DIFFERENCES IN PHOSPHORUS-ZINC INTERACTION AMONG SUNFLOWER (*Helianthus Annuus* L.), BRASSICA (*Brassica Napus* L.) AND MAIZE (*Zea Mays* L.)

Maqsood Ahmad Gill, Shamsa Kanwal, Tariq Aziz* and Rahmatullah
Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad.

Phosphorus and zinc interact both in plants and soil; hence may affect the availability and utilization of each other. A pot experiment was conducted to study these interactions in brassica, maize and sunflower. Two levels each of P (0 & 100 mg kg^{-1}) and Zn (0 & 15 mg kg^{-1}) were applied along with recommended doses of N and K. Species differed significantly for their response to applied P and Zn for shoot dry matter (SDM), P and Zn concentration in shoots, their uptake and use efficiencies. In maize, combined application of both P and Zn increased SDM, shoot P and Zn concentration, and their uptake compared to control. Increase in shoot P uptake due to P application ranged between 31 to 77% over control. Application of Zn increased shoot P concentration in maize (19%) but reduced in sunflower (66%) over control. Combined application of both P & Zn caused 56 % increase in Shoot P concentration in maize over control. Phosphorus induced reduction in shoot Zn concentration ranged between 22 % (in maize) and 50 % (in sunflower). Maximum reduction in shoot Zn concentration and uptake due to applied P was observed in brassica. Zinc use efficiency was decreased in maize and sunflower with combined application of P and Zn over plants grown with only P application. Differential P and Zn use efficiencies of maize, sunflower and brassica caused significant differences in P-Zn interactions in these species.
Key words: P-Zn interaction, P induced Zn deficiency, brassica, maize, sunflower

INTRODUCTION

Micro-nutrient deficiencies in plants are becoming increasingly important globally because of the increasing concerns over the effects of low levels of micro-nutrients especially Zinc (Zn) in human food (Cakmak, 2002; Welch and Graham, 1999). Zinc deficiency in soils is common in arid and semi-arid regions. Little or no use of Zn fertilizers along with unbalanced fertilization further aggravated Zn deficiency in soils resulting lower Zn contents in grains (Rashid and Rayan, 2004). Behavior of Zn in soils highly depends upon pH, $CaCO_3$ contents and amount of other nutrients especially of P (Rahmatulla, et al., 1994; Loneragen et al., 1982).

Phosphorus-Zinc interactions have been widely investigated in plants (Marschner, 1995). This interaction falls in two categories according to whether increasing P application decrease, or do not decreases Zn concentration in plant shoots (Floneragen and Webb, 1993). Application of large amounts of P is also likely to cause a reduction in the availability of Zn concentration in grains as well as in plant tissues (Buekert et al., 1998). Low Zn supply in soil, but a high P supply markedly enhances P concentration in plant tissues, which may cause P toxicity and contribute to symptoms resembling Zn deficiency (Loneragen et al., 1982). It is therefore, necessary to measure the effect of soil P availability on total Zn uptake and utilization efficiency in different crop species.

Crop cultivars / species show genotypic variations in P (Kosar et al., 2002; Gill et al., 2002; Kosar et al., 2003) as well as Zn uptake and utilization efficiency (Zhu et al., 2001; Irshad et al., 2002; Li et al., 2003). Genotypic variations in tolerance to P & Zn deficiencies can be exploited to increase crop production in soils low in available Zn and P and can be a better strategy in low input sustainable agriculture systems especially in developing countries. Breeding or selection for efficient crop cultivars/species can be a best approach to manage the P and Zn deficiencies in soils with limited P and Zn supply, hence interactions between P uptake efficiency and Zn uptake are of practical importance.

Keeping in view these facts, a pot experiment was undertaken to investigate the interactive effects of P and Zn supply on plant growth and tissue concentration of P and Zn in three crop species viz. maize, sunflower and brassica.

MATERIALS AND METHODS

The effect of applied P, Zn and their interaction was evaluated under wire house in three different crop species (maize, sunflower and brassica). Soil samples of 0-15 cm depths were collected, air dried, sieved, and analyzed for physico-chemical properties. The prepared soil was filled in glazed pots @ 7 kg pot^{-1}. Phosphorus was applied @ 0 & 100 mg kg^{-1} and Zn @ 0 and 15 mg kg^{-1} while N and K were applied @ 150 & 80 mg kg^{-1} respectively to these pots. Pots were kept in completely randomized design. Ten seeds of each of three species were sown in pots. Plants were thinned to four in each pot after four days of germination. Distilled water was used for irrigation. Plants were harvested after four weeks of germination. Harvested plants were washed with distilled water and blotted dry with tissue papers. Fresh weight of washed shoot samples was recorded and samples were dried in a forced air-driven oven to record shoot dry matter (SDM). Shoot samples were ground to 40 mesh and were digested in diacid mixture of (HNO_3:$HClO_4$). The digested samples were analyzed for P concentration using vanado-molybdate yellow color method on a UV-visible spectrophotometer at 420 nm (Chapman and Pratt, 1961) and for Zn concentration on an atomic absorption spectrophotometer (Perkin Elmer: aanlyst 100). Phosphorus and Zn uptake was calculated by using the formula:

Nutrient uptake (mg pot^{-1}) = SDM (g pot^{-1}) X shoot nutrient concentration (mg g^{-1})

Phosphorus and Zn utilization efficiency was calculated by the formula as described by Siddique and Glass (1981).

Maximum increase in SFW was observed again in Brassica (107 %) followed by maize (61 %) and sunflower (29 %). Similar trend was observed again in SDW. Brassica exhibited maximum increase in SDW due to combined application of P and Zn.

Phosphorus Nutrition

There were significant main and interactive effects of species and treatments on P concentration, uptake, and utilization efficiency of plants (Table 2, Fig 1). Maize and Brassica did not respond to applied P in terms of shoot P concentration. Shoot P uptake significantly differed among three species and was higher in maize followed by brassica. Applied P significantly increased P uptake in brassica and sunflower. Shoot P use efficiency was also increased due to applied P, however, maximum increase in SPU was observed in maize followed by sunflower.

$$\text{PUE } (g^2 \text{ SDM mg}^{-1} \text{ shoot P}) = \frac{1}{\text{Shoot P concentration(mg g}^{-1})} \times \text{SDM (g pot}^{-1})$$

$$\text{ZnUE (g2 SDM mg-1 shoot Zn)} = \frac{1}{\text{Shoot Zn concentration (mg g}^{-1})} \times \text{SDM (g pot}^{-1})$$

Where PUE and ZnUE represent phosphorus use efficiency and zinc use efficiency respectively.

The data was statistically analyzed according to standard procedures using computer software package (MSTAT-C) (Russell and Eisensmith, 1983). Dunken multiple range test (DMR) was used to separate means for significant treatments and species means at 5% probability (Steel et al., 1996).

RESULTS

Biomass Accumulation

There was significant main and interactive effects of species and treatments on shoot fresh weight (SFW) as well as shoot dry weight (SDW) accumulation (Table 1). Maize accumulated maximum SFW and SDW compared to sunflower and brassica. Application of P in soil caused a significant increase in shoot fresh weight of brassica and maize, however, sunflower did not respond to applied P. Maximum increase in SFW (141 %) and SDW (128 %) due to P application was observed in Brassica.

Application of Zinc to soil increased SFW and SDW in all of three species. Increase in SFW differed significantly among species and ranged between 46 % (Sunflower) to 140 % (Brassica) while increase in SDW ranged between 17 and 128 %. Combined application of P and Zn in soil resulted in an increase in SFW of all of the species compared to control (Table 1), however, percent increase varied significantly among the species.

Application of Zn in soil caused significant reduction (44 %) in shoot P concentration in sunflower, however, Shoot P concentration in maize and brassica was not affected by applied Zn.

Species differed significantly in their response to applied Zn in terms of P uptake. Shoot P uptake was reduced in sunflower, not affected in maize and was increased highly significantly in brassica due to applied Zn. Phosphorus use efficiency was increased due to applied Zn in brassica and maize, however in sunflower it was decreased.

Zinc Nutrition

Shoot Zn concentration was maximum in brassica followed by maize and sunflower. Applied Zn caused significant increase in shoot Zn concentration in maize and brassica, however, shoot Zn concentration in sunflower was unaffected (Table 3). Shoot Zn uptake was markedly increased in all of the species and ranged between 49 to 300 %. Shoot Zn use efficiency was significantly decreased in maize and sunflower due to applied Zn (Fig 2).

Application of P in soil caused a reduction in shoot Zn concentration in maize and sunflower; however in brassica applied P caused significant increase in shoot Zn concentration. Shoot Zn uptake was significantly increased in brassica and maize due to applied P. Shoot Zn use efficiency in maize and sunflower was increased due to applied P. Combined application of P and Zn increased Zn uptake and Zn use efficiency in brassica and maize crops.

Table 1. Shoot fresh and dry matter accumulation of maize, sunflower and brassica species

Treatments	Shoot fresh weight (g)			Shoot dry matter (g)		
	Maize	Sunflower	Brassica	Maize	Sunflower	Brassica
Control	51 c	52 c	27 c	7.2 c	6.4 b	3.2 c
+ Zn	80 b	76 a	66 a	10.2 b	7.5 a	7.3 a
+ P	82 a	50 d	65 a	11.9 a	7.5 a	7.3 a
P + Zn	82 a	67 b	56 b	12.3 a	6.6 b	6.0 a-c

Table 2. Shoot P concentration and uptake of maize, sunflower and brassica

	Shoot P concentration (g P100 g^{-1}SDM)			Shoot P uptake (mg P pot^{-1})		
	Maize	Sunflower	Brassica	Maize	Sunflower	Brassica
Control	0.16 b	0.29 a	0.35^{NS}	21.5 b	15.5 b	11.1 c
+ Zn	0.19 ab	0.10 c	0.35	21.5 b	12.2 c	21.4 a
+ P	0.16 b	0.16 b	0.34	20.5 b	20.3 a	19.6 b
P + Zn	0.25 a	0.25 a	0.32	30.8 a	14.4 b	20.4 ab

Table 3. Shoot Zn concentration, and uptake of maize, sunflower and brassica

	Shoot Zn concentration (mg Zn kg^{-1}SDM)			Shoot Zn uptake (mg Zn pot^{-1})		
	Maize	Sunflower	Brassica	Maize	Sunflower	Brassica
Control	64 b	70 a	58 c	0.41 cd	0.41 b	0.19 d
+ Zn	77 a	70 a	105 a	0.70 b	0.61 a	0.76 a
+ P	50 c	35 c	99 b	0.46 c	0.30 c	0.59 b
P + Zn	66 b	56 b	59 c	0.85 a	0.37 b	0.35 c

DISCUSSION

The results showed positive interaction between P and Zn for biomass accumulation in all species compared to treatment obtaining no fertilizer. Shoot fresh and dry weight accumulation markedly decreased in sunflower and brassica grown in pots obtaining both P and Zn compared to plants grown in pots obtaining only Zn, showing a negative P-Zn interaction for SFW.

Maize responded well to applied P in growth medium in terms of shoot P concentration. However, brassica and sunflower did not respond significantly to applied P as P concentration was statistically similar in plants grown with and without P. Response to Zn application significantly differed among species for shoot P concentration. Earlier scientist also reported inconsistent results of applied Zn in different crops for tissue P concentration (Singh et al., 1988; Gianquinto et al., 2000). The present results showed that addition in Zn supply increased P concentration in maize; however, in case of sunflower applied Zn reduced shoot P concentration significantly. Shoot P concentration in brassica did not differ due to applied Zn which may be attributed to its higher root exudation as reported earlier by Hoffland et al., (1989). A positive P-Zn interaction for shoot P concentration was observed in maize as combined application of P and Zn increased shoot P concentration.

Applied Zn in soil caused a significant increase in Zn concentration in all of the species. This is in general agreement with Kaya and Higgs (2001) and Monfilla et al. (2003). Large applications of P fertilizers to soils without Zn addition (low in available Zn) can depress tissue Zn concentration (Robson and Pitman, 1983; Gianquinto et al., 2000). The present results showed that P addition markedly influenced shoot Zn concentration in all of the species. Shoot Zn concentration was markedly reduced in maize and sunflower, however, reduction was non-significant in brassica due to applied P compared to control. Zinc uptake by all of three species markedly reduced due to applied P in soil which is in general agreement with the findings of Gianquinto et al. (2000). It has also been argued that P induced Zn concentration in shoots is caused by a dilution effect of increased shoot growth rather than by reduced Zn uptake by roots (Singh et al., 1988).

Reduction in Zn concentration due to high P supply will reduce the nutritional quality of foods which is a major concern (Cakmak, 2002) because of widespread Zn

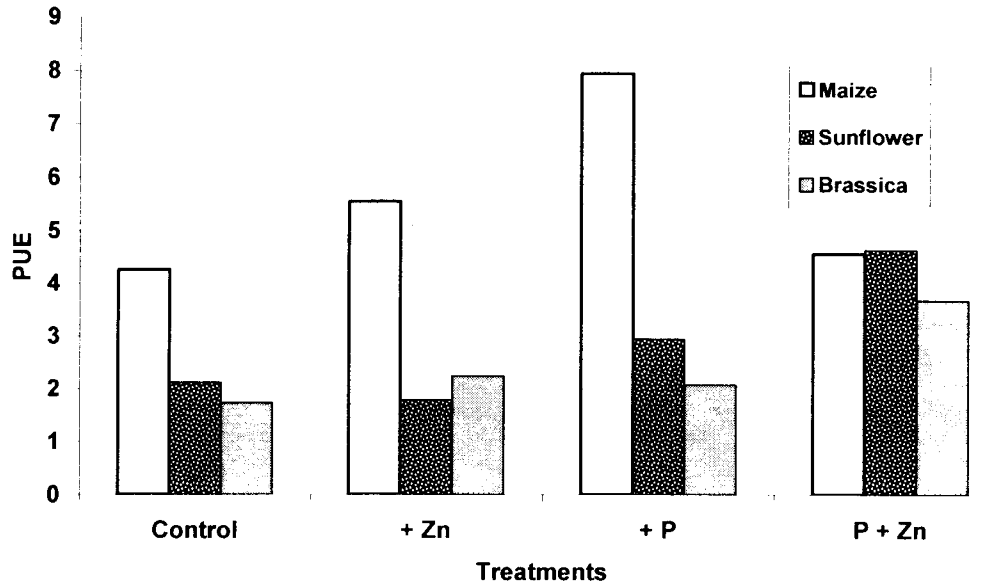

Fig. 1. Phosphorus use efficiency (g2 SDM mg-1 shoot P) of maize, sunflower and brassica affected by applied P and Zn

deficiency in humans (Buerkert, et al., 1998). An increase in P supply reduced molar ratio (MR) of Zn to P in shoots of all species compared to plants grown with Zn only (Fig 3). Low MR may cause a decrease in Zn bioavailability. Hence Zn fertilization would be considered together with P application for better nutritional quality of the products.

Species differed significantly for P and Zn use efficiencies which is in general agreement to earlier work (Akhtar et al., 2003; Kosar et al., 2002; Irshad et

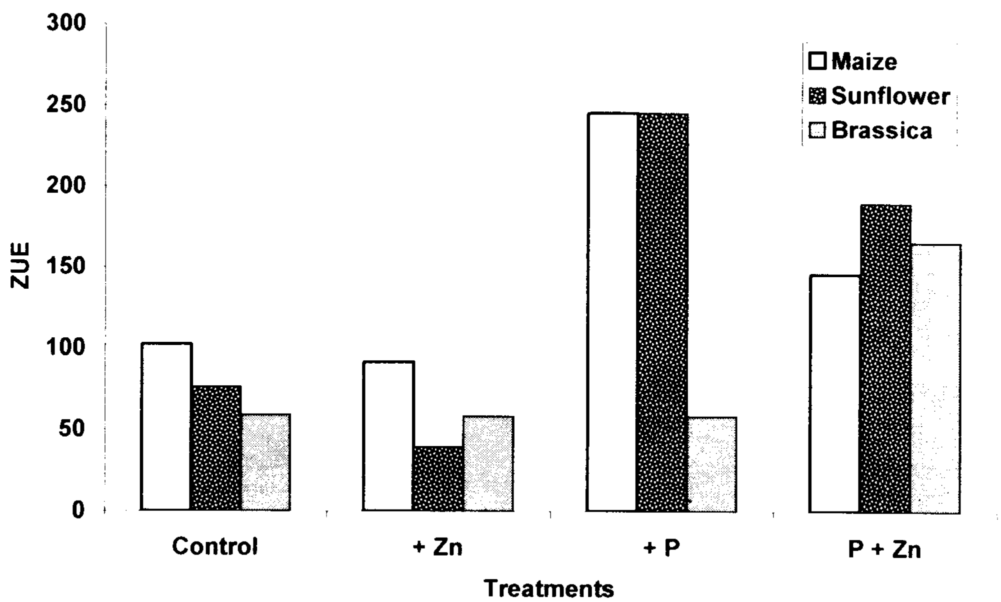

Fig. 2. Zinc use efficiency (g2 SDM mg-1 shoot Zn) of maize, sunflower and brassica affected by applied P and Zn

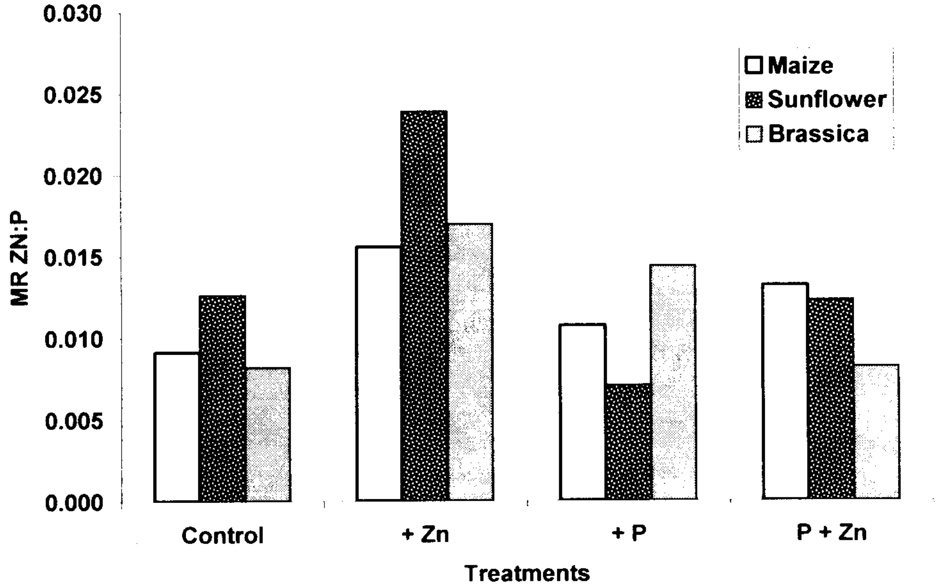

Fig. 3. Molar ratio of Zn:P in Maize, Sunflower and Brassica as affected by applied P and Zn

al., 2004). Maximum P and Zn use efficiency was observed by maize followed by sunflower and brassica. Shoot P use efficiency was increased in maize and sunflower as P supply was increased in soil without Zn addition. However, addition of P in soil along with Zn application caused significant reduction in maize but it was increased in sunflower and brassica.

CONCLUSION

Crop species differed in P and Zn use efficiencies. Phosphorus application significantly reduced shoot Zn concentration in all of species hence molar ratio of Zn to P. However, reduction in Zn concentration differed among species which was attributed to the differences in their P and Zn use efficiencies. The reduction in Zn concentration in shoot with an increase in P supply was attributed to dilution effect. Physiological studies are needed regarding P-Zn interactions in different crop species for crop and site specific fertilizer recommendations and nutritional management.

REFERENCES

Akhtar, M.S., M.A. Gill, T. Aziz and Rahmatullah. 2002. Differential phosphorus requirement and utilization efficiency of brassica genotypes. Pak. J. Agri. Sci. 39 (3): 188-191.

Buekert, A., C. Haake, M. Ruckwied and H. Marschner. 1998. Phosphorus application affects the nutritional quality of millet grain in the Sahel. Field Crops Res. 57: 223-235.

Cakmak, I. 2002. Plant nutrition research: Priorities to meet human needs for food in sustainable ways. Plant Soil 247: 3-24.

Chapman, H.D. and P.F. Pratt. 1961. Phosphorus. P. 160-170. In: Methods of Analysis for soils, plants and waters. Div of Agri. Sci. Univ. California, USA.

Floneragan, J. and M.J. Webb. 1993. Interaction between zinc and other nutrients affecting the growth of plants. In: Zinc in Soils and Plants. A.D. Robson (Ed). pp: 121-125. Kluwaer Academic Publishers, London.

Gianquinto, G, A. Abu-Rayyan, L.D. Tola, D. Piccotino and B. Pezzarossa. 2000. Interaction effects of phosphorus and zinc on photosynthesis, growth and yield of dwarf bean grown in two environments. Plant Soil 220: 219-228.

Gill, M.A. and Z. Ahmad. 2003. Inter-varietal Differences of absorbed-phosphorus utilization in cotton exposed to P-free nutrition: Part II. P-Absorption and remobilization in plant. Pak. J. Sci. Res. 55(1-2): 10-14.

Hoffland, E., G.R. Findenegg and J.A. Nelemans. 1989. Solubilization of rock phosphate by rape. 2. Local root exudation of organic acids as a response to P starvation. Plant Soil 113: 161-165.

Irshad, M., M.A. Gill, Rahmatullah, I. Ahmad, T. Aziz and I. Ahmed. 2004. Growth response of cotton cultivars to Zn deficiency stress in chelator-buffered nutrient solution: A new technique to study. Pak. J. Bot. 36 (2): 373-380.

Kaya, C. and D. Higgs. 2001. Growth enhancement by supplementary phosphorus and iron in tomato cultivars grown hydroponically at high zinc. J. Plant Nutr. 24(12): 1861-1870.

Kosar, H.S., M.A. Gill, Rahmattullah, T. Aziz and M. Imran. 2002. Solubilization of tricalcium phosphate by different wheat genotypes. Pak. J. Agric. Sci. 39(4): 273-277.

Kosar, H.S., M.A. Gill, T. Aziz, Rahmatullah and M.A. Tahir. 2003. Relative phosphorus utilization efficiency of wheat genotypes. Pak. J. Agric. Sci. 40 (1-2): 28-32.

Li, H.Y., Y.G. Zhu, S.E. Smith and F.A. Smith. 2003. Phosphorus zinc interaction in two barley cultivars differing in phosphorus and zinc efficiencies. J. Plant Nutr. 26(5): 1085-1099.

Logeragan, J.K., D.L. Grunes, R.M. Welch, E.A. Aduayi, A. Tengah, V.A. Lazar and E.E. Cary. 1982. Phosphorus accumulation and toxicity in leaves in relation to zinc supply. Soil Sci. Soc. Amer. J. 46: 345-352.

Marschner, H. 1995. Mineral Nutrition of Higher Plants; Academic Press, London.

Montilla, I., M.A. Parra and J. Torrent. 2003. Zinc phytotoxicity to oilseed rape grown on zinc loaded substrates consisting of Fe oxide-coated and calcite sand. Plant Soil. 257: 227-236.

Rahmatullah, M.A. Gill, B.Z. Sheikh and M. Salem. 1994. Bioavability and distribution of Zn among inorganic fractions in calcareous soils. Arid Soil Res. Rehab. 8: 227-234.

Rashid, A. and J. Ryan. 2004. Micronutrients constraints to crop production in soils with Mediterranean-type characteristics: A review. J. Plant Nutr. 27 (6): 959-975.

Robson, A.D. and M.G. Pitman. 1983. Interaction between nutrients in higher plants. In: Encyclopaedia of Plant Physiology, New Series; Lauchli, A. and R. L. Bieleski , (Eds.). Springer-Verlag, Berlin, Germany 15A: 287-312.

Russell, D.F. and Eisensmith. 1983. MSTAT-C. Crop Soil Sci. Dept., Michigan State Univ., USA.

Siddique, M. Y. And A. D. M. Glass. 1981. Utilization index: a modified approach to the estimation and comparison of nutrient utilization efficiency in plants. J. Plant Nutr. 4: 289-302.

Singh, J.P., R.E. Karamanose and J.W.B. Stewart. 1988. The mechanisms of phosphorus-induced zinc deficiency in bean (*Phaseolus vulgaris* L.). Can. J. Soil Sci. 68: 345-358.

Steel, R., J. Torrie and D. Dickey. 1996. Principles and procedures of statistics. A biometrical approach. 3rd Eds. McGraw Hill Book Co., New York.

Welch, R.S. and R.D. Graham. 1999. A new paradigm for world agriculture: meeting human needs, productive, sustainable and nutritious. Field Crops Res. 60: 1-10.

Zhu, Y.G., S.E. Smith and F.A. Smith. 2001. Zinc phosphorus interaction in two cultivars of spring wheat (*Triticum aestivum* L.) differing in P uptake efficiency. Ann. Bot. 88:941-945.