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To cite this article: N. K. Fageria & V. C. Baligar (1997) Phosphorus-use efficiency by corn genotypes, Journal of Plant Nutrition, 20:10, 1267-1277, DOI: [10.1080/01904169709365334](https://doi.org/10.1080/01904169709365334)

To link to this article: <https://doi.org/10.1080/01904169709365334>



Published online: 21 Nov 2008.



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Phosphorus-Use Efficiency by Corn Genotypes

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ABSTRACT

Phosphorus (P) deficiency is a principal yield-limiting factor for annual crop production in acid soils of temperate as well as tropical regions. The objective of this study was to screen nine corn (*Zea mays* L.) genotypes at low (0 mg P kg⁻¹), medium (75 mg P kg⁻¹), and high (150 mg P kg⁻¹) levels of P applied in an Oxisol. Plant height, root length, shoot dry weight, root dry weight, shoot-root ratio, P concentration in shoot and root, P uptake in root and shoot, and P-use efficiency parameters were significantly ($P < 0.01$) influenced by P treatments. Significant genotype differences were found in plant height, shoot and root dry weight, P uptake in root and shoot, and P-use efficiency. Based on dry matter production and P-use efficiency, genotypes were classified as efficient and responsive, efficient and nonresponsive, nonefficient and responsive, and nonefficient and nonresponsive.

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INTRODUCTION

Corn is grown on approximately eight million hectares of acidic ($\text{pH} < 5.6$) soils, where P deficiency is an important limitation to its production (Pandey et al., 1994). The deficiency of P can be easily corrected through the use of P fertilizers; but due to the natural low P level and the high P-fixation capacity of acid soils, a higher dose is required for adequate crop yields. Due to the high price of phosphatic fertilizers, such a solution is not normally within the economic reach of farmers, especially in the developing countries. Under these situations, corn cultivars adapted to a lower level of P would provide a complementary solution for improving crop yield on acid, P-deficient soils.

A number of studies indicate genetic variation in the response to P by corn genotypes (Fox, 1978; Clark, 1991). This suggests that it would be worthwhile to attempt to identify P-efficient corn genotypes, a first step in breeding P-efficient cultivars. The objective of this study was to evaluate corn genotypes for P-use efficiency.

MATERIALS AND METHODS

A greenhouse experiment was conducted to evaluate P-use efficiency in nine corn genotypes. The soil used in the experiment was an Oxisol (clayey, kaolinite, isothermic Typic Haplustox). It had the following chemical and textural properties before the application of P treatments: pH 5.0 (1:2.5 soil-water ratio), extractable P $0.4 \text{ mg} \cdot \text{kg}^{-1}$, extractable potassium (K) $12 \text{ mg} \cdot \text{kg}^{-1}$, extractable calcium (Ca) $0.4 \text{ cmol}_c \cdot \text{kg}^{-1}$, extractable magnesium (Mg) $0.3 \text{ cmol}_c \cdot \text{kg}^{-1}$, extractable aluminum (Al) $0.1 \text{ cmol}_c \cdot \text{kg}^{-1}$, extractable copper (Cu) $1.1 \text{ mg} \cdot \text{kg}^{-1}$, extractable zinc (Zn) $0.3 \text{ mg} \cdot \text{kg}^{-1}$, extractable iron (Fe) $36 \text{ mg} \cdot \text{kg}^{-1}$, and extractable manganese (Mn) $7 \text{ mg} \cdot \text{kg}^{-1}$ of soil.

Phosphorus and K were extracted by the Mehlich 1 extracting solution [0.05M hydrochloric acid (HCl) + 0.0125M sulfuric acid (H_2SO_4)]. Phosphorus was determined colorimetrically, and K by flame photometry. Calcium, Mg, and Al were extracted with 1M potassium chloride (KCl). Aluminum was determined by titration with sodium hydroxide (NaOH), and Ca and Mg by titration with EDTA. Micronutrients were determined on a portion of the extract of P by atomic absorption spectrophotometry. Organic matter was determined by the Walkley-Black method, and textural analysis by pipette method. Soil analysis methods used in this study are described in a soil analysis manual published by FMBPAPA (1979).

The treatment consisted of three P levels, i.e., low (0 mg P kg^{-1}), medium (75 mg P kg^{-1}), and high (150 mg P kg^{-1}), and nine corn genotypes. A complete randomized design was used in a factorial arrangement, and treatments were replicated three times. The study was conducted in plastic pots, with 4 kg of soil in each. Each pot received 8 g dolomitic lime and was subjected to wetting and

drying cycles for three weeks before sowing. At the time of sowing, in addition to P treatments, each pot received a basal application of 320 mg nitrogen (N) as ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$, 647 mg K as potassium chloride (KCl), and 500 mg FTEBR-12 as a source of micronutrients. These basal fertilizer rates were based on the recommendations of Fageria et al. (1995). Each pot contained three plants, which were frequently watered to maintain moisture at approximate field capacity. Plants were harvested at 19 days after sowing.

After harvesting the tops, the roots were removed from the soil with the use of a water jet. The tops, as well as roots, were washed with distilled water several times before drying. Plant material (roots and tops) was dried in a forced-draft oven at about 70°C until of a constant weight, and milled. Ground material was digested with mixtures of nitric (HNO_3) and perchloric (HClO_4) acids (2:1). The P concentration in the digest was determined colorimetrically (Morais and Rabelo, 1986). All data were analyzed by analysis of variance, and the F-test was used to evaluate treatment significance. Tukey's test was used to compare treatment means at a 5% probability level.

RESULTS AND DISCUSSION

All the plant growth and P uptake parameters were significantly affected by P treatments (Table 1). Genotypes were significantly different, however, in relation to plant height, shoot and root dry weight, P uptake in root and shoot, and P-use efficiency. Phosphorus x genotype interactions were significant for plant height, shoot dry weight, and P uptake in shoot, indicating that the genotype rank may change under variable P levels and the need for evaluation under different P levels, if these plants parameters are taken as selection criteria. All plant growth and P uptake parameters showed significant linear response by the addition of P levels in the soil except P concentration in the root. Quadratic responses, however, were significant for plant height, shoot dry weight, P concentration in shoot, P concentration in root, and P uptake in shoot.

Growth parameters and P uptake responses to applied soil P levels are presented in Table 2. All growth and P uptake parameters increased significantly with increasing levels of soil P. This means that the soil used in the experiment was appropriate for screening purposes. One of the prerequisites of varietal screening for mineral stress is that the growth medium should be deficient in the nutrient under investigation (Fageria, 1989).

To identify which of the growth parameters is most sensitive to P deficiency, increases in plant height, shoot dry weight, shoot-root ratio, P concentration in shoot, P concentration in root, and P uptake in shoot at medium and high P levels as compared to a low P level were calculated (Table 3). Among growth parameters, shoot-root ratio exhibited the maximum increase in growth with P addition and was followed by dry weight of shoot. Among P uptake parameters, P uptake in shoot increased maximally at the medium P level, followed by P concentration in

TABLE 1. Significance of F values and orthogonal contrasts derived from analysis of variance for variables measured on nine genotypes of corn at three P levels.

Variable	P levels	Genotypes	P x G	P linear	P quadratic	CV %
Plant height	**	**	*	**	**	7
Root length	**	NS	NS	**	NS	15
Shoot dry weight	**	**	*	**	**	13
Root dry weight	**	**	NS	**	NS	29
Shoot/root ratio)	**	NS	NS	**	NS	26
P conc. in shoot	**	NS	NS	**	**	12
P conc. in root	**	NS	NS	NS	**	30
P uptake in shoot	**	**	*	**	*	18
P uptake in root	*	*	NS	*	NS	42
P-use efficiency	**	**	NS	--	--	25

*, **Significant at 0.05 and 0.01 probability levels, respectively. NS=not significant.

TABLE 2. Influence of P levels on growth and P-uptake parameters across nine corn genotypes.

Plant parameter	Low P (0 mg P kg ⁻¹)	Medium P (75 mg P kg ⁻¹)	High P (150 mg P kg ⁻¹)
Plant height (cm)	45.0c	70.00b	77.00a
Root length (cm)	50.00a	47.00a	42.00b
Shoot dry weight (g/pot)	1.06c	2.27b	2.75a
Root dry weight (g/pot)	0.74a	0.56b	0.47b
Shoot/root ratio	1.55c	4.13b	6.21a
P conc. in shoot (g Kg ⁻¹)	1.06c	3.07b	4.21a
P conc. in root (g Kg ⁻¹)	0.78b	1.04a	0.88ab
P uptake in shoot (mg/pot)	1.12c	6.97b	11.55a
P uptake in root (mg/pot)	0.59a	0.58a	0.43b
P-use efficiency (mg/mg)	--	170.00a	131.00b

Values for each growth parameter and P uptake under different levels of P followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

TABLE 3. Increase (%) in corn growth and uptake parameters at medium and high soil P levels as compared to low soil P level.

Plant parameter	Medium P (75 mg P kg ⁻¹)	High P (150 mg P kg ⁻¹)
Plant height	56	71
Shoot dry weight	114	159
Shoot-root ratio	166	307
P conc. in shoot	190	297
P conc. in root	33	13
P uptake in shoot	522	93

Growth or P uptake increase = [(growth at medium or high P - growth at low P)/growth at low P] x 100.

shoot. This means that shoot weight and P uptake in shoot were the most sensitive response parameter to P deficiency. Shoot weight is much more easily determined as compared to root weight and is recommended for P-screening studies of corn genotypes under greenhouse conditions.

Phosphorus x genotype interactions for plant height and shoot dry weight were significant (Table 1), indicating that the three P levels cause different responses in corn growth as the P level increases. There were significant ($P < 0.01$) differences among genotypes for each P level for plant height (Table 4). Shoot dry weight, however, was significant at low and medium P levels. Plant height ranged from 39 to 50 cm at the low P level, from 58 to 84 cm at the medium P level, and from 68 to 87 cm at the high P level. In the case of shoot dry weight, the variation was 0.8 to 1.6 g·pot⁻¹ at the low P level, 1.7 to 3.3 g·pot⁻¹ at the medium P level, and 2.4 to 3.4 g·pot⁻¹ at the high P level. Plant height and shoot dry weight across P levels varied from 68 to 87 cm and 1.7 to 2.78 g·pot⁻¹ respectively. Genotype BR 112 produced significantly higher dry matter at the low and medium P levels. This genotype also had significantly higher height as compared to other genotypes. Similarly, genotype Dina 170 had significantly lower dry matter as well as plant height at the low and medium P levels.

Root length across P levels of nine genotypes ranged from 41 to 50 cm, however, genotypes did not differ significantly in relation to this trait (Table 5). Similarly, shoot-root ratio and P concentration in root and shoot did not vary significantly among genotypes across three P levels. Root dry weight, as well as P uptake in root, significantly differed among corn genotypes.

Critical P concentration in corn tissue, reported by Mallarino (1995), ranged from 2.3 to 2.5 g·kg⁻¹. Jones et al. (1990) also reported a critical value of P in corn

TABLE 4. Plant height and shoot dry weight of nine genotypes of corn under different P levels.

Genotype	Plant height (cm)			Average	Shoot-dry weight (g/pot)			Average
	Low P	Medium P	High P		Low P	Medium P	High P	
AG 519	44ab	72ab	73abc	63b	1.0bcd	2.3bc	2.6a	2.00c
BR 107	47ab	68b	71bc	62b	0.9bcd	1.7c	2.5a	1.70c
BR 112	51a	84a	87a	74a	1.6a	3.3a	3.4a	2.78a
BR 126	42ab	72ab	81abc	65b	0.9bcd	2.4bc	2.4a	1.89c
BR 451	46ab	70b	83ab	66b	1.0bcd	2.2bc	2.8a	1.98bc
C 701	39b	58b	68c	55c	0.9bcd	1.9c	2.6a	1.79c
C 805	46ab	69b	80abc	65b	1.2bc	2.6b	3.3a	2.35b
Dina 170	39b	66b	77abc	61bc	0.8d	1.8c	2.7a	1.74c
Sintetico 6	50a	72ab	75abc	66b	1.3ab	2.3bc	2.4a	1.99bc
F-test	**	**	**	**	**	**	NS	**
CV %	7	7	7	7	13	11	13	13

**Significant at 0.01 probability level. NS=not significant.

Means in the same column followed by the same letter are not significantly different at 0.05 probability level by Tukey's level.

TABLE 5. Root length, root dry weight, shoot-root ratio, P concentration in root and shoot, and P uptake in root of nine corn genotypes.

Genotype	Root length (cm)	Root length (g/pot)	Shoot-root ratio	P. conc. in root (g Kg ⁻¹)	P conc. in shoot (g Kg ⁻¹)	P uptake in root (mg/pot)
AG 519	50a	0.54b	4.07a	0.96a	2.87a	0.53ab
BR 107	46a	0.54b	3.64a	0.80a	2.86a	0.44ab
BR 112	50a	0.81a	4.01a	0.10a	2.68a	0.76a
BR 126	41a	0.52b	3.99a	1.04a	2.71a	0.55ab
BR 451	51a	0.62ab	3.95a	0.93a	3.00a	0.56ab
C 701	44a	0.55ab	3.90a	0.87a	2.78a	0.46ab
C 805	45a	0.61ab	4.79a	0.89a	2.68a	0.57ab
Dina 170	45a	0.47b	3.82a	0.79a	2.74a	0.37b
Sintetico 6	47a	0.62ab	3.48a	0.85a	2.65a	0.55ab
F-test	NS	**	NS	NS	NS	*
CV %	15	29	26	30	12	42

*, **Significant at 0.05 and 0.01 probability levels, respectively. NS = not significant.

Means in same column followed by the same letter are not significantly different 0.05 probability level by Tukey's test.

TABLE 6. Phosphorus uptake in the shoot and P-use efficiency of nine corn genotypes under different P levels.

Genotype	P uptake in shoot (mg/pot)			Average	P use efficiency (mg/mg) across medium and high P levels
	Low P	Medium P	High P		
1. AG 519	1.11bc	7.41ab	11.29ab	6.60b	140ab
2. BR 107	0.99c	5.02b	11.37ab	5.79b	123b
3. BR 112	1.63a	9.79a	14.05a	8.48a	145ab
4. BR 126	0.87c	7.31ab	9.93ab	6.03b	195ab
5. BR 451	1.10bc	7.38ab	12.51ab	6.99ab	128ab
6. C 701	0.90c	6.18ab	10.59ab	5.88b	130ab
7. C 805	1.20abc	7.94ab	12.99ab	7.38ab	140ab
8. Dina 170	0.80c	4.93b	12.01ab	5.90b	197a
9. Sintetico 6	1.53ab	6.77ab	9.18b	5.82b	153ab
F-test	**	**	*	**	**
CV %	15	18	14	18	25

*, **Significant at 0.05 and 0.01 probability levels, respectively. NS = not significant.

Means in the same column followed by the same letter are not significantly different at 0.05 probability level by Tukey's test.

P use efficiency = (dry matter yield of root and shoot across medium and high P level - dry matter yield of root and shoot at low P level) / (P accumulation in root and shoot across medium and high P level - P accumulation in root and shoot at low P level).

tissue in the early growth stage, from 2.5 to 4.0 g·kg⁻¹. When we compared our values with these values only at low P (Table 2), the P concentration in the shoot was below the critical level. At the medium and high P levels, the plant shoot P concentration was above the critical level. This means that P concentration limited corn yield only at low P concentration.

Phosphorus uptake under three P levels differed significantly among genotypes (Table 6). At the low P level, it ranged from 0.87 to 1.63 mg·pot⁻¹ at the medium P level, from 4.93 to 9.79 g·kg⁻¹; and at the high P level, from 9.18 to 14.05 g·kg⁻¹. Low and high values of P uptake in shoot are related to dry matter production. Phosphorus-use efficiency also differed significantly among genotypes across P levels (Table 6). Genotype Dina 170 had the highest P-use efficiency, and genotype BR 107 had the lowest. Based on dry matter production (root plus shoot) at the low P level and P-use efficiency, the genotypes were classified into four groups

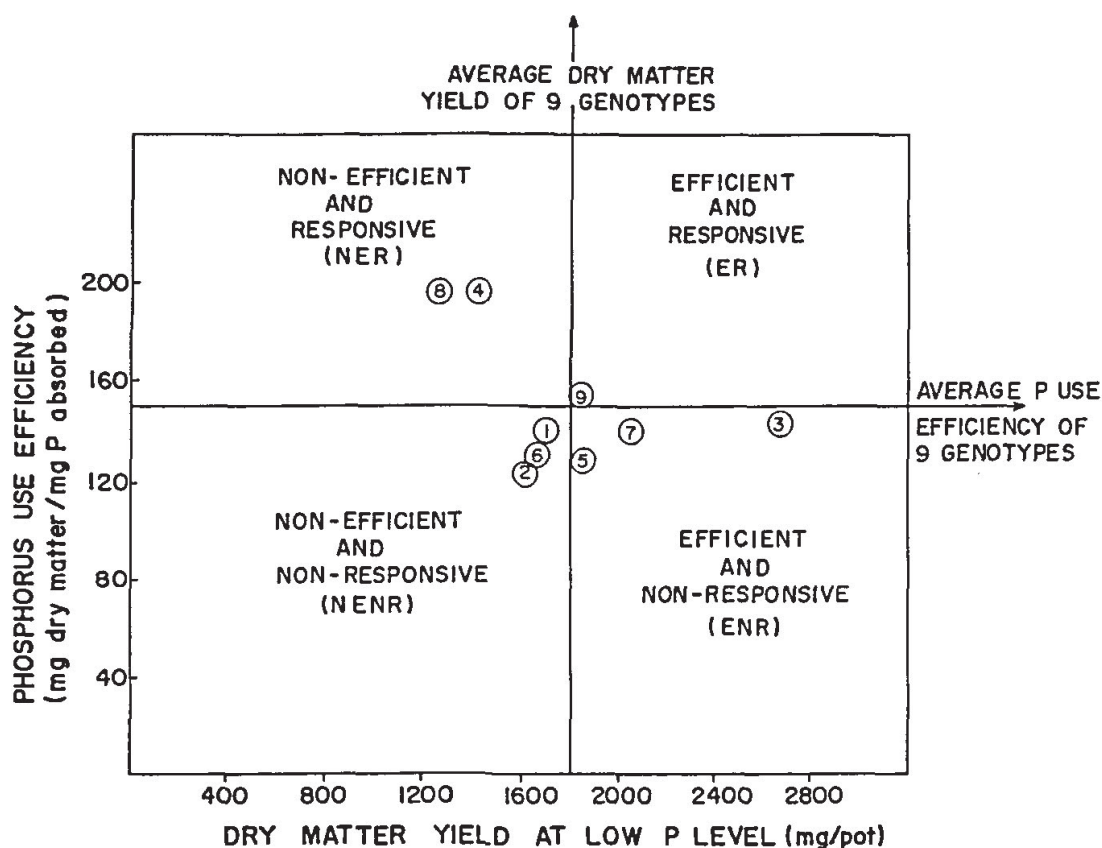


FIGURE 1. Classification of nine corn genotypes for phosphorus-use efficiency. Values in the circles refer to cultivar numbers, which are numbered in Table 6.

(Figure 1), according to the methodology proposed by Fageria and Baligar (1993). These groups were as follows:

- 1) Efficient and responsive: Genotypes which produced dry matter yield higher than the average of nine genotypes at the low P level and responded well with the addition of P (average P-use efficiency, higher than the average of nine genotypes), were classified as efficient and responsive. Genotype Sintetico 6 falls into this category.
- 2) Efficient and nonresponsive: In this group are genotypes which produced higher than average dry matter yield, but P-use efficiency was lower than the average of nine genotypes. Genotypes BR 112, BR 451, and C 805 fall into this category.
- 3) Nonefficient and responsive: In this group are genotypes which produced less than average dry matter yield, but P-use efficiency was higher than average. In this group fall genotypes BR 126 and Dina 170.
- 4) Nonefficient and nonresponsive: In this group are genotypes which produced lower than average dry matter yield as well as lower than average P-use

efficiency. In this group fall the genotypes AG 519, BR 107, and C 701. From a practical point of view, genotypes which fall under the group efficient and responsive are the best ones. These genotypes can produce well under a low P level and respond well with P application. The second group, which can be used under low technology or under a low P level and can produce well, are the efficient and nonresponsive.

CONCLUSIONS

The use of P-efficient genotypes to increase and/or stabilize crop production has become increasingly attractive in recent years due to the high cost of fertilizers and to pollution problems. Results of this study indicate that corn genotypes differ significantly in their P requirements. Dry matter production per unit of P uptake can be used as a criterion for P-screening studies of corn under greenhouse conditions.

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