Screening of tolerant maize genotypes in the low phosphorus field soil

Huimin Jiang[A, B], **Juncheng Yang[A, B]**, Jianfeng Zhang[A, B] and Yannan Hou[A, B]

[A]Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, 100081 Beijing, China, Email jcyang@caas.ac.cn
[B]Key Lab. of Plant Nutrition and Nutrient Cycling, Ministry of Agriculture of the People's Republic of China, 100081 Beijing, China, Email yangjch@263.net

Abstract
Exploring the genetic resources of crops is an alternative method of coping with reduced phosphorus (P) availability in soils. In this study, 116 maize inbred lines with various genetic backgrounds collected from several Agricultural Universities and Institutes in China were employed in a field experiment to indentify maize genotypes tolerant of low P soil. Overall, 15 maize inbred lines were selected from the field experiment according to the 100-grain weight in P-deficient soil at maturity when compared to the value in plants grown in P-sufficient soil. All of the selected lines were then subjected to a second field experiment to evaluate indexes for assessment of low-P tolerant maize genotypes. Based on the results of the two experiments, adventitious root angle, PO representing decrease rate of the root length, root surface area and root volume were preliminarily defined as the screening indexes of low-P tolerant genotypes in the seedling stage of the field experiment. Additionally, the 100-grain weight and grain P utilization efficiency were found to be suitable for screening indexes of low-P tolerant genotypes during the mature stage in the field experiment.

Key Words
Low-P stress, four quadrant analyses, root morphology.

Introduction
As many other plants, maize is sensitive to P and confronted with the dilemma of "P-deficiency in heredity" (Usuda and Kousuke 1991). In recent years, some researchers have involved in screening and improving the tolerance to P deficiency in maize cultivars (Yao Qi-lun *et al.* 2007; Zhang Jing *et al.* 2004; Yan Liu *et al.* 2004). However, many trails results are based on hydroponics and pot experiments and the selected genotypes have not been validated in the field. Therefore, this research was conducted to screen tolerant maize genotypes in low P soil. To accomplish this, 116 maize inbred lines with various genetic backgrounds collected from several Agricultural Universities and Institutes in China were employed in the field experiment I, which resulted in selection of 15 maize inbred lines that were evaluated in the field experiment II to identify an index system for assessment of low-P tolerant maize genotypes. The results presented here should aid in screening for seminal germplasms tolerant to P-deficiency and apply available materials for breeders.

Materials and methods
Plant materials
116 maize inbred lines with various genetic backgrounds were employed in field experiment I in 2007. Overall, 15 maize inbred lines were selected from the experiment I based on the difference in their 100-grain weight. Specifically, the low P-tolerant genotypes DSY-30, DSY-2, DSY-31, DSY-20, DSY-21, DSY-39, DSY-101, DSY-33, DSY-32, DSY-23 and DSY-93 and the P-sensitive genotypes, DSY-113, DSY-79, DSY-129 and DSY-48 were selected for use in field experiment II in 2008.

Treatments
Field experiment I and II employed a randomized complete block design. Two treatments with different P application levels of 0 and 120 kg P_2O_5/hm^2 corresponded to the treatments of PO and PI; i.e., P-deficiency and P sufficiency. Urea, superphosphate and potassium chloride were supplied with N (225 kg N/hm^2 in total, 1/2 N as basal, the other 1/2 N as top-dressing at bell-mouthed stage), P (as basal application), and K (105 kg K_2O/hm^2 as basal application), respectively.

Measurement
Field experiment I: the 100-grain weight and grain P content of the different maize inbred lines were measured. Field experiment II: In the seedling stage, roots and shoots were determined morphological traits. Then the 100-grain weight and grain P content were determined.
Equations
PO decrease rate (%) = (value analysis of PI - value analysis of PO) / (value analysis of PI) × 100%

Results
Effect of low P stress on the100-grain weight of different maize genotypes in the field experiment I and II
The histogram in Figure1 indicated the PO decrease rate of the 100-grain weight of different maize genotypes. As a whole, through testing (KS test, Z value was 0.928, P value of two-tailed test was 0.356) and confidence, confidence interval, the results met the normal distribution. Selection of maize genotypes tolerant to low P soils indicated that 100-grain weight was increased under low-P stress and the changes rates of PO decrease rate were on the left of -2.5% of confidence, as well as the PO decrease rate were lower than 5%. Low-P sensitive genotypes were selected, when PO decrease rate was higher than 10%.

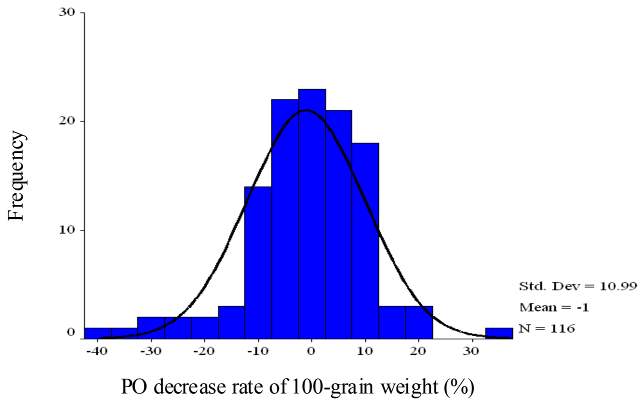

Figure1. Histogram of PO decrease rate of the 100-grain weight of 116 maize inbred lines.
Four quadrant analyses of the 100-grain weight for the selected typical maize genotypes revealed that low-P tolerant maize genotypes were primarily distributed in the first and fourth quadrants in the field experiment I, which indicated efficient genotypes. However, low-P sensitive maize genotypes were mainly distributed in the second and third quadrant, which indicated inefficient genotypes (Figure 2). Based on the PO decrease rate of the 100-grain weight and the four quadrant analyses, the following 15 inbred lines were selected for further analysis: low P-tolerant genotypes, DSY-30, DSY-2, DSY-31, DSY-20, DSY-21, DSY-39, DSY-101, DSY-33, DSY-32, DSY-23 and DSY-93; P-sensitive genotypes, DSY-113, DSY-79, DSY-129 and DSY-48. The same result was obtained in the field experiment II.

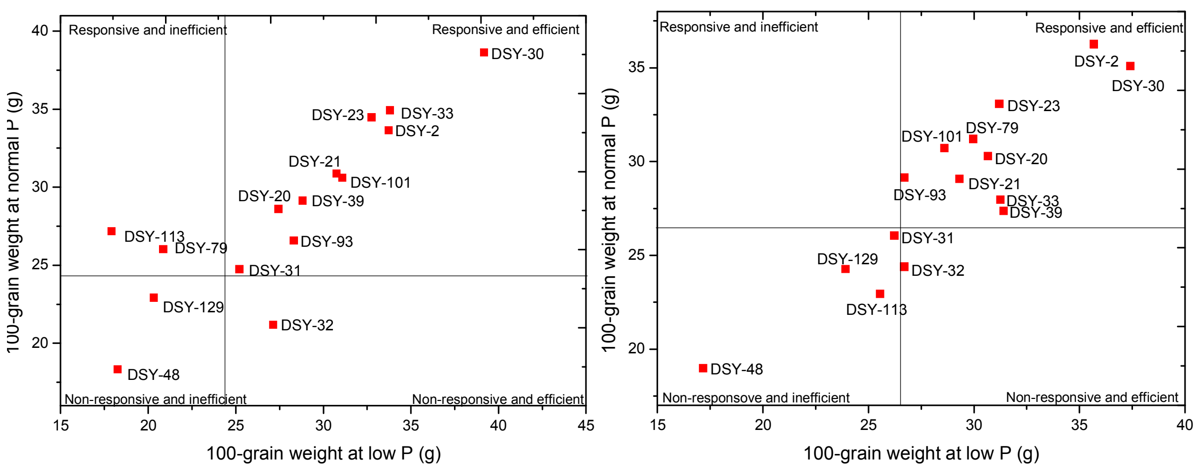

Figure 2. The 100-grain weight of typical inbred lines of maize under PO and PI treatments in field experiment Ⅰ (left) and II (right)

Effect of low P stress on grain P utilization efficiency of different maize genotypes in the field experiment I and II

Grain P utilization efficiency by 15 typical maize genotypes was investigated in field experiments I and II (Figure 3 and Figure 4). There was a significant difference in grain P utilization efficiency between low-P tolerant and sensitive maize genotypes (P<0.05). The Grain P utilization efficiency of low-P tolerant genotypes was higher than that of low-P sensitive genotypes in the field experiment I and II, regardless of whether the plants were grown in P deficient or sufficient soil. The grain P utilization efficiency of P sensitive genotype DSY-48 was lower than that of other genotypes under P deficiency and sufficiency conditions.

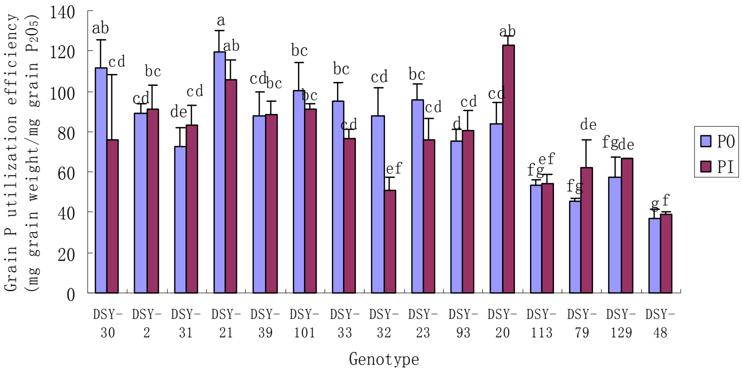

Figure 3. Grain P utilization efficiency under different P treatments in field experiment I .

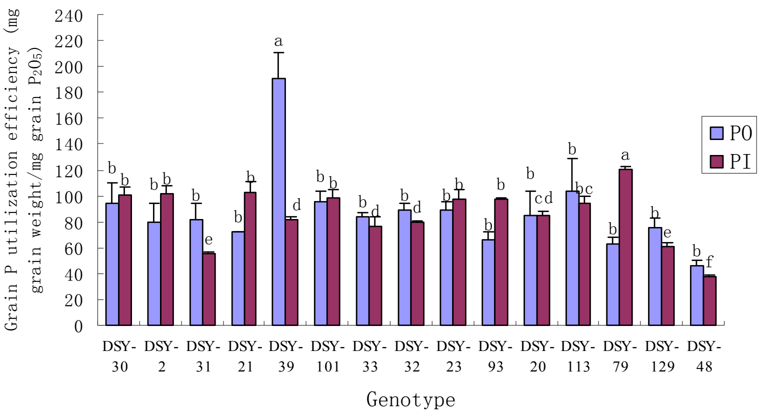

Figure 4. Grain P utilization efficiency under different P treatments in field experiment II.

Effects of low P stress on root indexes of different maize genotypes during the seedling stage in the field experiment II

Root architectural plasticity may be an important factor in the acquisition of immobile nutrients such as P by plants. The results of this study suggested that an adventitious root angle may be correlated with low P adaptation. Adventitious root angles of maize genotypes under PO treatment were smaller than those under PI treatment (Figure 5). Adventitious root of DSY-48 (low-P sensitive genotype) had deepest growth angle, while those of DSY-30; DSY-33 (low-P tolerant genotype) had shallower growth angles than the other genotypes under low P stress. Our results demonstrated that variation for adventitious root angle existed in maize, but that P could modulate root shallowness independently and that a shallower root system was beneficial for plant performance in maize grown under low P conditions.

Root morphological parameters such as PO decrease rate of root length, root surface area and root volume were shown in Table 1. Increased root lengths were observed for maize varieties grown under low-P stress. Specifically, 64% of the genotypes that were tolerant to low P showed increased root lengths under low-P stress, while only 25% of the genotypes that were sensitive to low P showed increased root length under low P treatment. The PO decrease rate of DSY-93 was significantly higher than that of other genotypes. The total root surface area and root volume of low-P tolerant genotypes were higher than those of low-P sensitive genotypes under low P stress, except for DSY-113. These findings indicated that low-P tolerant genotypes could accelerate root growth under low P conditions, resulting in roots exploring more soil space for the uptake of nutrients.

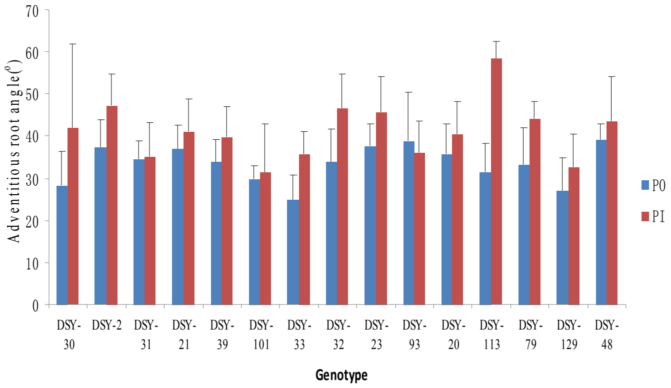

Figure 5. Influence of the P treatment on the adventitious root angle of typical maize genotypes.

Table 1. PO decrease rate of root morphology during the seedling stage in field experiment II.

Genotype	No.	Root length PO decrease rate (%)	Root surface PO decrease rate (%)	Root valume PO decrease rate (%)
P tolerant	DSY-30	-6.91	-16.08	-25.60
	DSY-2	-56.65	-10.11	22.05
	DSY-31	11.01	18.10	25.00
	DSY-21	-17.25	5.48	23.81
	DSY-39	-7.38	8.28	21.24
	DSY-101	-1.11	-5.42	-9.91
	DSY-33	50.25	34.35	13.04
	DSY-32	34.14	40.00	45.03
	DSY-23	11.82	5.32	-1.00
	DSY-93	-127.40	-53.17	-2.97
	DSY-20	-45.45	-47.57	-49.68
P sensitive	DSY-113	-68.90	-56.37	-45.57
	DSY-79	17.60	26.66	34.46
	DSY-129	28.21	22.67	16.67
	DSY-48	2.27	3.31	4.43

Conclusion

This field study clearly demonstrates that species differ in their ability of P to take up from the soil and that these differences were attributed to the morphology and physiology of plants relative to their germplasm base. Based on these results, an effective method of increasing P-efficiency is to develop P-efficient cultivars that can achieve a high yield under P deficient conditions. The results of this study also indicated that soil P availability during maize seedling development is critical for early growth and grain yield of maize. In this study, adventitious root angle, PO decrease rate of the root length, root surface area and root volume were preliminarily defined as the screening indexes for low-P tolerant genotypes during the seedling stage. In addition, the 100-grain weight and grain P utilization efficiency were defined as the screening indexes of low-P tolerant genotypes during the maturing stage in the field.

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