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Phosphorus Efficiency of Different Maize *(Zea mays*, L.*)* Genotypes Grown on Calcereous Soil

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ABSTRACT

This research aimed to study P efficiency of ten maize genotypes (*zea mays*, L.) under two levels of P in calcareous soil and to quantify the contribution of root growth in P uptake. Plants were grown in potted soil with two levels of available P in soil 40(low P) and 270 (high P) mg P/ kg soil in glasshouse with five replicates in randomized complete block design. The maize genotypes were harvested 4 weeks after transplanting. All plants increased significantly with increasing P level, except code 1, code 3, code 7 and code 8 (single hagen 10, 15, Bshaier 13 and Pioneer 3062 respectively), there was no significant difference between shoot dry matter at low and high P level. Maize genotypes (code1, code 3, code 7, and code 8) attained more than 80% of its maximum yield already at the lower level of available P. In contrast, at low level of available P, maize genotypes code 5 and code 9 (single hagen 123 and 151 respectively) attained only 21.9% and 14.7% respectively of their highest yield. This signified that maize genotypes (code1, code 3, code 7, and code 8) had high P efficiency, whilst maize genotypes (code 5 and code 9) had low P efficiency. Maize genotypes code1, code 3, code 7 and code 8 had longer roots in limited P supply followed by code 2, code 4 and code 6 (single hagen 12, 122 and 129 respectively), and the shorter roots observed in maize genotypes code 5, code 9, and code 10 (single hagen 155). The adaptation of maize genotypes to low level of soil P is closely related to better developed root system and the increase in root length under P stress may be one of the possible mechanisms of P efficiency in maize. At low P level, code 1 and code 7 were the highest P uptake per plant. In contrast, code 5 and code 9 were the lowest maize P uptake. In conclusion, the results of this study suggested that root growth system would be a suitable plant parameter for selecting P efficient maize genotypes especially under limited P supply.

Additional Index Words: Maize Genotypes, phosphorus efficiency, root length.

INTRODUCTION

Maize (*Zea mays,* L.) is one of the most important cereal crops in Egypt and the world. Maize in the world rank the third crop surpassed only by wheat and rice. It is used mainly for human consumption and animal feed. Efforts are focused on increasing productivity of this crop by growing high yielding new genotypes under the most favorable cultural treatments with highly nutrient efficiency especially phosphorus.

Phosphorus (P) is one of the 17 essential elements needed for plant growth and reproduction. Phosphorus is indispensable to all forms of life because of its genetic role in nucleic acids and function in biological energy transfer via adenosine triphosphates (ATP). Ozanne (1980) reported that, P is one of the most yield limiting factors in many arid and semi-arid soils. To mitigate this problem, the application of commercial fertilizers was the most common recommendation. However, there are various concerns associated with the use of commercial fertilizers in general and P fertilizers in particular. These concerns are: firstly, the resource-poor farmers of tropics and subtropics are unable to use fertilizers due to lack of money and/ or unavailability of fertilizers (Egle *et al.*, 1999). Secondly, due to the prevailing adverse chemical properties of tropical and sub tropical soils (acidity and alkalinity). Phosphorus is rapidly transformed to hardly available form even after fertilizer application (Marschner, 1995). The third reason is the increase of legislative regulations than restrict the use of commercial fertilizers, so as to minimize environmental hazards due to run-off and leaching (Sattelmacher *et al.,* 1994). The above- mentioned limitations of commercial fertilizers on one hand and the increase world population that has led to the cultivation of marginal land on the other hand necessitated the look for the most potential solution.

In calcareous soils, phosphorus may be immobilized by any or all the following mechanisms: a) adsorption on active sites of $CaCO_3$ b) precipitation by Ca in the system resulting in reduced P availability C) reaction with the exchangeable Ca. The amounts of calcium carbonate affect distinctly the soil properties related to plant growth, whether they are physical, such as the soil water relations, and crusting, or chemical such as the

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availability of plant nutrients (FAO, 1984). In addition, at high pH (more than 8.0), the P in soil becomes unavailable.

Plant species differ in their ability to grow under low available phosphorus in soil, i.e. they differ in their P efficiency (Fageria and Costa, 2000; Bhadoria *et al.*, 2002). Phosphorus efficiency can be generally defined as the ability of a crop plant to produce high yield in a soil (or other media) that is limiting in phosphorus supply (Gourley *et al.*, 1994). Also, may be defined as the ability of a plant to produce a certain percentage of its maximum yield (80% of maximum yield) at low level of soil P (Föhse *et al.*, 1988). Phosphorus efficiency can arise in two ways: I) the efficiency with which P is utilized to produce yield, i.e. the amount of P needed in the plant to produce one unit of dry matter. This is often called P utilization efficiency or internal P requirement and it is the P concentration in the plant to produce a given percentage of its maximum yield (for example 80 – 90% of maximum yield) (Föhse *et al.*, 1988; and Bhadoria *et al.*, 2002). II) The P uptake efficiency of the plant is the ability of the root system to acquire P from the soil and accumulate it in the shoots (Bhadoria *et al.*, 2002).

Differences in phosphorus utilization efficiency may occur among plant species or genotypes of the same species due to differences in amounts of shoot dry matter produced per unit of P acquired (Rao *et al.*, 1997). This may be related to the ability of plants to conserve, re-translocation, and use inorganic P in its tissue (Caradus and Snaydon, 1987).

The aim of this work may eventually help to generate maize genotypes with enhanced P efficiency and help to select the highly P efficient maize genotypes from the ten maize genotypes which examined in this study, thus leading to improved fertilizer management and increased crop yield at low P soils.

MATERIALS AND METHODS

Soil preparation:

The soil used in this work was collected from El-Banger El-Sukkar region, Alexandria, Egypt from a depth of about 0 -40 cm. The soil was air-dried, sieved through a 2 mm sieve to homogenize and separate roots from soil. The main soil physical and chemical properties are shown in Table (1). The soil properties were determined according to the methods describing by (Black, 1965).

Basal applications of N, K and Mg fertilizers were corporate with each kg soil at a rate of 150 mg N as NH_4NO_3, 150 mg K as K_2SO_4, and 40 mg Mg as $MgSO_4$ per kg soil. Two rates of phosphorus (40 and 270 mg P/ kg soil) were applied to obtain low and high levels of available P as determined by sodium bicarbonate method (Olsen *et al*, 1954).

Pot experiment:

Each plastic pot (Ø=11cm) was uniformly filled with 280 g of the prepared soil and compacted to bulk density of about 1.4 g cm^{-3}. One week before planting, all pots were watered to the volumetric moisture content 0.25 cm^3cm^{-3}, which correspond to the field capacity.

Ten maize genotypes were collected as seed (single hagen) and its detailed information is given in Table 2:

Uniform seedlings of maize genotypes each having two or three pairs of fully grown leaves, were selected and transplanted into the pots at the rate of one seedling per pot. The N fertilizer (in the form of ammonium nitrate NH_4NO_3 (35%)) was applied in splits as required in the time course for plant growth at the rate of 50 mg/20 ml water for each pot.

The maize genotypes were harvested 4 weeks after transplanting and the shoots were separated from roots. The shoots were then dried at 70ºC/48 hours (Steyn, 1959) to constant weight in a forced-draft oven for 48 hours and then weighed and milled for analysis.

Phosphorus was extracted from soil samples at harvest by sodium bicarbonate (0.5N) method according to (Olsen *et al.*, 1954) and determined by ascorbic acid – molybdenum blue method at wave length of 406 nm as described by Murphy and Riley (1962). Samples of plant material were wet digested with H_2SO_4–H_2O_2 (Lowther, 1980) and phosphorus was determined by vanadomolybdophosphoric method (Jackson, 1967).

Root length was measured using the line intersect method according to Tennant (1975) method.

Table 1. Physical and chemical properties of the soil

Sand %	Silt %	Clay %	Soil texture	pH	EC dSm^{-1}	OM %	$CaCO_3$ %	N(1) mg/kg	P(1) mg/kg
57	19	24	Sandy clay loam	8.2	2.1	0.2	30.8	9.52	5.61

(1) Available N and P

Table 2. List of maize genotypes and experimental code numbers used in the experiment

Genotypes (Single hagen)	10	12	15	122	123	129	Bshaier 13	Pioneer 3062	151	155
Code	1	2	3	4	5	6	7	8	9	10

Statistical methods:

The treatments were arranged in a randomized complete block design and replicated five times. Data were analyzed by using analysis of variance in SAS (SAS institute INC. Cary, USA 1996). Tukey test was used to compare treatment means. Comparisons of different parameters were analyzed by regression analysis. A significance level of $\alpha = 0.05$ was used in all analysis.

RESULTS AND DISCUSSION

Shoot dry matter and shoot P concentration:

Based on shoot dry matter distinct differences were observed among the genotypes at low and high P levels (fig. 1). Screening of genotypes for shoot dry matter may provide the best estimation on the productivity of the plant at low P soils.

Some genotypes (code 5 and code 9) exhibited severe visible P deficiency symptoms at low P supply, i.e., stunted growth, small leaves and purple coloration of the leaves. The P efficient genotypes grow without P deficiency symptoms at low P level whereas P inefficient genotypes exhibited severe P deficiency symptoms. The purple discoloration of the leaves due to the accumulation of anthocyanin and other flavinoides in the leaf tissue (Bergmann, 1993) could be a mechanism of tolerance to P stress. This is in line with the suggestion of Hrazdina and Zobel, (1991) and Schopfer, (1984) that, through this pigmentation, plants cells may be protected against oxygen-free radical induced in P deficient leaves under illumination.

At low P level, there was highly significant difference between all maize genotypes. The maize genotypes code 1 , code 3, code 7 and code 8 gave a significant higher yields, than that of code 5 and code 9. The maize genotypes code 1 , code 3, code 7 and code 8 had about seven-fold higher shoot dry matter than code 9 and about 5 fold higher than code 5 at low P level (fig. 1). The reduction of shoot dry matter in the P inefficient genotypes was due to the shortage of available P in the soil.

At high P supply, there was no significant difference between all maize genotypes, except the maize genotypes code 1 and code 7 were significantly higher than code 5 (fig. 1). All plants increased significantly with increasing P levels, except code 1, code 3, code 7 and code 8, there was no significant difference between shoot dry matter at low and high P levels (fig. 1). The code 2, code 4 and code 6 maize genotypes produced about two times higher shoot dry matter at high P level than at low P level. On the other hand, code 10 produced about three times higher, code 5 produced five times higher and code 9 produced nine times higher shoot d.m. at high P level than at low P level. This is in line with Alt and Ladebusch (1984), who observed that, the plant yield increased significantly with increasing P supply. Also, Abou El Seoud (2008) reported that, the shoot dry matter of tagetes plant was increased significantly as a result of increasing P supply. These results have been also reported by Dechassa *et al.*, (2003) and Abou EL Seoud (1998 and 2005).

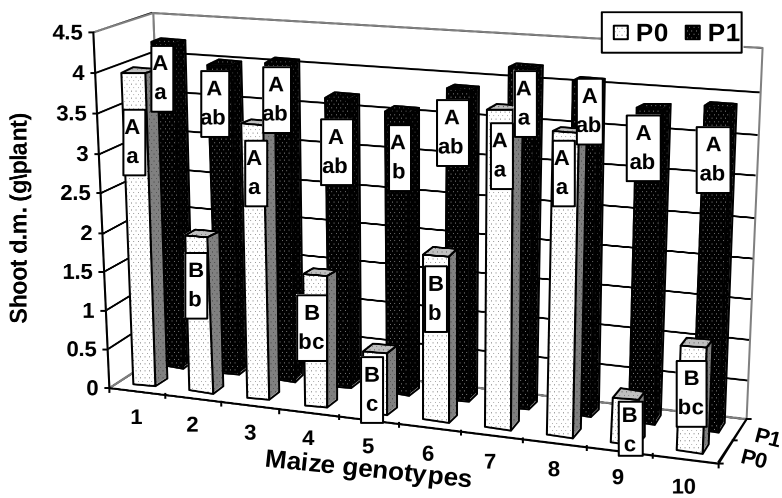

Fig. 1. Shoot dry matter (g/plant) of maize genotypes as affected by P supply (different letters indicate significant differences; small letters between different maize genotypes, capital letters between P levels, $P \leq 0.05$; d.m. = dry matter ; P0 = low P level, P1= high P level)

With regard to the shoot dry matter, nutrient efficiency is the ability of a plant to produce higher shoot yield at low P level (Gourley *et al.*, 1994). Based on this definition, four maize genotypes (code 1, code 3, code 7 and code8) were considered to be P efficient and two genotypes (code 5 and code 9) were regarded as P inefficient among 10 genotypes.

The relative yield is the shoot yield at low level expressed as a percentage of that at high P level. Relative yield was measured to compare the differences in yield between low and high P levels. Better yielding genotypes at low P supply had a high relative shoot yield since they did not have huge differ in yield at high P supply (less than 20%). Maize genotypes (code1, code 3, code 7, and code 8) attained more than 80% of its maximum yield already at the lower level of available P, (fig. 2). In contrast, at low level of available P, maize genotypes (code 5 and code 9) attained 21.9% and 14.7% respectively of their highest yield. This signified that maize genotypes (code1, code 3, code 7, and code 8) had high P efficiency, whilst maize genotypes (code 5 and code 9) had low P efficiency. Then code1, code 3, code 7, and code 8 were tolerant to low available P in soil compared to code 5 and code 9. By other words, maize genotypes (code1, code 3, code 7, and code 8) were superior to the other genotypes depend on shoot dry matter, and relative yield at low P level, and hence considered as P efficient. On the other hand, the two genotypes (code 5 and code 9) were selected as P inefficient due to their poor yield performances under limited P supply. Several authors (Bhadoria *et al.*, 2002 and Fageria and Costa, 2000) have stated that plant species or even genotypes of the same species varied in their ability to grow on the soil of low P availability. Similar results were also observed in the present experiment. In the same line, Akter, 2003 reported that significant differences were observed among the potato genotypes in the experiment grown in low P soil.

Increasing P supply rates had a significant positive effect on the shoot P concentration of all maize genotypes. At low level of available P, shoot P concentration of maize genotypes (code1, code 3, code 7 and code 8) were significantly increased than that of the other maize genotypes. This could be due to increase acquisition of P by increasing the extension of depletion zone around the root (fig. 3). In contrast, at high level of P supply, there was no significant difference between all maize genotypes except maize genotype code 9 (fig. 3).

The P concentration in shoot of maize genotypes (code1, code3, code7 and code 8) at high P level was about 2-fold higher only that at the low P level. However, the P concentration in shoot of the other maize genotypes (code 2, code5, code6, code 9 and code 10) at high P level was about 2.8-fold, 3.1-fold, 4.1-fold, 2.7-fold, 4.7-fold and 3.7-fold respectively higher than those at low P level.

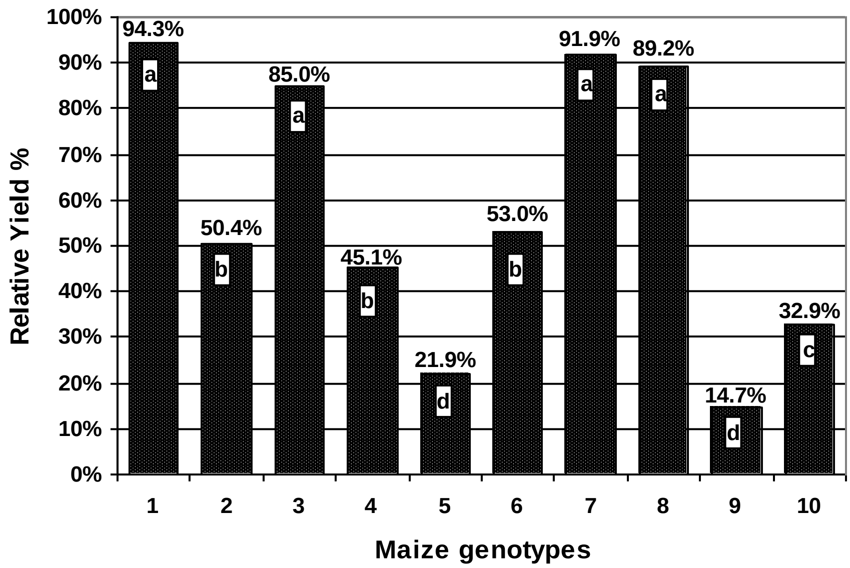

Fig. 2. Relative yield (%) of maize genotypes as affected by P supply (different letters indicate significant differences; P ≤ 0.05)

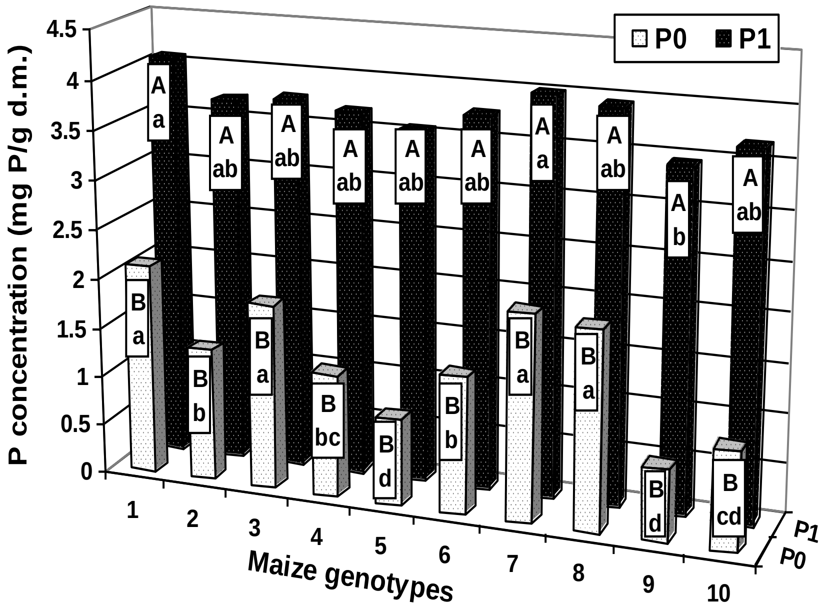

Fig. 3. Phosphorus concentration (mg P/g d.m.) of maize genotypes as affected by P supply (different letters indicate significant differences; small letters between different maize genotypes, capital letters between P levels, $P \leq 0.05$; d.m. = dry matter; P0 = low P level, P1= high P level)

The shoot P concentration at which maize genotypes (code1, code3, code 7, and code 8) achieved more than 80% of their maximum yield amounted to 2.13, 1.87, 2.08 and 2.01 mg P/g d.m. respectively. I n contrast, the other maize genotypes (code 2, code 4, code 5, code 6, code 9 and code 10) attained their highest yield at the relatively higher shoot P concentration of 3.7, 3.68, 3.56, 3.75, 3.44 and 3.66 mg P/g d.m. respectively. The shoot P concentration at which the first 4 maize genotypes attained their maximum yield was low being only about 1/2nd (in average) of that observed for the other 6 maize genotypes (fig. 3). Therefore, based on the conventional P use efficiency definition, the first 4 maize genotypes (code 1, code 3, code 7 and code 8) had high P use efficiency, whereas the other maize genotypes had low P use efficiency. High P use efficiency of the first 4 maize genotypes might be due to the plants retained small amounts of P in the root system and translocated maximal amounts to the shoots for the production of dry matter (Blair and Cordero, 1978).

Maize genotypes code 1 and code 7 required the low level of P to obtain 94.3% and 91.9%, respectively of the maximum yield, while the maize genotype code 3 obtained only 85% of the maximum yield at the same P level. This may be influenced by root growth characteristics (Barber 1995; Gahoonia *et al.*, 1999; and Jungk 2001).

Root growth:

Morphological root characteristics such as root length and root/shoot ratio were evaluated to characterize the mechanisms of P efficiency of efficient and inefficient genotypes. The amount of phosphorus taken up by plant from the soil depends on the size of the root system and its distribution in the soil profile (Abou EL Seoud, 2005). In other words, plant having long and extensive root system can explore large volume of the soil and take up more P than those with short roots.

There was no significant difference between root length of all maize genotypes at low and high P levels, except code 5, code 9 and code 10, the root length increased significantly with increasing P levels.

At low P level, significant differences in root length among the genotypes were observed (fig. 4). Maize genotypes code1, code 3, code 7 and code 8 had longer roots in limited P supply followed by code 2, code 4 and code 6, and the shorter roots observed in maize genotypes code 5, code 9, and code 10. The adaptation of maize genotypes to low levels of soil P is closely related to better developed root system and the increase in root length under P stress may be one of the possible mechanisms of P efficiency in maize (Alves *et al.*, 2001).

Phosphorus efficient genotypes (code1, code 3, code 7 and code 8) had longer root at low P level. This result affirms the proposition that plants growing in P limited soil tend to have longer roots (Manske *et al.,* 2000; Dechassa, 2001and Gaume *et al.,* 2001). Plants having larger root systems are able to absorb higher amounts of P from the soil and achieve greater yields than those having smaller root system (Abou El Seoud, 2008). Similarly, Föhse *et al.,* (1988) observed that, at low P content, the proportion of roots produced increases. This mechanism is an adaptation of plants to improve their uptake efficiency when P is a limiting growth factor. Also, Alves *et al.,* (2001) showed that the adaptation of maize genotypes to low levels of soil P is closely related to a better developed root system. On the other hand, there was no significant difference between all maize genotypes in root length at high level of P (fig. 4).

Phosphorus uptake:

Shoot P uptake was calculated as the product of shoot P concentration times dry matter yield. At low P level, the total P taken up by plants of the efficient genotypes followed the same trend as shoot dry matter yield. Phosphorus uptake by all maize genotypes was increased significantly with increasing P supply. Similarly, Schenk and Barber (1979) observed improvement in the amount of P uptake of maize with increasing the supply of P to the plant. The efficient maize genotypes code1, code 3, code7 and code 8 at high P level were about 2 times higher than that at low P level. In contrast, there were great differences in the other maize genotypes between high and low P supply (fig. 5).

At low P level, the efficient genotypes (code1, 3, 7 and 8) were higher than the other maize genotypes (fig. 5). Code 1 and code 7 were the highest P uptake per plant at low P level. In contrast, code 5 and code 9 were the lowest in maize P uptake. The maize genotype code 1 was higher than code 5 and code 9 by about 12.5-fold and 20.7-fold respectively. That could be due to increase root system of efficient maize genotypes which lead to increase P depletion zone, compared to the other inefficient genotypes which had small root system. In the same line, Eticha (2000) reported that the efficient cabbage genotypes took up more P from the soil under deficient P supply.

At high P level, the P uptake of efficient maize genotypes code 1, 7 and 8 were significantly higher than the other maize genotypes. On the other words, there was still significant difference in P uptake between all maize genotypes at high P level, but the difference between them less than that at low P level. The maize genotype code 1 was higher by about 1.32-fold only than code4, code 5 and code 9 at high P level (fig. 5).

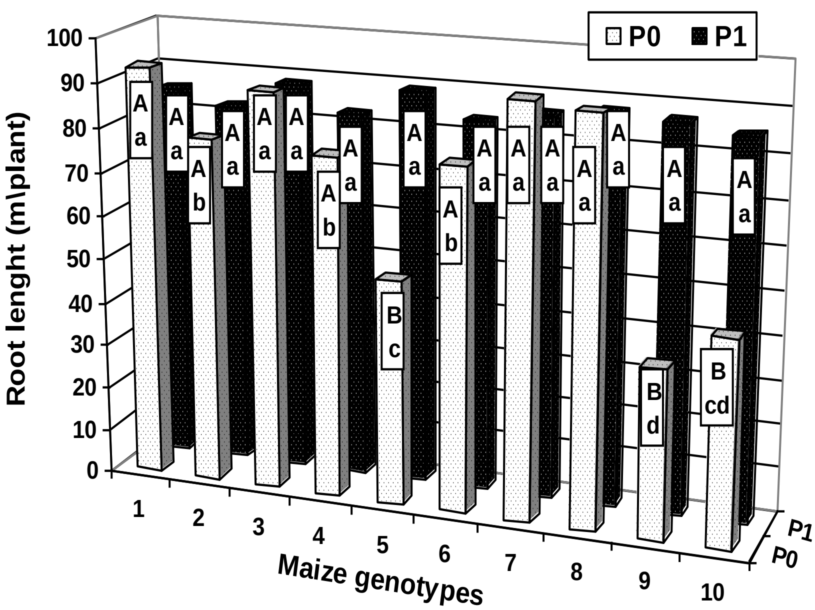

Fig. 4. Root length (m/plant) of maize genotypes as affected by P supply (different letters indicate significant differences; small letters between different maize genotypes, capital letters between P levels, P ≤ 0.05; P0 = low P level, P1= high P level)

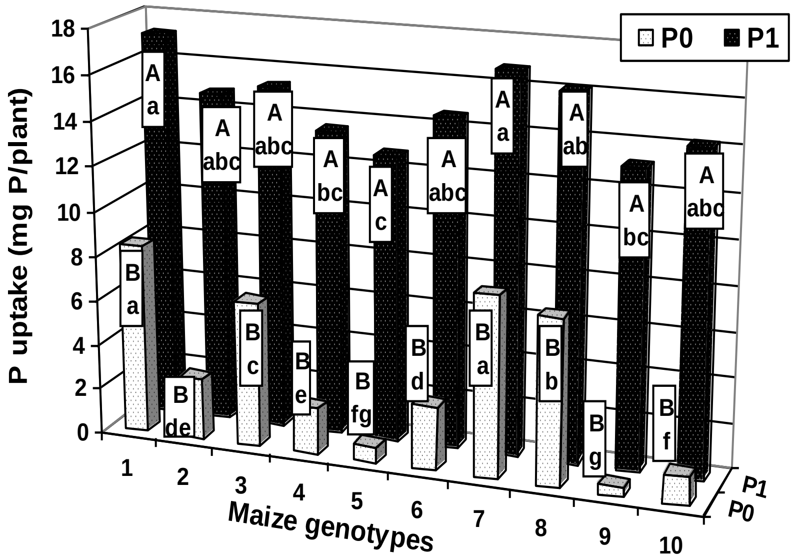

Fig. 5. P uptake (mg P/ plant) of maize genotypes as affected by P supply (different letters indicate significant differences; small letters between different maize genotypes, capital letters between P levels, P ≤ 0.05; P0 = low P level, P1= high P level)

On the other hand, there was no significant difference in root length between all maize genotypes at high P level (fig. 4). That could be lead to the other factor most commonly enhancing P uptake of plants as root hairs and/or association of roots with mycorrhiza (Bolan 1991) or other physiological root factors involved in the P uptake such as exudation of organic acids which are considered to mobilize phosphorus in the rhizosphere (Hinsinger, 2001).

In conclusion, the results of this study suggested that root growth system would be a suitable plant parameter for selecting P efficient maize genotypes especially under limited P supply and also selected the efficient maize genotypes under the same conditions of this experiment.

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الملخص العربي

كفاءة الفوسفور لأصناف مختلفة من الذرة النامية فى الأراضى الجيرية

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هذا البحث يهدف إلى دراسة كفاءة الفوسفور لأصناف مختلفة من الذرة عند مستويات مختلفة من التسميد الفوسفورى فى أراضى جيرية ولتقدير مساهمة نمو الجذور فى إمتصاص الفوسفور بواسطة 10 أصناف من الذرة . زرعت النباتات فى أصص بمستويين من الفوسفور المتاح بالتربة(40 و270 مجم فوسفور/كجم تربة) وذلك فى صوبة زجاجية بتصميم إحصائى قطاعات عشوائية كاملة لخمس مكررات. وتم حصاد نباتات الذرة بعد 4 أسابيع من الزراعة وقد إزدادت جميع الصفات النباتية التى تم دراستها معنوياً بزيادة مستوى التسميد الفوسفورى لجميع الأصناف ما عدا الأصناف (كود 1 و 3 و 7 و 8 (هجن فردى 10 و 15 و بشاير 13 و بيونيير 3062 بالترتيب))حيث لا يوجد فرق معنوى بالنسبة للوزن الجاف للمجموع الخضرى عند المستوى الأعلى والمستوى المنخفض من الفوسفور. وأصناف الذرة (كود 1 و 3 و 7 و 8) أعطت أكثر من 80% من المحصول الأعظم عند المستوى المنخفض من الفوسفور المتاح وعلى العكس فعند المستوى المنخفض من الفوسفور فإن أصناف الذرة (كود 5 و 9 (هجن فردى 123 و 151))أعطت فقط 21.9% و 14.7% على الترتيب من أعلى محصول. وهذا يثبت أن أصناف الذرة (كود 1 و 3 و 7 و 8)كانت ذات كفاءة فسفور عالية بينما أصناف الذرة (كود 5 و 9) كانت كفاءتها للفوسفور أقل. وقد أوضحت النتائج أيضاً أن أصناف الذرة (كود 1 و 3 و 7 و 8) كان لها مجموع جذرى أطول عند إمداد فوسفورى محدود ويلى ذلك أصناف الذرة (كود 2 و 4 و 6 (هجن فردية 12 و 122 و 129)) وأن قصر المجموع الجذرى قد لوحظ فى أصناف الذرة (كود 5 و 9 و 10 (هجن فردى 155)).ومن النتائج يتضح أن هناك تأقلم أصناف الذرة مع المستويات المنخفضة من الفوسفور بالتربة قد يرجع لتطور أفضل فى النظام الجذرى وزيادة طول الجذر تحت الإجهاد الفوسفورى وقد يكون هذا أحد الميكانيكيات الممكنة لكفاءة الفوسفور بنبات الذرة. وعند مستوى الفوسفور المنخفض كان صنفى الذرة (كود 1 و 7) هو الأعلى فى إمتصاص الفوسفور لكل نبات وعلى العكس فصنفى الذرة (كود 5 و 9) كان أقل فى إمتصاص الفوسفور. وفى النهاية فإن نتائج هذه الدراسة تشير إلى أن نمو النظام الجذرى هو العامل المناسب لإختيار صنف الذرة الأكفأ خاصة تحت ظروف من الإمداد المنخفض من الفوسفور.