

The materials for testing under the collaborative projects will involve known donors, elite lines, early generation segregants, and derivatives from cell and tissue culture having tolerance to the soil stresses characteristic of the target regions.

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Table 1—**World rice land, yield and production**

Region/Country	*Area* (000 *ha*)	*Yield* (*mt/ha*)	*Production Rough Rice* (000 *m t*)
East Asia	41,419	3.9	160,476
Southeast Asia	33,715	2.1	71,557
South Asia	53,374	1.9	101,620
West Asia and North Africa	1,120	4.1	4,567
Sub-Sahara Africa	4,391	1.2	5,323
Europe	386	4.4	1,683
USSR	550	3.8	2,105
Latin America	7,485	1.8	13,681
USA & Oceania	1,138	5.1	5,846
World	143,578	2.6	366,858

Source: World Rice Statistics, IRRI, 1980.

Table 2.—**Problem soils of South and Southeast Asia**

	Area in thousands of ha			
Country	*Saline soils*	*Alkali soils*	*Acid sulfate soils*	*Peat soils*
Bangladesh	2,479	538	700	800
Burma	634	—	180	—
India	23,222	2,500	390	8
Indonesia	13,213	—	2,000	16,035
Khmer Republic	1,291	—	200	—
Malaysia	3,040	—	160	2,450
Pakistan	6,456	4,000	—	—
Philippines	400	—	100	17
Vietnam	982	—	1,000	1,500
Thailand	1,456	—	670	200
Total	53,173	7,038	5,310	21,010

Table 3—Mineral stresses in problem soils

Problem Soil	*Mineral Stress (es)*
Saline Soils	Chlorides and sulfates of Na, Ca and Mg pH: <8.5; $EC_e >$ 4m mhos/cm at 25 °C.
Alkali or Sodic Soils	Carbonates and bicarbonates of Na. pH: >8.5; ESP$>$ 15% $EC_e < 4$m mhos/cm at 25 °C. Zn—deficiency.
Saline-Sodic Soils	High ESP, $EC_e >$ 4m mhos/cm at 25 °C. Ca deficiency, carbonate toxicity and Zn-deficiency
Acid Sulfate Soils	Al and Fe toxicity; P-deficiency; pH <3.5–5; H_2S; salt; organic acids, and low base status
Iron Toxic Soils	Fe^{++}; low pH. Salinity in some cases.

Contd. from Table 3:

Problem Soil	*Mineral Stress (es)*
P–deficient Soils	Low in available phosphorus Fix added fertilizer phosphate. Fe toxicity and base deficiency Acid Soils; Zn–deficiency, deficiency, salinity and alkalinity–vertisols.
Zn–deficient Soils	Zn–deficiency Associated with alkalinity in sodic soils, with p-deficiency and Fe deficiency in vertisols, with K deficiency in calcic soils, and with multiple nutritional deficiencies and multiple toxicities in histosols.
Aerobic Soils	Fe-deficiency in all soils. Mn and Al toxicity on acid soils.

Table 4—Saline soils

Soil class	*Other growth-limiting factors*
Arid saline soils	Alkalinity, B toxicity, Zn deficiency, N and P deficiencies.
Acid coastal saline soils	Fe toxicity, P deficiency, flooding
Neutral and alkaline coastal saline soils	Zn deficiency, B toxicity, flooding
Coastal peat soils	N, P, Zn, Cu deficiencies, H_2S toxicity, Fe toxicity, toxicity of organic substances, flooding

Table 5—Acid sulfate soils

Soil class	*Other growth-limiting factors*
Coastal soils	Salinity, Fe toxicity, N and P deficiencies flooding
Old inland soils	N and P deficiencies
Peat soils	Fe toxicity, H_2S toxicity, N, P, Cu Zn deficiencies, flooding, salinity

Table 6—Phosphorus-deficient soils

Soil class	*Other growth-limiting factors*
Acid sulfate soils	Strong acidity, Al toxicity, Fe toxicity, N deficiency, base deficiency, high electrolyte content
Ultisols and Oxisols	Fe toxicity, base deficiency
Vertisols	Zn deficiency, Fe deficiency, salinity, alkalinity

Table 7—Zinc-deficient soils

Soil class	*Other growth-limiting factors*
Saline-sodic and sodic soils	Salinity, N, P, and Fe deficiencies
Vertisols	P and Fe deficiencies; salinity, alkalinity
Calcareous soils	K deficiency
Peat soils	N. P, K, Si, Cu deficiencies; H_2S toxicity; flooding

Table 8—Reclamation of Problem Soils

Saline Soils: Leaching of excess salt with water and improvement of drainage.

Sodic Soils: Replacement of excess sodium in the exchange complex with calcium and leaching of exchanged Na. Gypsum ($CaSO_4 . 2H_2O$) is the most common amendment. Acids and acid forming substances eg H_2SO_4 or $Al_2(SO_4)_3$ can be used.

Acid Sulfate Soils: Continued submergence.

Iron Toxic Soils: Application of lime.

P-deficient Soils: Application of phosphate fertilizer.

Zn-deficient Soils: Soil aeration by drying and application of Zn.

Aerobic Soils: Increase of pH by addition of lime.

Table 9—State of origin in India of some salt tolerant rices

State	*Variety*
Orissa	SR 26 B
West Bengal	Chin 13, Nizersail, Kumergore, Sitasail, Badshabhog, Patnai 23
Bombay (Maharasthra) and Gujarat	Kalarata 2–18, Kalatara 1–24, Khare Bhat, Bhurarata 4–10, Bhurarata 2–10, Morchuka
Andhra Pradesh	C 75, C 87, C 327, C 1032, T 892
Kerala	Cheriviruppu, Pokkali
Mysore (Karnataka)	Bilekagga, Karekagga, Arya
Punjab	Jhona 349

Source: Rices of India by R. H. Richarria and S. Govindaswami.

Table 10—Some properties of soils used in screening for mineral stresses

Property	*Soil* *Acid Sulfate Soil (Malinao)*	*Zn-deficient soil (Lipa Clay Loam)*
pH (1:1)	3.5	8.0
Total N (%)	0.12	0.48
Avail. P (ppm)	7	35
Exch. K (me/100 g)	0.18	—
EC (mmho/cm)	0.99	—
CEC. me/100 g)	10.1	40.3
Org. C (%)	1.39	9
Active Fe (%)	2.5	0.50
Mn .%.	0.001	0.54
Available Zn (ppm)	—	1.8

Table 11—Scoring for tolerance to iron toxicity

Scale	*Observations*
1	Nearly normal growth and tillering
2	Nearly normal growth and tillering, oldest leaf shows brown spots
3	Nearly normal growth and tillering, some old leaves are purple or orange-yellow
5	Growth and tillering retarded, many discolored leaves
7	Growth and tillering have stopped, most leaves are discolored or dead
9	Almost all plants are dying or dead

Table 12—Rating tolerance to phosphorus deficiency

Relative Tiller[1] *Number (%)*	*Rating*
100–76	Tolerant
75–51	Moderately tolerant
50–26	Moderately susceptible
25–0	Susceptible

[1] $\frac{\text{No. of tillers in 0.5 ppm culture solution}}{\text{No. of tillers in 10 ppm culture solution}} \times 100$

Table 13—Scoring for Zn deficiency

Observation	*Score*
Normal healthy growth and tillering	1
Normal growth and tillering, slight discoloration of basal leaves	2
Slight stunting; some tillering; some basal leaves are brown	3
Growth and tillering severely retarded; about half the number of leaves is brown	5
Cessation of growth and tillering, most leaves are brown	7
Almost all plants are dead or drying	9

Table 14—Number of rices screened for problem soil tolerance at IRRI from 1969-1980

Stress	*Number*	
	Screened	*Tolerant*
Salinity	48,671	9,206
Alkalinity	10,585	2,254
Iron toxicity	2,285	85
P–deficiency	4,178	451
Zn–deficiency	11,600	817
Peat soil	1,281	81
Fe–deficiency	572	68
Al/Mn toxicity	505	46

Table 15—Rices tolerant to different adverse soil stresses

Salinity

Arya
Badshabhog
Bhurarata 2–10
Bhurarata 4–10
Bilekagga
BKN FR 76059–16–2
Cheriveruppu
Chin 13
CSSR 1 (Damodar)
CSSR 2 (Dasal)
CSSR 3
C 23–3–1
C 34–1–2
C 75
C 87
C 327
C 1032
DA 29
Getu
Jhona 349
Kalarata 1–24
Kalarata 2–18
Khare Bhat
Karekagga
Kuatik Putih
Kumargora
Morchuke
Nizersail
Nona Bokra
Nona Sail
Patnai 23
Pokkali
Sita sail
SR 26 B

IR8
IR36
IR42
IR43
IR44
IR46
IR48
IR50
IR 52
IR54
IR1561–228–2
IR2031–729–2
IR2053–436–1–2
IR2153–26–3–5–2
IR2307–247–2–2–3
IR2863–35–3–3
IR4227–28–3–2
IR4422–6–2–3–1
IR4422–98–3–6–1
IR4432–20–2
IR4432–28–5
IR4462–22A–2–10
IR4515–4–1–15
IR4563–52–1–1–3–6
IR4619–57–1
IR4630–22–2–17
IR4763–73–1–12
IR5657–33–2
IR5853–198–1–2
IR8067–41
IR8073–65–6–1
IR8236–B–B–336–3–2
IR8241–B–B–86–2
IR8241–B–B–650–2

IR9109–71–2–1
IR9129–136–2
IR9217–58–2–2
IR 9732–119–3
IR9763–11–2–2–3
IR9849–25–3–2
IR9852–19–2
IR9884–54–3
IR9975–5–1
IR10198–66–2
IR10206–29–2
IR10229–3–2
IR10232–17–2
IR11248–131–3–2–2
IR13149–3–2–2
IR13149–43–2
IR13240–39–3
IR13240–53–6
IR13292–5–3–1
IR13419–113–1
IR13426–19–2
IR14632–22–3
IRI7491–5–4–3–3
IR19660–23–2–1
IR19746–28–2–2–3

Contd. from Table 15

Alkalinity

Billekegga 36
BR 4–10
CSSR 1(Damodar)
CSSR 2 (Dasal)
Getu
Giza 139
M 114
M 242
MI 273
Pokalli
IR20
IR36
IR38
IR42
IR46
IR52
IR54
IR1561–228–3–3
IR1820–210–2
IR2035–290–2–1–1
IR2070–522–6
IR2307–84–2
IR2307–217–2–3
IR4–11
IR4227–28–3
IR4227–109–1–3–3

IR4417–179–1–5–2
IR4432–28–5
IR4432–52–6–4
IR4595–4–1
IR4630–22–2–17
IR4870–15–1
IR7545–27–3–2
IR8073–65–6–1
IR8192–200–3–3–1–1
IR8608–125–3–3
IR9209–181–3–5
IR9224–162–3–1–3–2
IR9703–41–3–3–1
IR9715–7–2
IR9736–16–1–2
IR9758–150–3
IR9764–45–2–2
IR9805–97–1
IR9808–9–2
IR9846–256–3
IR11418–15–2
IR13149–3–2–2
IR13149–19–1
IR13419–113–1
IR14632–22–3
IET1444

Iron Toxicity

B2149–PN–26–1
BW 78
BW 100
Candung Go Gung
Dewaredderi
IR20
IR32
IR36
IR38
IR40
IR42
IR43
IR44
IR46
IR52
IR54
IR1632–93–2–2
IR2031–729–3
IR2035–290–2–1
IR2070–210–4–42
IR2070–820–2
IR2151–190–3–5–5
IR2153–26–3–5–2
IR2307–86–1–2
IR2307–247–2–2–3
IR2797–105–2–3
IR2797–125–3–2–2
IR2798–115–2–3

IR2832–176–6–2
IR2863–35–3–3
IR2979–15–2
IR3518–96–2–2–2
IR3839–1
IR3941–25–1
IR4227–28–3–2
IR4422–480–2–3–3
IR4432–52–6–4
IR4442/165–1
IR4568–225–3–2
IR4625–296–4
IR4863–54–2–2–3
IR5741–73–2–3
IR8192–200–3
IR9129–136–2
IR9129–209–2–2–2
IR9379–221–1
IR9788–19–2
IR9846–215–3
IR13149–43–2
IR13168–143–1
IR13419–113–1
IR14632–2–3
IR19743–25–2–2
IR19743–46–2–3

Acid Sulphate Soils

IR36
IR42
IR46
IR52
IR1632–93–2–2

IR2070–820–2–3
IR2797–105–2–2–3
IR4683–54–2–2–2–3
IR9129–136–2
IET1444

Contd. from Table 15

Phosphorus Deficiency

BR51-91-6
Pelita 1/1
IR20
IR26
IR34
IR38
IR42
IR46
IR52
IR54
IR1632-93-2-2
IR2071-176-1-1
IR2071-685-3-5-4-3
IR2070-178-2-3-4
IR1514A-E666
IR4417-179-1-52
IR4427-58-5-2
IR4432-52-6-4
IR5853-213-6-1
IR6023-10-1-1
IR9559-PP889-1
IR9761-19-1
IR9763-11-2-2-3
IR9764-45-2-2
IET5863
IR13299-96-2-2

Zinc Deficiency

IR20
IR34
IR42
IR44
IR46
IR2070-423-5
IR2797-105-2-2-5
IR8067-41
IR13149-3-2-2
IR2307-247-2-2-3
IR9109-71-2
IR9758-112-1-2-3
IR9830-36-1
IR11418-15-2
MR346
IR2061-522-6
IR5178-1-1
IR5982-7-6
IR4568-86-1-3-2
IR5983-13-1
IR6115-1-1
IR7760-4-8
IR7790-18-1
IR8192-31-2
IR2071-685-3-5-4-3
IR5716-18-1
IR9764-45-2-2
IR4422-480-2-3-3

Peat Soil

Bengawan
Cepat
Kuatik Putih
CI-8638-5
IR34
IR42
IR44
IR54
IR5983-13-1
IR8192-31-2
IR2071-685-3
IR3880-10
IR4508-86-1
IR9129-136-2
IR9217-58-2
IR9814-6-3

Aluminum/Mangrove Toxicity

IR43
IR46
IR48
IR52
IR54
IR2797-105-2
IR4432-52-6
IR1754-F5B-22
Monolaya
Azucena
Dinalaga
MI-48

Iron Deficiency

IR36
IR43
IR46
IR52
IR2797-105-2-2-3
IR4432-52-6
IR5982-7-6-1
IR8608-189-2
IR9129-456-2
IR13168-143-1
Azucena
Azmil
Dinalaga
MI-48

Table 16—Correlation coefficients based on ratings of 44 genotypes for their reaction to various adverse soils

Character		*Salinity*	*Alkalinity*	*Fe-toxicity*	*Peat soil*	*P-deficiency*
Zn-deficiency	...	0.224	0.074	0.075	0.002	0.054
Salinity	...		0.154	0.146	–0.009	–0.014
Alkalinity	...			0.245	–0.005	0.114
Fe-toxicity	...				–0.171	–0.015
Peat soil	...					0.055

Table 17—Parentage of the best salt tolerant varieties/lines from IRRI

Varieties/lines	*Parents*
IR4630–22–2–5–1–3	Pelita I-1, *Pokkali*, Peta TN1, Tetep, Mudgo, DGWG, CP-SLO, Sigadis, Tadukan, TKM 6, O. nivara, Gam Pai 15
IR9732–119–3	IR36, Bg 34–8
IR9852–19–2	Sigadis, TN1, Peta, DGWG, CP-SLO, Mudgo, Tetep, Tadukan, TKM 6, CR 94–13, O. nivara
IR9884–54–3	*N. Bokra*, O. nivara, CR94-13, Peta, TNI, TKM 6, DGWG, Chow sung, BPI 176, Tadukan, Mudgo, BPI 121, Tetep, Gam Pai 15, CP–SLO, Sigadis
IR36 IR42	Peta, DGWG, Tadukan, TKM, TNI, CR 94–13 O. nivaz, CP–SLO, Sigadis
IR46	Sigadis, TNI, Peta, DGWG, CP–SLO, Mudgo, HR 21, Tetep, O. nivara, 17–1Lt, WC 1263, CR 94–13, NMS4

Table 18—Genetic behavior of tolerance for zinc deficiency in two crosses. Screening was conducted in concrete beds, IRRI, 1978 wet season

		Frequency of ratings on zinc deficiency tolerance[b]										
Generation[a]		3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Cross (IR20/E425)												
P_1 IR20 (T) ...	...			1	8	2						
P_2 E425 (S) ...	...						1	3	5	1		1
F_1 (IR20/E425)	...					1	1					
F_1 (E425/IR20)	...					1	1					
F_3 progeny ...	...	2	5	21	20	32	19	3	5	2		
Cross (IR30/E425)												
P_1 IR30 (T) ...	...			1	3	6	1					
P_2 E425 (S) ...	...						1	6	1	2	1	
F_1 (IR30/E425)	...			1								
F_1 (E425/IR30)	...		1	1								
F_3 progeny ...	...	1	20	37	27	19	5	6			1	

[a] T=tolerant; S=sensitive. [b] Scale; 1=most tolerant; 9=most sensitive.

Table 19—Differential response of rices grown on phosphorus deficient soils to added phosphorus

	Yield (t/ha)		
Designation	0 *kg P/ha*	25 *kg P/ha*	*response* (%)
IR1529–680–3	1.8	3.5	94
IR1561–228–3	1.9	2.5	32
IR2071–588–5	2.9	4.3	48
IR28	2.9	3.2	10
IR2070–414–3–9	4.1	4.6	12
IR2070–423–2	4.1	5.1	24

Table 20—Differential response of rices grown on zinc deficient soil to zinc treatment*

	(Yield t/ha)		*Response*
Designation	*Without ZnO*	*With ZnO*	(%)
IR1544A–E666	3.4	4.0	17
IR2071–625–1	3.4	4.6	35
IR29	3.2	3.6	13
IR2035–290–2	2.4	2.6	8

* Seedlings dipped in 2% zinc oxide suspension.

Table 21—Proposed international collaborative projects on adverse soils, 1981–1985

	No. of collaborative research projects							
Problem area	*Egypt*	*India*	*Indonesia*	*Malaysia*	*Pakistan*	*Sri Lanka*	*Thailand*	*Vietnam*
Salinity (inland)	1	1	—	—	1	—	1	—
Salinity (coastal)	1	2	—	—	—	—	1	1
Alkalinity	—	2	—	—	1	—	—	—
Acid sulfate soil problems	—	—	1	1	—	—	—	1
Peat soil problems (inland)	—	—	1	1	—	—	1	1
Peat soil problems (coastal)	—	—	1	—	—	—	—	—
Iron toxicity	—	1	—	1	—	1	—	—

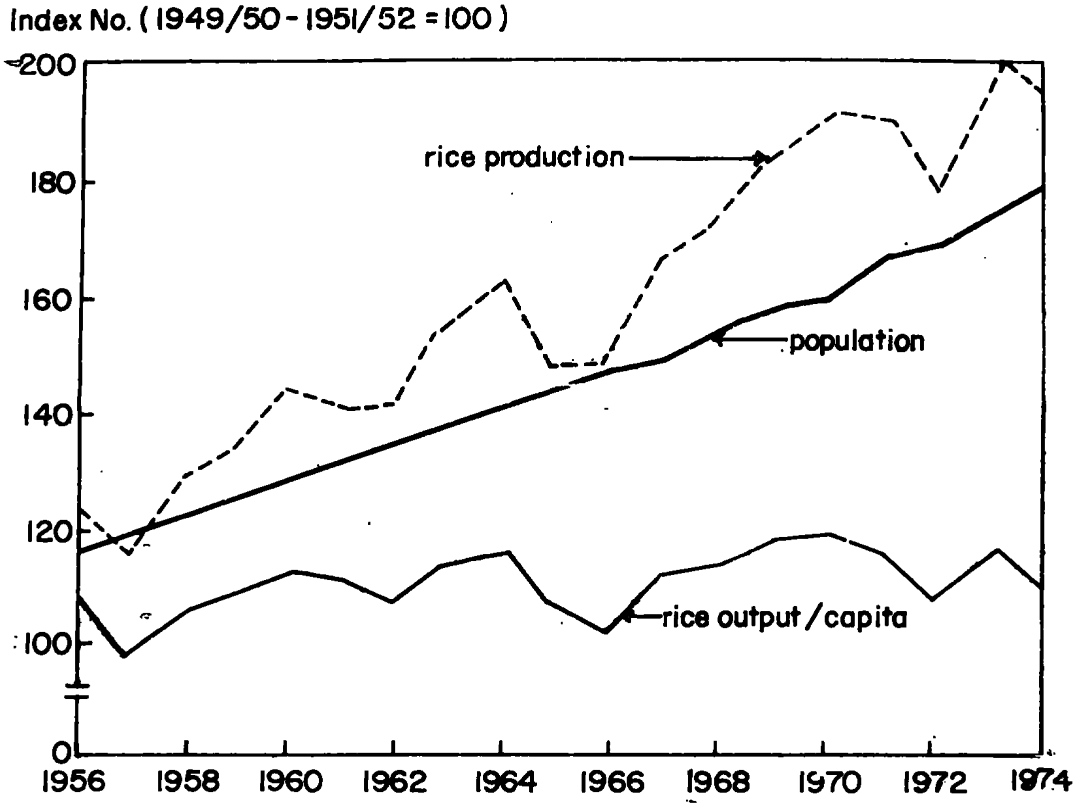

Fig. 1. World rice production and per capita consumption in relation to population.

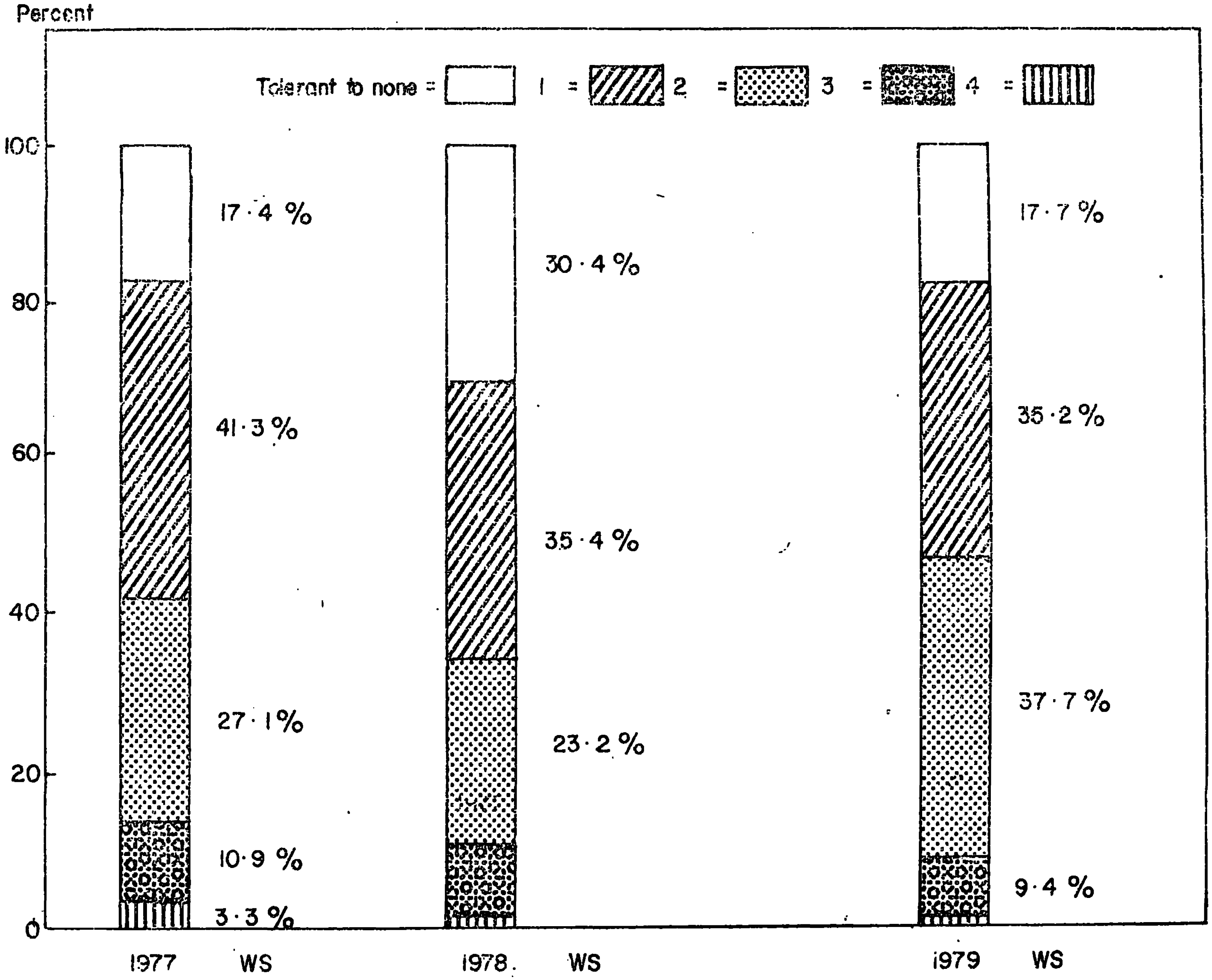

Fig. 2. Tolerance levels that have been developed to salinity and alkalinity (2) phosphorus deficiency (3) and zinc deficiency (4).

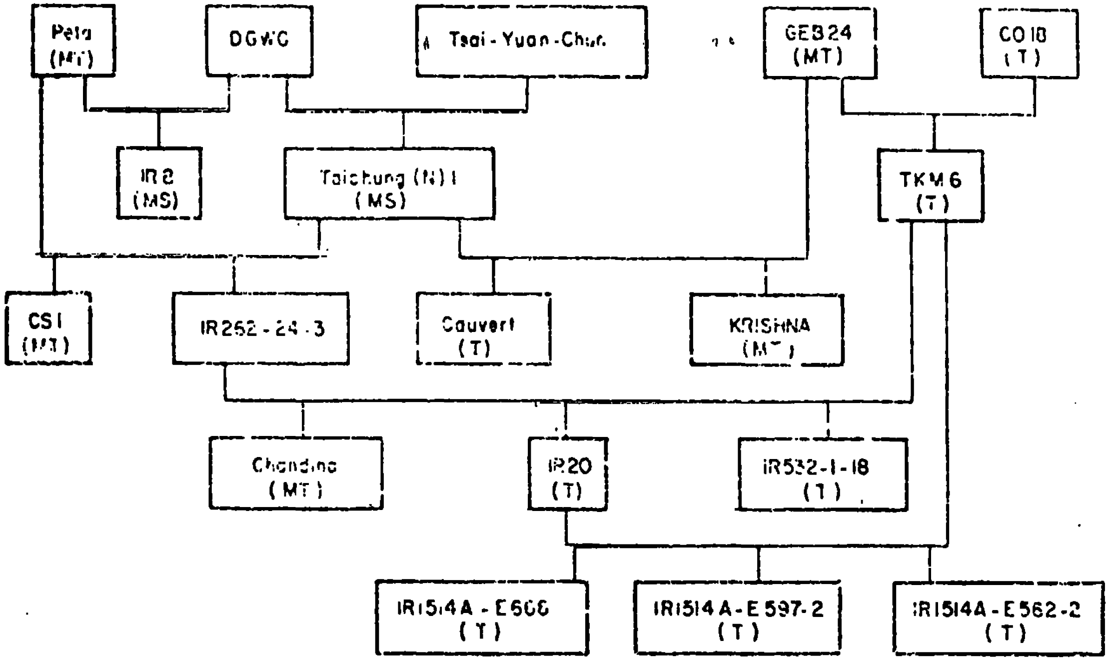

Fig. 3. Ancestry of sources of tolerance to zinc deficiency. T = tolerant; MT = moderately tolerant; MS = moderately susceptible; S = susceptible. IRRI, 1975.

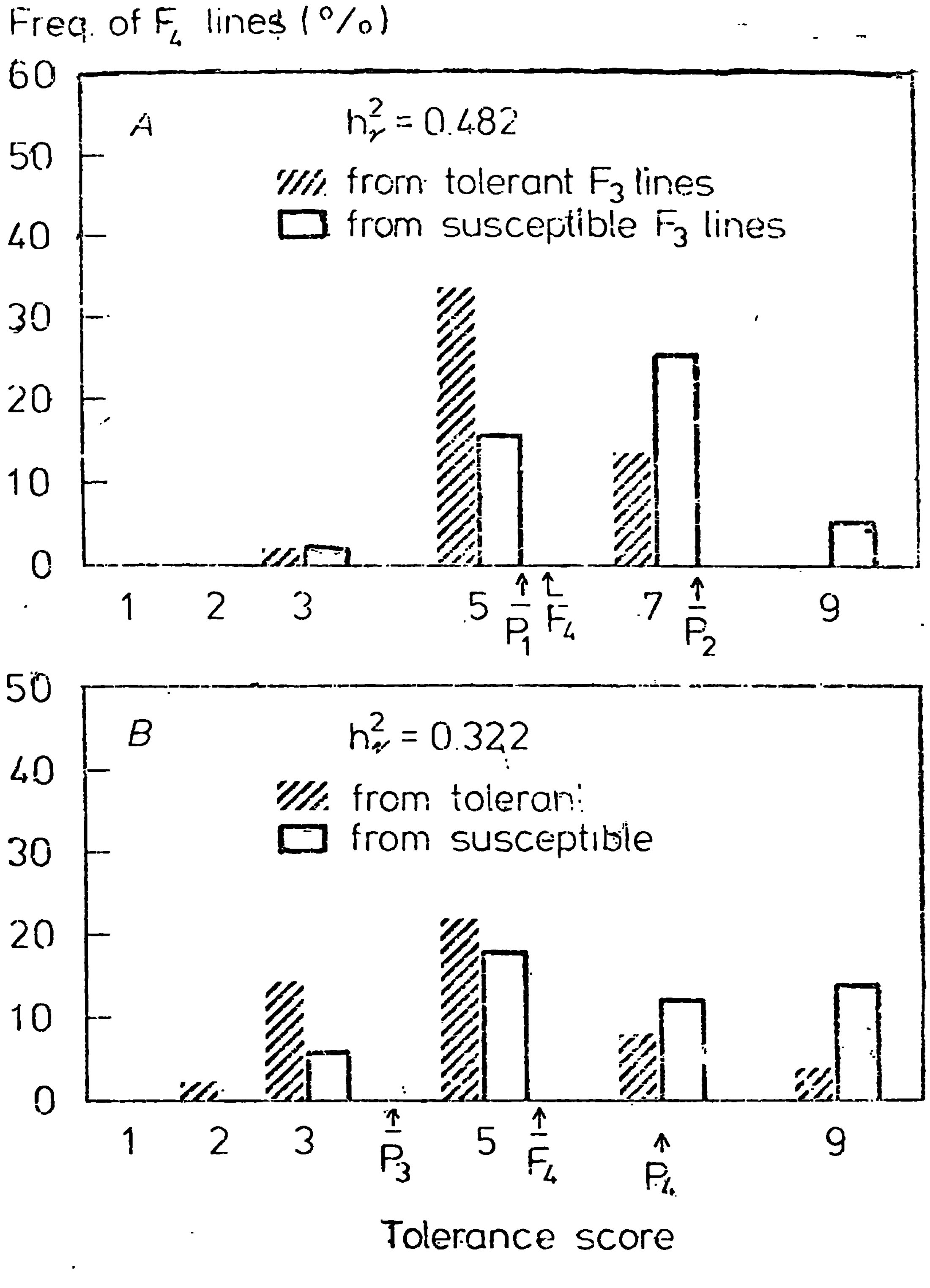

Fig. 4. Frequency distribution of F_4 lines from (A) moderately tolerant and (B) tolerant parents based on salinity score.

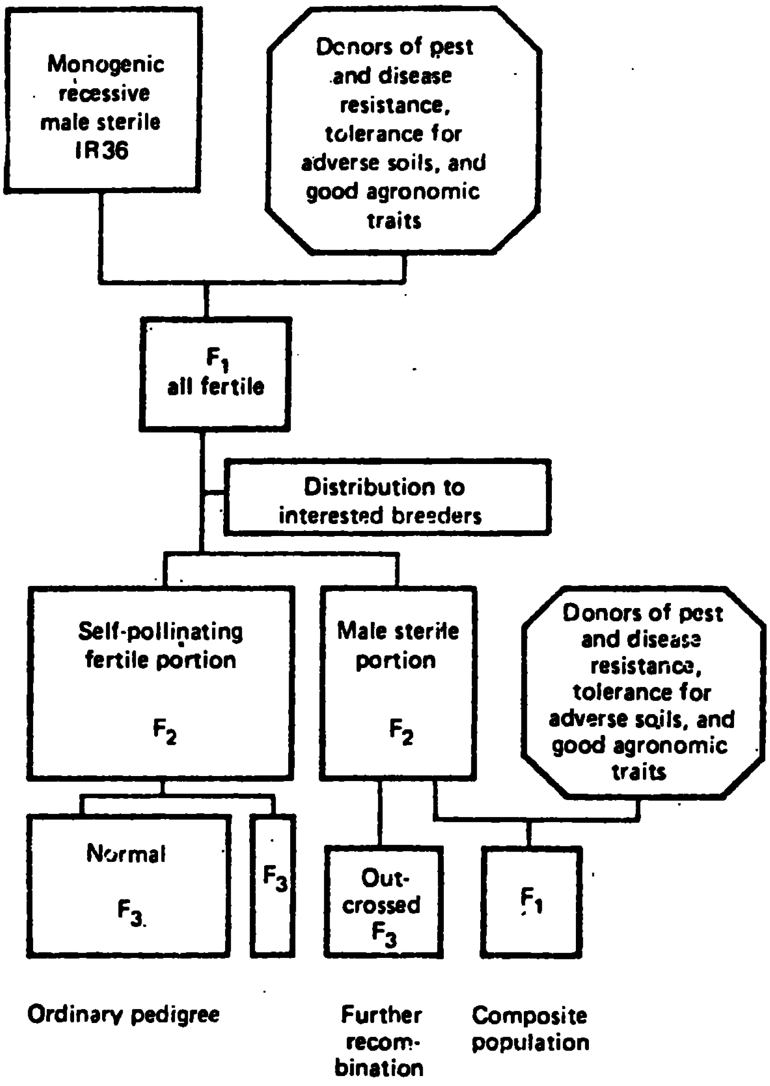

Fig. 5. Use of monegenic male sterility. IRRI, 1978.

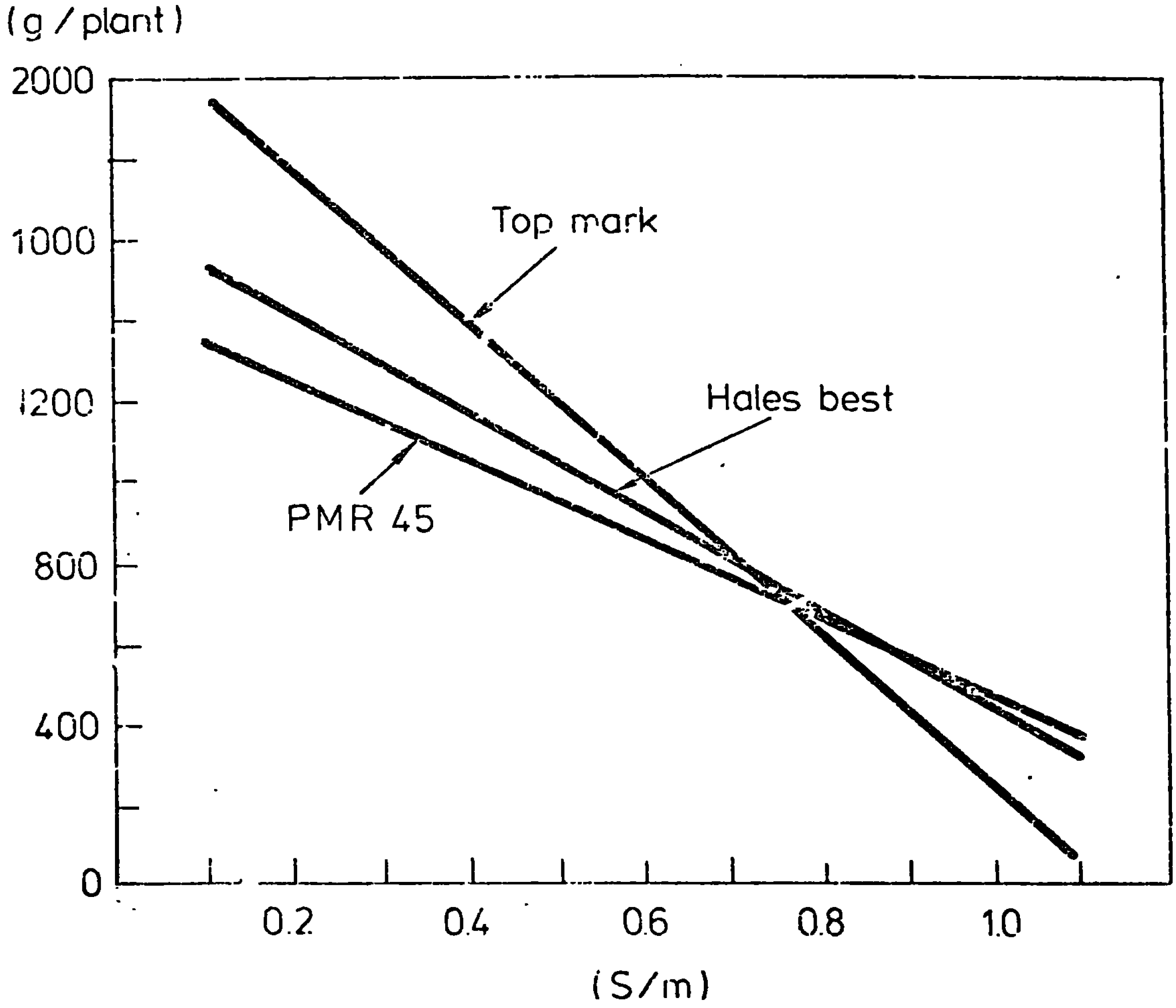

Fig. 6. Reduction in marketable yield of 3 muskmelon varieties as a function of soil salinity (From Shannon and Francois, 1978).

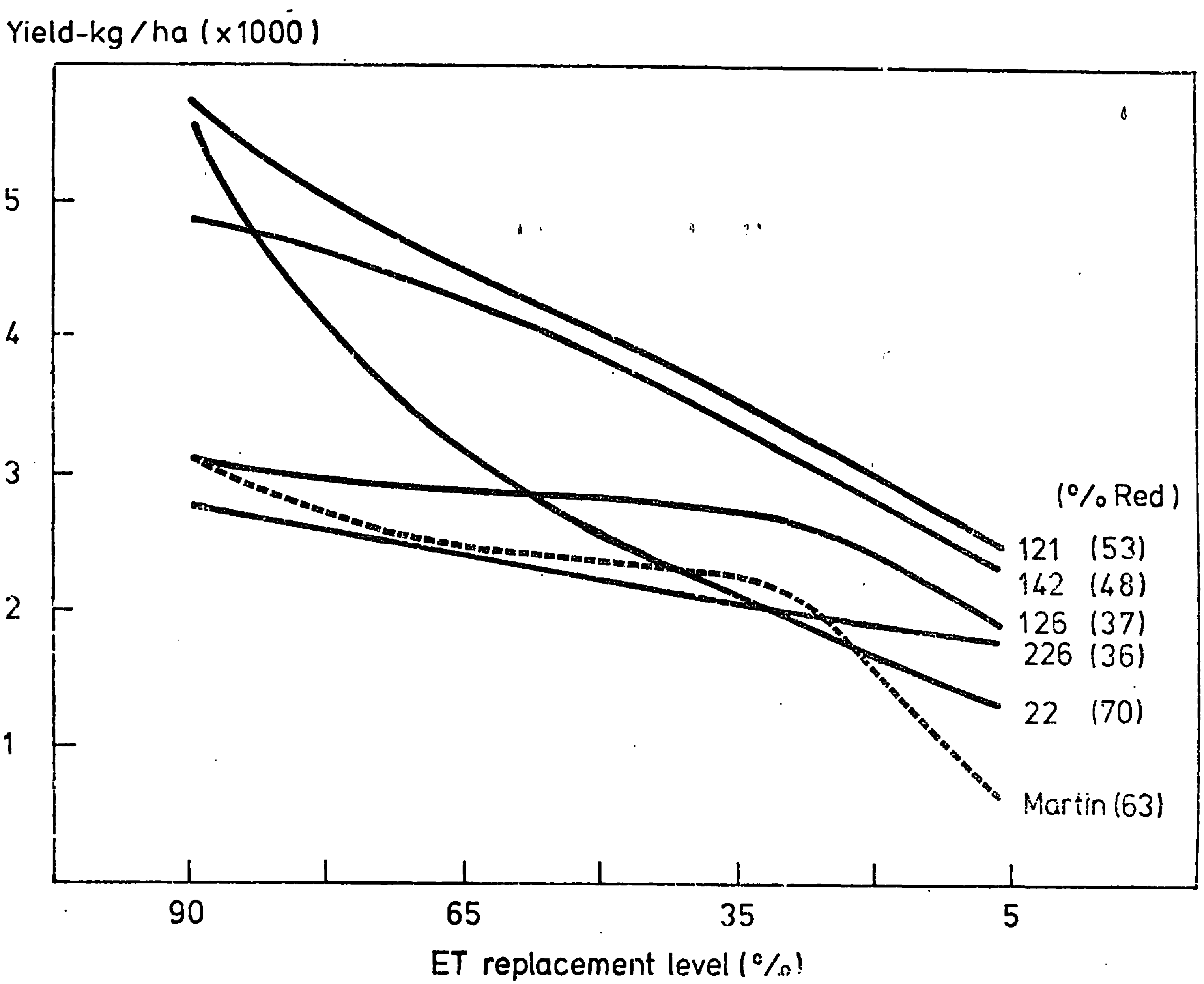

Fig. 7. Yield stability of some sorghum lines from population NP9BR across an irrigation gradient (Adapted from Sullivan et al.).

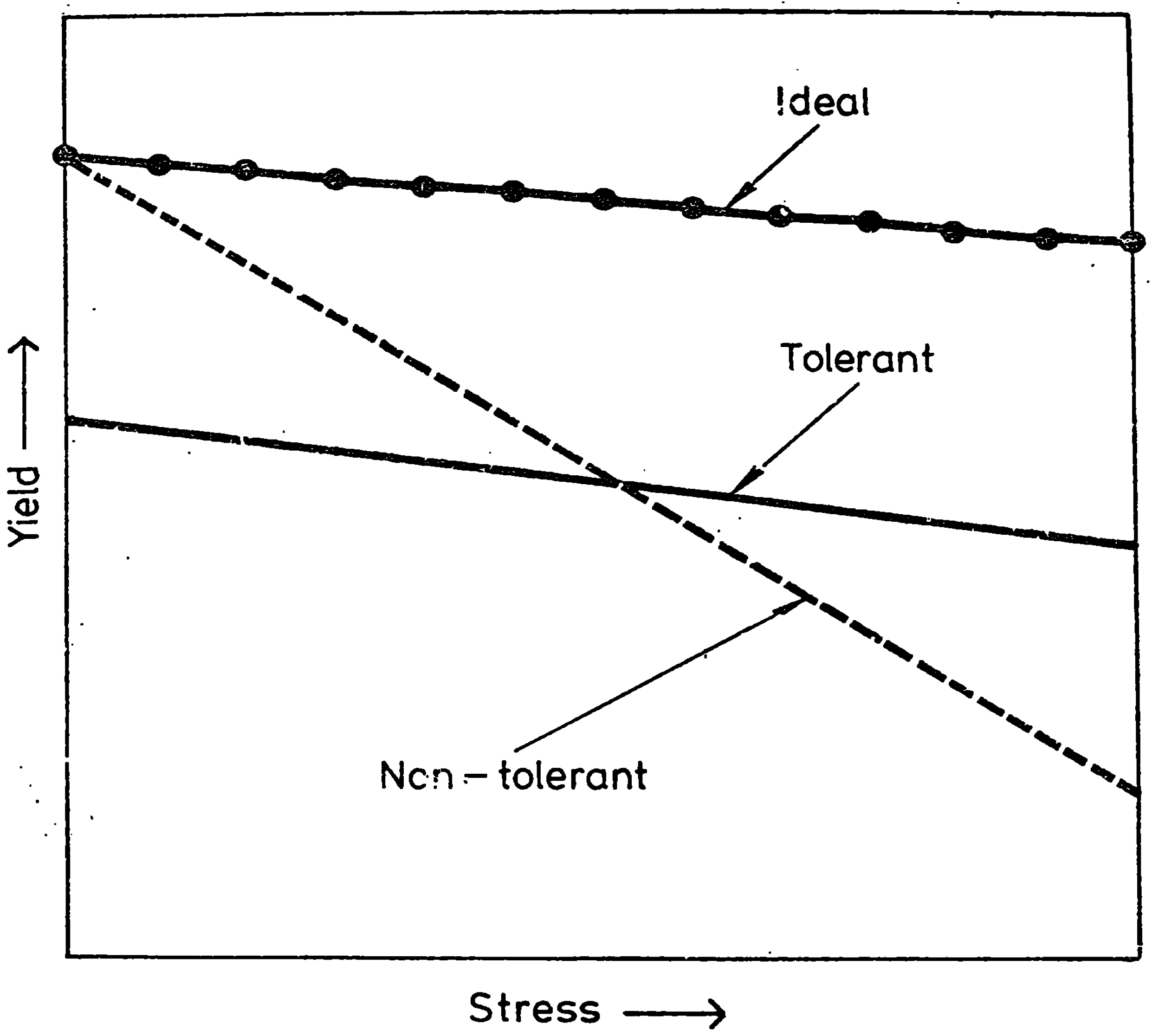

Fig. 8 . Schematic representation of varietal behaviour to stress.