A New Methodology to Select Cultivars Tolerant to Aluminum and with High Yield Potential

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Introduction

Recent years have evidenced an increased interest in the evaluation of various crops for their tolerance to aluminum in the soil. This interest is greater in developing countries where population pressures have forced agriculture to move to acid, marginal soils. Often, improved technologies, such as the varieties of the "green revolution," are not adapted to produce in these soils without applications of lime, which often is not available to farmers because of geographic location, lack of transportation, or economic reasons. What is necessary for farmers in these areas of acid soils is an "adaptive revolution," whereby improved varieties or lines adapted to acid soils can be identified for immediate use or use in breeding programs.

In the bibliography various works can be found on evaluation of cultivars of various crops for their tolerance to acidity or aluminum toxicity in the laboratory, greenhouse, or field, and sometimes combining some of these. In some of these works, the authors wished to evaluate a number of cultivars for their tolerance to Al toxicity. However, there was not a good method to evaluate cultivars for tolerance to high percentages of Al saturation and, at the same time, evaluating their high yield potential under these Al-toxic soil conditions. A method has now been developed which serves this objective.

Methods and materials

The work summarized in this paper was carried out between 1979

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and 1982 by the authors (Piha and Nicholaides, 1983) in a Typic Paleudult, fine loamy, siliceous, isohyperthermic soil near Yurimaguas, Peru, at Peru's Agricultural Experimental Station utilized by the Tropical Soils Research Program. More details of various experiments conducted with rice, sweet potato, soybean, peanut, and cowpea can be found in the 1980-1981 Technical Report of the Tropical Soils Research Program (Piha and Nicholaides, 1983).

Model

To evaluate data from a number of crop cultivars for their tolerance to Al toxicity and high yield potential under these Al-toxic conditions in the soil, a graph must first be constructed. The abscissa (X axis) is the absolute yield in Al-toxic conditions and the ordinate (Y axis) is the yield with Al toxicity relative to that without Al toxicity (Figure 1). Second, the graph must be divided in two areas by constructing a horizontal line with 85% relative yield to separate tolerant (above the line) from sensitive (below the line) cultivars. Many times in the literature, 80% relative yield is used to evaluate Al tolerance. In this case, we decided to use a stricter criterion and selected 85%.

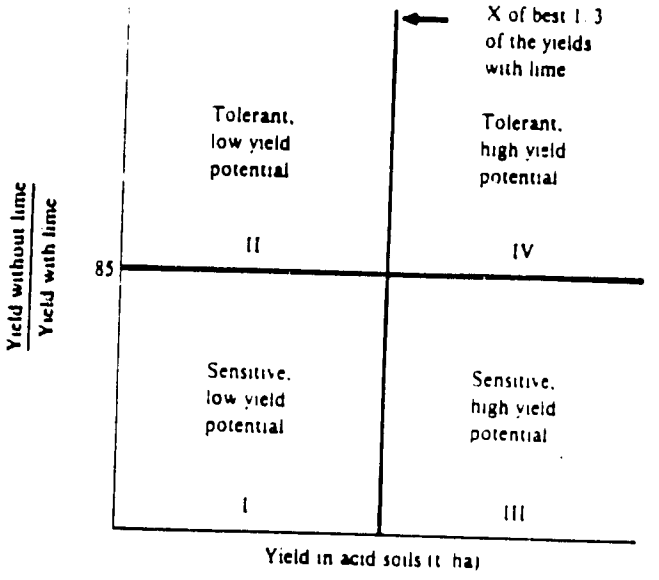

Figure 1. *Model to separate cultivars according to their tolerance to Al toxicity and their high yield potential under these stress conditions.*

To divide high from low yield potential cultivars, a line perpendicular to the abscissa has been constructed using average yields of the best one-third of the cultivars in the trial with lime application —in other words, without Al toxicity—to make sure we have high yields. Other criteria can also be used to determine this vertical line, but this method always gives an accurate indication of good crop yield under the trial's actual conditions.

The graph now has four quadrants. The cultivars falling in quadrant IV are those tolerant to Al toxicity and also with high yield potential under these toxic conditions. Cultivars falling in quadrant I are not Al tolerant nor do they have high yield potential. Those in quadrant II possess Al tolerance, while those in quadrant III have high yield potential under Al toxicity (very few cultivars fall in quadrant III).

Selected cultivars and breeding lines [52 rice, 25 sweet potato, 22 soybean, 11 peanut, and 27 (trial 1) and 10 (trial 2) cowpea] were evaluated by use of the model with field data from 1979 to 1982 near Yurimaguas, Peru, for tolerance to aluminum toxicity and high yield potential under these toxic conditions. Some properties of soils in the trial are shown in Table 1. Each trial had both Al-toxic and nontoxic (by liming) conditions. Neither phosphorus nor any other essential element was deficient in the soil since sufficient amounts of any essential element found by soil analysis to be deficient were applied to correct the deficiency.

Results and discussion

Rice

Of the 52 cultivars evaluated, 20 did not yield due to *Pyricularia* attack. The rest showed variable degrees of resistance. Using the new method to evaluate the remaining 32 cultivars, we found that three (Colombia 1, IR 9671-61141-5, and Suakoko 8) fell into quadrant IV, indicating tolerance to Al toxicity and high yield potential under these toxic conditions (Figure 2). The cultivar CICA 8 almost fell in quadrant IV, but its 77% relative yield placed it in quadrant III; however, its 3.25 t/ha yield in soil with 78% Al saturation was considered to be good. Data on yield of some selected varieties and lines are shown in Table 2. Two varieties, Colombia 1 and Suakoko 8, have the desired characteristics of both Al tolerance and high yield potential.

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Table 1 Selected soil properties in the trials to evaluate tolerance to Al in varieties and breeding lines of rice, sweet potato, soybean, peanut, and cowpea near Yurimaguas, Peru.

Crop	Soil condition	pH	Al	CEC	Al saturation (%)	P (Olsen modified) (ppm)
			(meq/100 cc)			
Rice						
	Unlimed	4.2	4.0	5.1	78	17
	Limed	4.9	1.7	5.4	31	19
Sweet potato						
	Unlimed	4.3	2.0	3.0	67	12
	Limed	4.9	1.1	3.2	34	13
Soybean						
	Unlimed	4.3	1.8	2.7	67	11
	Limed	5.3	0.2	2.9	7	25
Peanut						
	Unlimed	4.2	4.7	5.7	82	10
	Limed	4.9	1.9	5.4	35	10
Cowpea (trial 1)						
	Unlimed	4.2	1.2	1.9	63	13
	Limed	5.1	1.0	3.6	28	25
Cowpea (trial 2)						
	Unlimed	4.2	3.6	5.1	71	12
	Limed	5.0	1.2	4.9	24	11

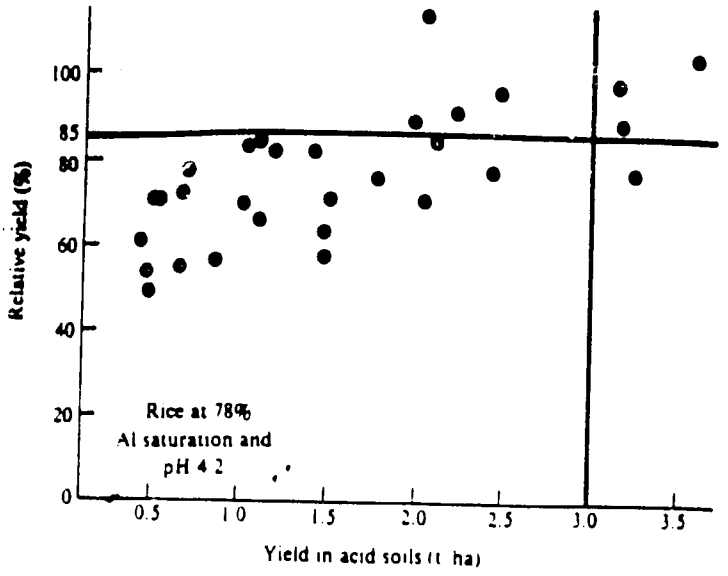

Figure 2. *Use of the model to indicate rice cultivars tolerant to Al and with high yield potential under Al toxicity stress*

Table 2. Some measurements of selected rice cultivars produced in soils with 78% and 31% Al saturation near Yurimaguas, Peru.

Line or variety	Yield[a] (t/ha)		Relative grain yield	Relative weight of vegetation (green)
	Unlimed soil	Limed soil	(%)	
IR 4422-62	2.03	1.81	113	103
Colombia 1	3.57	3.48	104	97
Suakoko 8	3.14	3.21	97	95
IR 4-2[b]	2.42	3.14	77	86
CICA 8	3.25	4.19	[illegible]	84
Tox 494	2.03	3.04	70	80
Carolino[b]	1.48	2.43	62	58
INTI	0.34	1.97	18	43

a. Index of *Pyricularia* attack to leaf $\bar{X}$ for unlimed soil = 3.0
$\bar{X}$ for limed soil = 2.2

b. Local varieties.

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Sweet potato

The 20 cultivars of sweet potato produced a wide range in the graph (Figure 3), but none fell into quadrant IV. Some cultivars, such as Modelo-2, had good relative yields (97%), but their absolute yields (Table 3) under Al toxic conditions were not better than the average of the best one-third of the cultivars without Al toxicity. Therefore, according to the model, none of the cultivars evaluated had both tolerance and high yield potential.

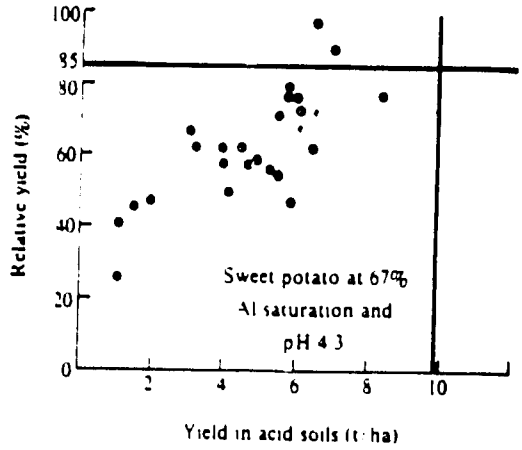

Figure 3. *Use of the model to indicate sweet potato cultivars tolerant to Al and with high yield potential under Al toxicity stress.*

Table 3. **Some measurements of selected sweet potato cultivars produced in soils with 67% and 34% Al saturation near Yurimaguas, Peru.**

Line name and number		Dry weight (t/ha)		Relative yield	Relative yield of vegetation at harvest	Relative crop index
		Unlimed soil	Limed soil		(%)	
Modelo-2	(Y-19)	6.6	6.7	97	111	100
Tambor	(Y-26)	5.4	11.0	[illegible]	50	98
Navarro	(Y-18)	6.0	[illegible]	76	123	62
---	(Y-06)	4.0	[illegible]	57	125	48
Modelo-1	(Y-20)	5.9	12.6	47	50	58
—	(Y-23)[a]	0.1	2.2	7	59	8

a. Peruvian line, all others from International Institute of Tropical Agriculture (IITA)

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Soybean

This crop was more susceptible to Al toxicity than any other crop evaluated (Figure 4). The best relative yield was only 58% (Table 4). In a trial in North Carolina, no soybean varieties were found which entered quadrant IV by use of the Piha and Nicholaides' method (Gill, 1983). Dr. Tony Juo from the International Institute of Tropical Agriculture (IITA) says this institute has already found some soybean lines that are tolerant to Al. Evaluation of these lines with others not tolerant to Al toxicity using the proposed approach will be interesting.

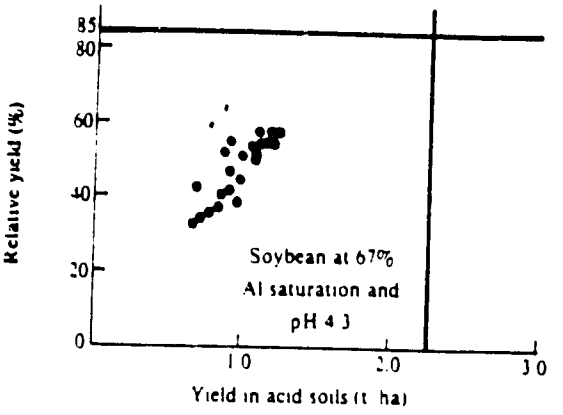

Figure 4. *Use of the model to indicate soybean cultivars tolerant to Al and with high yield potential under Al toxicity stress.*

Table 4 **Some measurements of selected soybean varieties grown in soils with 67% and 7% Al saturation near Yurimaguas, Peru.**

Variety	Yield[a] (t/ha)		Relative grain yield	Relative height	Relative number of pods
	Unlimed soil	Limed soil	(%)		
Hardee	1.23	2.13	58	74	75
SJ-2	1.20	2.07	58	72	70
Mineira	0.93	1.70	55	91	70
Jupiter[b]	0.93	2.23	42	72	90
Improved Pelican	0.76	2.20	35	82	52

a. Days to first harvest. $\bar{X}$ in acid soil = 84
$\bar{X}$ in limed soil = 89

b. Local variety.

Peanut

Peanut evaluation was very intriguing because, although none of the cultivars entered quadrant IV indicating tolerance and high yield potential (Figure 5), one line (UF 78307), supplied by Dr. Al Norden from the University of Florida, yielded more than 2 t/ha (Table 5) under very toxic Al conditions (82% Al saturation). This line has been used in breeding programs in North Carolina and Peru and its progeny has also demonstrated tolerance to Al (Katz, 1983). Evaluation of F_2 and F_3 lines continues.

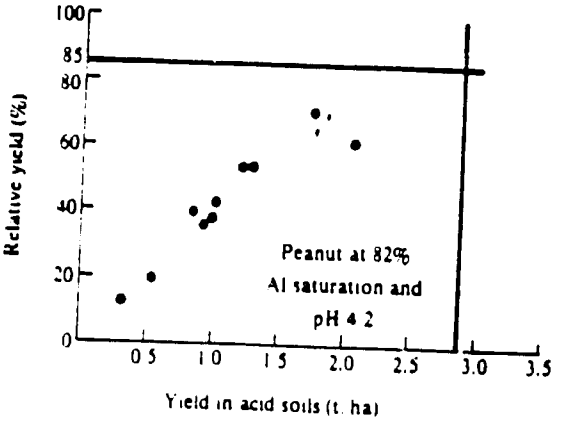

Figure 5 *Use of the model to indicate peanut cultivars tolerant to Al and with high yield potential under Al toxicity stress.*

Table 5 **Some measurements of selected peanut cultivars grown in soils with 82% and 35% Al saturation near Yurimaguas, Peru.**

Line or variety	Shelled yield (t/ha)		Relative grain yield	Relative shelling percentage	Relative weight of vegetation (green)
	Unlimed soil	Limed soil	(%)		
UF 78305	1.75	2.48	71	95	62
UF 78307	2.08	3.37	62	97	63
Florigiant	1.27	2.34	54	90	63
Tifrun	1.02	2.38	43	90	55
Blanco Tarapoto[a]	0.55	2.69	20	54	126
NC 6	0.31	2.30	13	57	108

a. Local variety

Cowpea

The first trial with cowpea apparently did not have sufficient Al saturation percentage (63%) to create adequate stress, thus, most cultivars fell into quadrant IV (Figure 6). Of the 27 cultivars evaluated, nine (all from IITA) yielded more than 2 t/ha in soils with 63% Al saturation. Some examples are shown in Table 6.

Due to the lack of a good range for cowpea, another trial was placed in soils with higher Al saturation (71%) and a better range was obtained. Although none of the cultivars entered quadrant IV, the TVX 1836-013J cultivar from IITA almost fell into quadrant IV. Results of trials 1 and 2 with cowpea (Tables 6 and 7; Figures 6 and 7) emphasize the fact that the term "tolerant to Al" is only relative and its definition depends largely on the conditions where the evaluation is carried out. Whatever is tolerant to 63% Al saturation is not necessarily tolerant at 71% Al saturation.

However, it seems that cowpea, as a species, has a general tolerance to Al toxicity. In both trials, cultivar Vita 4 (from IITA) yielded more than 2 t ha and showed 99% relative yields. Cultivars Vita 8, 6, and 7 yielded more than 1.7 t ha and had relative yields of 85%. We believe there are cowpea varieties adapted to soils with a high percentage of Al saturation and which can yield well under Al toxicity.

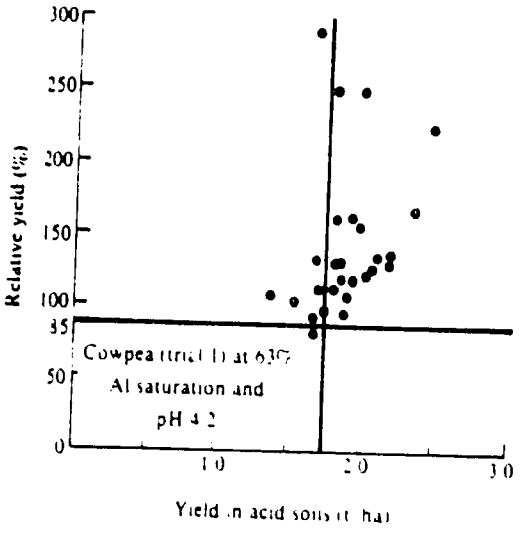

Figure 6. *Use of the model to indicate cowpea cultivars tolerant to Al and with high yield potential under Al toxicity stress (trial 1).*

Table 6. **Some measurements of various cowpea cultivars grown in soils with 63% and 28% Al saturation (trial 1) near Yurimaguas, Peru.**

Line or variety	Yield[a] (t/ha) Unlimed soil	Yield[a] (t/ha) Limed soil	Relative grain yield	Relative height (%)	Relative number of pods
Tvx 2394-01F	1.68	0.58	290	79	318
3 Mesino[b]	1.79	0.72	250	95	250
Tvx 66-2H	2.47	1.09	226	101	261
Tvx 1999-01F	2.38	1.43	166	99	162
Blackeye 5	1.75	1.90	92	97	88
Vita 5	1.72	2.04	84	91	91

a. Days to first harvest. $\bar{X}$ in acid soils = 66

$\bar{X}$ in limed soils = 68.

b. Local variety

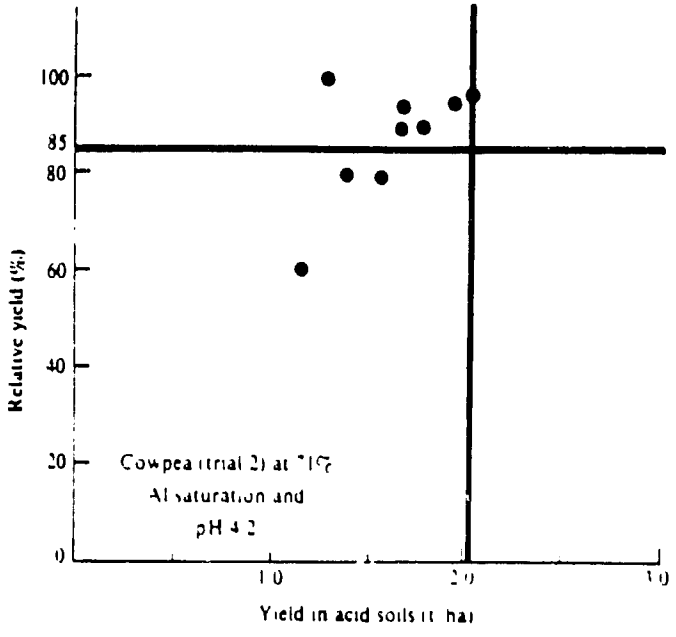

Figure 7. *Use of the model to indicate cowpea cultivars tolerant to Al and with high yield potential under Al toxicity stress (trial 2).*

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Table 7. Some measurements of various cowpea cultivars grown in soils with 71% and 24% Al saturation (trial 2) near Yurimaguas, Peru.

Line or variety	Yield (t/ha)		Relative grain yield	Relative height	Relative number of pods
	Unlimed soil	Limed soil	(%)		
Tvx 1836-013J	1.30	1.32	99	74	100
Vita 4	2.05	2.12	96	76	94
Tvx 1193-70	1.91	2.01	95	75	86
Tvx 66-2H	1.80	2.03	90	81	89
2 Mesino[a]	1.68	1.94	87	79	89
Vita 5	1.16	1.94	60	56	59

a. Local variety

Summary and conclusions

The proposed method serves well to simultaneously evaluate a number of cultivars for both tolerance to high Al saturation percentages and high yield potential under Al toxic conditions. This method can be adapted to evaluate a number of cultivars for their tolerance to any stress condition. The phrase "tolerant to Al" is a relative phrase and its definition depends on conditions with which a species is evaluated.

A new method is proposed for evaluating a large number of cultivars of any crop species under any soil stress condition, including aluminum toxicity. This method was used to differentiate tolerance to aluminum toxicity of 52 rice, 20 sweet potato, 22 soybean, 11 peanut, and 27 cowpea cultivars in field experiments near Yurimaguas, Peru from 1979 to 1982. Several rice and cowpea cultivars were revealed by the new method to be not only aluminum tolerant, but to possess high yield potential under aluminum toxic soil conditions.

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