Scientific Research and Essays Vol. 5(16), pp. 2304-2311, 18 August, 2010
Available online at http://www.academicjournals.org/sre
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Responses of wheat genotypes to phosphorus fertilization under rainfed conditions in the Mediterranean region of Turkey

Kursat Korkmaz[1*], Hayriye Ibrikci[2], Ebru Karnez[2], Gokhan Buyuk[3], John Ryan[4], Hacer Oguz[2] and Ahmet Can Ulger[5]

[1]Department of Soil Science, Faculty of Agriculture, Ordu University, Ordu, Turkey.
[2]Department of Soil Science, Faculty of Agriculture, Cukurova University Adana, Turkey.
[3]Adiyaman University, Adiyaman, Turkey.
[4]International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.
[5]Department of Field Crops, Faculty of Agriculture, Cukurova University, Adana, Turkey.

Accepted 29 June, 2010

Phosphorus (P) deficiency is a common crop growth-limiting factor in Mediterranean climatic and soil conditions because of low availability of native and added P, with consequent low use efficiency. Adaptation to such conditions is a function of the type of crop and also varies with genotypes within crops. The study evaluated responses of some of wheat genotypes to P application rates under typical rainfed Mediterranean climatic conditions in southern Turkey. Five wheat genotypes (Genc-99, Balatilla, Adana-99, Golia, and Panda) and five P application rates (0, 9, 17, 35 and 70 kg P ha^{-1}) were used in a 2-year (2002/03, 2003/04) field experiment. In general, increasing P application level enhanced the leaf (0.18 - 0.44 %) and grain P (0.08 - 0.18%) concentrations of the genotypes. Grain yields values ranged from 1.48 - 4.85 t ha^{-1} and optimum yields were achieved with 35 kg P ha^{-1} application rate in both years. The relationship between leaf P and grain yield was significant in the first year, but grain P and grain yield were not significantly related. Thus, leaf P (flag leaves) concentration can be used for identification of genotypes that could be adapted to low or high soil P availability under rainfed conditions. The relative yield changed among the genotypes, especially Balatilla and Adana-99 were different from the other genotypes and had a fairly good performance. While yield and drought efficiency are major objectives in wheat breeding programs in the Mediterranean region, the study indicates that attention should also be given to crop P efficiency.

Key words: Flag leaves, P application, P deficiency, P efficiency, wheat yield.

INTRODUCTION

After nitrogen (N), phosphorus (P) is the most important essential plant nutrient affecting growth and quality, and is invariably supplied with the form of commercial fertilizer (Stewart et al., 2005). The amounts and forms of P in soils are related to soil factors and climatic conditions. Soil P forms are categorized as either inorganic or organic. Although the relative importance of each is dependent on the environment; considerable variation exists in the species of P within both categories (Sims et al., 2005). Only a small fraction of the total P is available to plants (Matar et al., 1992). Therefore, the amount and source of P fertilizers used in crop production assume an important role as a major P source to plants. Low native soil P and high P "fixation" by calcium carbonate ($CaCO_3$) and iron (Fe) oxides in soils are the limiting factors (Ryan et al., 1985a, 1985b), and many studies have highlighted the contribution of soluble calcium (Ca) and solid-phase $CaCO_3$ to precipitation of P in calcareous soils (Ibrikci et al., 2005; Ryan et al., 1985a; 2008).

Phosphorus deficiency is a widespread problem in calcareous soils, and can be a major constraint to crop growth and yield production under conditions where no

*Corresponding author. E-mail: korkmaz60@gmail.com. Tel: +90- 452 234 70 98, +90 542 614 42 82. Fax: +90 452 234 44 00.

fertilizer P is applied. Crops use only 10 - 30% of fertilizer P in the year of application (Manske et al., 2000) and a decreasing amount in subsequent years. In agricultural production, environmental stresses are also limiting factors affecting P availability and uptake by plants, especially in water-limited soil (Wittenmayer and Merbach, 2005). Plants have evolved a wide range of strategies to deal with stress conditions, displaying an array of physiological responses to P availability that may increase P acquisition (Lynch, 1995; Gahoonia et al., 1997). This can be due to genotypic differences in plants (Fohse et al., 1991). Plants display an array of physiological responses to phosphorus availability, including morphological and architectural responses of root system that may affect phosphorus acquisition (Lynch, 1995; Gahoonia et al., 1997; Gill et al., 2005). This can be due to differences in root architecture (that is, root length, root radius, root surface area, root hair density, and rate of shoot growth) (Fohse et al., 1991). Root growth, leading to increased root-soil contact, is an important factor determining the uptake of less mobile nutrients such as phosphorus from soils (Schjorring and Nielsen, 1987). The response of plant to low-P availability may be an important strategy for enhanced P acquisition when P availability is low (Fohse et al., 1991; Gunes et al., 2006). Despite the low tissue P concentrations, some plant materials can provide sufficient P for a short-term P balance (Neumann et al., 1999).

Although genetic variation in P uptake efficiency has been widely reported in many crops, such as wheat, white lupin, and maize (Neumann et al., 1999; Alves et al., 2001), the mechanism of P efficiency in wheat and other crop species is not clearly understood. Plant species, as well as genotypes within the species are known to differ in the ability to grow well in soils low in P (Fohse et al., 1991; Ozturk et al., 2005). Phosphorus efficiency may arise from differential P uptake efficiency, the ability of plants to acquire P from the soil or from P use efficiency, the ability of plants to utilize P in shoot for dry matter production, or from a combination of these attributes (Blair, 1993).

While growth response to P fertilizer by crops is almost universal, differential responses among varieties, cultivars or lines within any crop species are commonly observed (Egle et al., 1999; Manske et al., 2001; Ozturk et al., 2005). Variations in plant morphology and physiology have been shown to be correlated with genotypic differences in plant utilization ability of soil available P (Lynch, 1995; Manske et al., 2001). In terms of responsiveness, genotypes may be classified as: (1) Efficient-responsive-plants that produce high yields at low levels of nutrients and that respond to higher levels of nutrient additions, (2) Efficient non-responsive-plants that produce high yields at low levels of nutrition but do not respond to nutrient additions, (3) Inefficient-non responsive-plants that produce low yields at low levels of nutrition but do not respond to nutrient addition, and (4) Inefficient-responsive plants with low yields at low levels of nutrition but have a high response to added nutrients (Gerloff, 1977). An earlier and preliminary study of 10 commonly grown wheat cultivars from the Cukurova region of southern Turkey in greenhouse conditions indicated three of the four response categories, except inefficient-responsive (Korkmaz et al., 2009). A logical follow-on from such a study is assessment under field conditions rather than in controlled environments. The only meaningful categorization in relation to P fertilization is based on how these cultivars behave under normal and uncontrolled conditions in the field. From a practical point of view, genotypes that produce high yield in a soil with a low level of P and respond well to added P are the most desirable.

Therefore, the objective of this applied field research was to assess the effect of P fertilization on grain yield, P uptake by grain, and leaf and grain P of wheat genotypes grown under typical rainfed field Mediterranean conditions in southern Turkey.

MATERIALS AND METHODS

A wheat-field trial were conducted during two cropping seasons (2002/03 and 2003/ 04) in the Cukurova region of southeastern Turkey. The soil was Typic Xerofluvent (Menzilat soil series) and was characterized by loam texture, pH 7.6, low organic matter content (1.6%), cation exchange capacity of 18 cmol kg^{-1}, high $CaCO_3$ (51%), and available P at 6.4 mg kg^{-1}. The latter value is considered marginal as far as P sufficiency is concerned in Mediterranean soils (Ryan and Matar, 1992).

The climate of the area is typical of the Mediterranean region, with hot and dry summers and mild and rainy winter seasons (Kassam, 1981). The average rainfall in the last 10-15 years was about 600 mm. During the experimental period of two growing seasons, the monthly rainfall (mm) in 2002 - 03 was: 40.6 (Nov.), 60.2 (Dec.), 76.5 (Jan.), 95.8 (Feb.), 62.5(Mar.), 53.1 (Apr.), 36.1 (May), and 15.0 (June), giving a total for the season of 439.8 mm. In the 2003 - 04 growing season rainfall (mm) was higher than in the previous year but unevenly distributed, being high early in the season and low later on, that is, 12.2 (Nov.), 127.5 (Dec.), 241.6 Jan.), 63.0 (Feb.), 3.0 (Mar.), 14.0 (Apr.), 9.7 (May) and 9.4 (June), giving a total of 480.4 mm. The seasonal distribution is graphically illustrated in Figure 1 along with variation in mean temperature which affects crop growth and evapotranspiration.

Experimental variables involved five levels of P (0, 9, 17, 35 and 70 kg P ha^{-1}) applied broadcast as triple superphosphate. Five wheat genotypes (Balatilla, Adana-99, Golia Genc-99 and Panda) were planted. Three of these genotypes (Balatilla, Adana-99, Golia) were considered efficient-responsive and two were efficient-nonresponsive (Genc-99 and Panda) from the Korkmaz et al., (2009) study's. These genotypes are widely grown in the southern Mediterranean coastal region and in southeastern Turkey.

Seeds were sown on Dec. 10, 2002 and Dec. 14, 2003; and harvested on June 1, 2003 and June 9, 2004 in 2 years based on the weather conditions of that specific year. The sowing density was 550 seeds m^{-2} in the both years. The experiment was arranged in a split- plot design with four replications, that is, a total of 100 plots, each with dimensions of 1.2 × 8 m. Potassium was applied as potassium sulfate (100 kg K ha^{-1}), and 1/3 of the N (80 kg ha^{-1}) was applied during planting; the remaining N was applied with broadcast application as 1/3 (80 kg ha^{-1}) at tillering and 1/3 (80 kg ha^{-1}) at the booting stages. Flag leaves (leaf blades) from each plot (30 - 40 samples) were collected prior to the booting stage

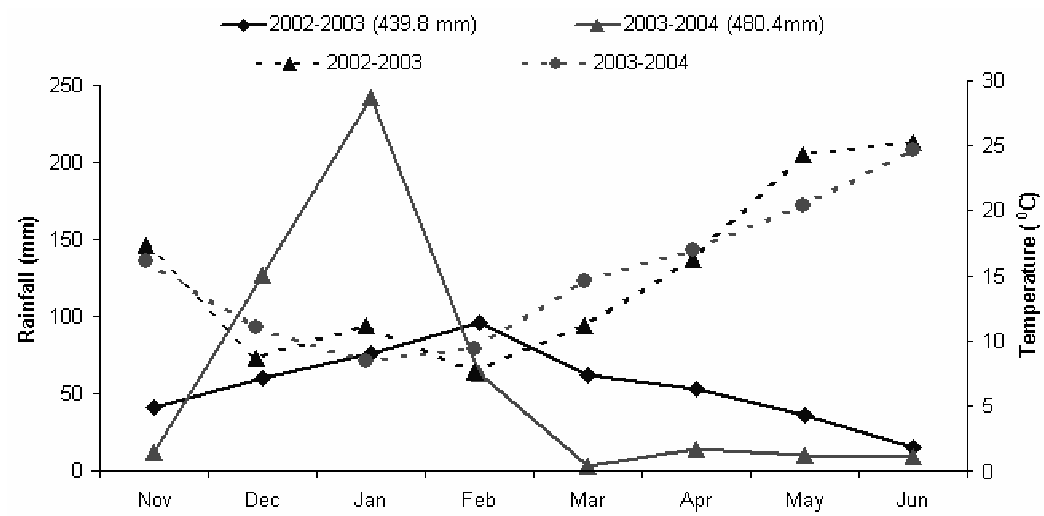

Figure 1. Seasonal monthly rainfall (mm) during the two growing seasons (2002 - 2003; 2003 - 2004).

Table 1. Selected features of the genotypes[1].

Genotype[2]	Year released	Origin	Yield potential[2]	Disease resistance	Protein content%
Bread wheat					
Golia	1999	Italy	High	Medium	11 - 13
Adana-99	1999	Mexico	High	Medium	12 - 13
Balatilla	2001	Mexico	High	Medium	11 - 13
Panda	1984	Italy	High	Medium	11 - 12
Genc-99	1999	Mexico	High	Medium	12 - 14

[1]Source: Korkmaz et al. (2009).

during each cropping season, rinsed with de-ionized water, dried at 65°C, and ground to pass a 2-mm sieve. The samples were dry-ashed at 550°C overnight and diluted with 0.3 *N* HCl to bring the P into the solution, and the solution was filtered. The P contents of the samples were determined according to the Murphy and Riley (1962) procedure.

The amount of grain P uptake was calculated based on grain yield multiplied by its P concentration values. Yield increment (YI) was calculated as follows (Tang et al., 2008):

$$YI (\%): (Y_P - Y_0)/Y_0 \times 100$$

where YI is percentage of grain yield which increase due to P application, Y_P is the grain yield with highest P application (t ha^{-1}), Y_0 is the grain yield without P application (t ha^{-1}). Data from all experiments were statistically analyzed using the MSTAT-C computer program

RESULTS

Grain yield

Grain yield was significantly increased by P application rates in the both years (Table 2), but there were only significant differences due to varieties in the first cropping season (2002 - 03). However, there were no significant interactions between genotypes and P application rates.

In the first year, grain yields in the unfertilized control ranged from 3.1 (Golia, Panda) to 3.7 t ha^{-1} (Balatilla). The highest grain yield was obtained from 35 kg P ha^{-1} application in both years, with the exception of Balatilla and Genc-99, which showed slightly higher values at the higher P application rate in 2002 - 03, and Genc-99 again in 2003-04.

Thus the relative responses of each variety are indicated for the 35 kg ha^{-1} level of applied P. Despite the absence of a statistical significant interaction between the genotypes and applied P, the relative responses at this level indicate genotypic differences (Table 2). These responses ranged from 13.5% for Balatilla to a height of 41.9% for Panda and 40.0% for Adana-99, with the relative responses of the other two varieties ranging from 22.2% (Genc-99) to 29 % (Golia).

In the second year of the experiment (2003 - 04), wheat grain yield was less than half of the expected yield compared to the previous year, presumably due mainly to the poorly distributed rainfall in that year. The yield increased with 35 kg P ha^{-1} application which ranged from

Table 2. Influence of P application rates on wheat grain yield in a 2-year field trial (2002-2003; 2003-2004).

Year	Genotype	P rate (kg P ha^{-1})					Yield increment with P35 (%)
		0	9	17	35	70	
		t ha^{-1}					
2002-2003	Genc-99	3.6	3.7	3.9	4.4	4.6	22.2
	Balatilla	3.7	4.0	4.1	4.2	4.3	13.5
	Adana-99	3.5	3.9	4.2	4.9	4.5	40.0
	Golia	3.1	3.4	3.5	4.0	3.9	29.0
	Panda	3.1	3.2	3.6	4.4	3.7	41.9
F-test	P rate (P)	***					
	Genotype (G)	***					
	P × G	NS					
2003-2004	Genc-99	1.5	1.9	2.4	2.5	2.7	66.7
	Balatilla	1.7	2.2	2.2	2.3	2.2	35.3
	Adana-99	2.1	2.4	2.6	3.1	2.2	47.6
	Golia	1.7	1.9	2.0	2.7	2.3	58.8
	Panda	2.1	2.3	2.7	2.9	2.0	38.1
F-test	P rate (P)	***					
	Genotype (G)	NS					
	P × G	NS					

***Indicates significances at P<0.001 and NS = non-significance.

38.1 - 66.7% (average of 49.3%) for the genotypes. Despite non significant effects of genotypes, there were differences in the yields of the varieties, whether unfertilized or fertilized. For instance, in the control plots, yields ranged from 1.5 kg ha^{-1} for Genc-99 to 2.1 kg ha^{-1} for Panda. When fertilized at the 35 kg P ha^{-1} rate, the yields varied from 2.3 t ha^{-1} for Balatilla to 2.9 t ha^{-1} for Panda. Two genotypes (Balatilla and Adana-99) in the first year and two (Adana-99 and Panda) in the second year fall in to the same efficiency classification indicated in the earlier greenhouse study of Korkmaz et al., (2009).

Again, as in the case of the yield data from the first cropping season, the interaction between P application rate and genotype was not significant, but some differences were apparent in the differential responses. Thus, at the maximum response level of 35 kg ha^{-1}, responses varied from 35.3% for Balatilla to 66.7 % for Genc-99. Even though some of the grain yield data was lower with 70 kg P ha^{-1} application, it is apparent that yield response was up to the 35 kg P application and leveled off after this rate. Therefore, based on statistical analysis, the only consistent effects observed in terms of crop grain yield were due to P fertilization, with poor expression of the genotype effect or the interactions with P fertilization.

Leaf and grain P concentrations

The statistical analysis of the data showed that there were significant differences ($p < 0.001$) in the leaf P concentrations due to P application (Table 3) in the first year (2002 - 03), but not in the second year (2003 - 04). Similarly, in 2002 - 03 there were significant effects of genotype, and the genotype by P interaction was significant. Regardless of P application rates and genotypes, the leaf P concentration ranged from 0.18 - 0.44% at the highest P application rate, and increased with applied P up to 35 kg P ha^{-1}, with no further increases. The interaction between genotypes and applied P is best illustrated by the extremes, that is, the P concentration in Balatilla increased from 0.18% in the control to 0.44 % or more than doubling of the concentration, while Panda showed no increase from the 0.24% in the control. In the second year, the P concentration varied within a limited range (0.24 - 0.28%), but only the effect of genotypes was significant with no significant effect of applied P or no interaction between the factors. There was also a significant relationship between leaf P concentration and the grain yield (Figure 2).

Grain yield in-genotype effect or the interactions with P fertilization of P application rates on grain P concentration was significant in both years (Table 4). On the contrary, the genotype and the genotype by P application rates interactions were significant for grain yield only the first year. The lowest values for grain P concentration of the genotypes were in the unfertilized control plots in both years, with concentrations varying between 0.08 - 0.15% in 2002 - 03 and 0.16 - 0.23% in 2003 - 04. Despite the significance indicated for the P application rate, it was

Table 3. Effects of P application rates on leaf P concentration of five wheat genotypes in a 2-year field trial.

Year	Genotype	P rate (kg P ha^{-1})				
		0	9	17	35	70
		% P				
2002-2003	Genc-99	0.25	0.27	0.27	0.32	0.32
	Balatilla	0.18	0.22	0.32	0.41	0.44
	Adana-99	0.22	0.24	0.29	0.34	0.23
	Golia	0.23	0.26	0.31	0.34	0.28
	Panda	0.24	0.27	0.22	0.22	0.24
F-test	P rate	***				
	Genotype	***				
	Rate × genotype	***				
2003-2004	Genc-99	0.26	0.27	0.28	0.28	0.27
	Balatilla	0.28	0.28	0.28	0.28	0.27
	Adana-99	0.25	0.26	0.27	0.26	0.26
	Golia	0.26	0.25	0.25	0.24	0.24
	Panda	0.27	0.28	0.28	0.28	0.26
F-test	P rate	NS				
	Genotype	***				
	Rate × genotype	NS				

*** indicates significances at $p < 0.001$ and NS = non-significance.

difficult to discern any consistent pattern of response to applied P within the genotypes in terms of grain P concentration.

Grain P uptake

Uptake of P by the crop is a consideration in the evaluation differential responses of genotypes to P application and is a function of the P concentration in the grain and the grain yield. There were large differences between the two cropping seasons for grain P uptake (Table 5). In the first year, with more favorably distributed rainfall, the main factors, P and genotypes, were significant, as was the interaction between these factors. However, in the second (less favorable) year, only the P factor was significant. In 2002 - 2003, grain P uptake ranged from 3.0 kg ha^{-1} for Adana-99 to 5.3 kg ha^{-1} for Genc-99 in the unfertilized control plots. Despite the significant effect of P, there was no consistent relationship with P application rates. Only in one variety (Adana-99) was uptake increased linearly with P application, and then up to the 35 kg ha^{-1} rate, with a decrease after-wards. At the 35 kg ha^{-1} level of applied P, the highest uptake was again with Adana-99, with the other four varieties being relatively similar. In the second year, the highest uptake in the control plots was with Adana-99 and the lowest with Genc-99. The response order remained relatively similar at the 35 kg ha^{-1} P application rate. In 2003 - 2004, there were varietal differences in the unfertilized control plots, with lowest values for Genc-99 and highest for Adana-99. In contrast to the first year, the response with increasing P application rates was more consistent up to the 35 kg ha^{-1} rate. In the case of Genc-99, the response was consistent up to 70 kg ha^{-1}, whereas uptake at this highest rate was lower than at the 35 kg ha^{-1} rate. While there were differences between varieties at all P levels, they were not significant. Differences between the yields from first and second year's trials could be attributed to the differences between climatic conditions of the two years in which the rainfall showed irregular distribution.

DISCUSSION

This field evaluation of wheat genotypes showed responses to applied P, thus indicating P deficiency in unfertilized soils as noted in numerous studies from the Mediterranean region (Matar et al., 1992; Ibrikci et al., 2005; Ryan et al., 2008). The effect of P fertilization was significant for all parameters considered, that is, P concentrations in the plant tissue and the grain as well as yield and P uptake. Growth responses that might have been more pronounced had the initial level of available soil P been lower; now through routine fertilization, finding a suitable field site low in available P for such trials

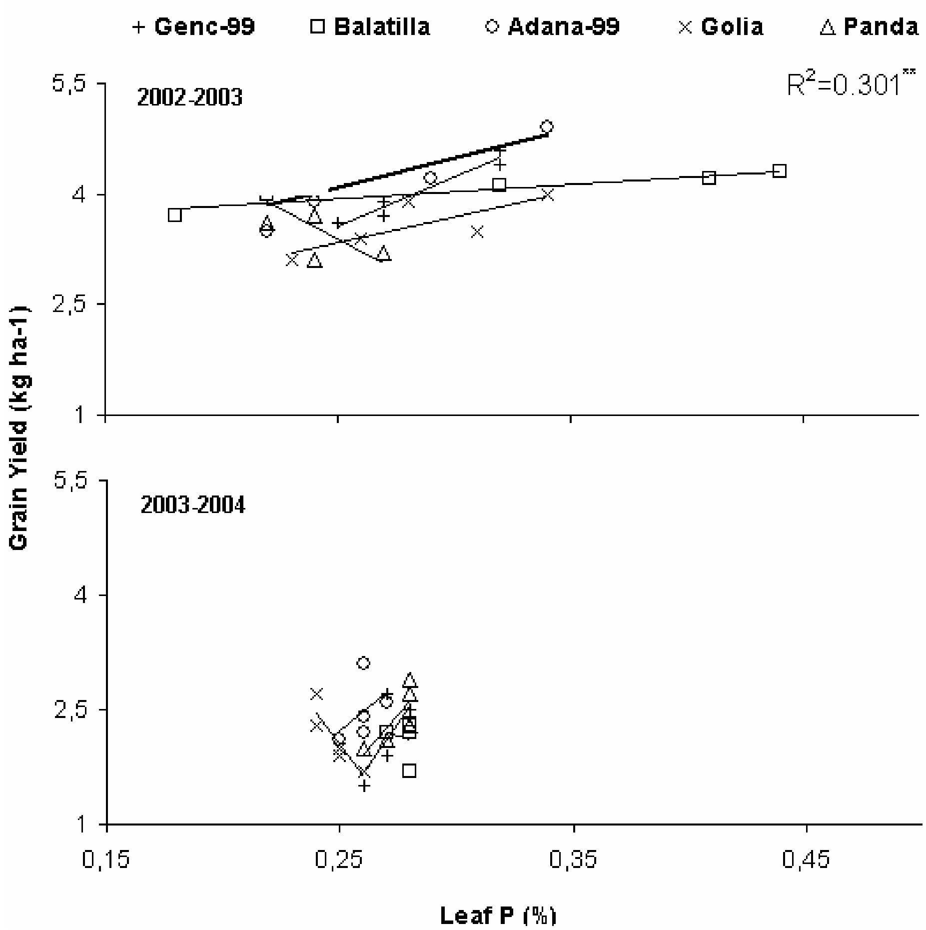

Figure 2. Relationship between leaf P concentration and grain yield in 2 growing seasons.

trials is often problematic. The P value in the unfertilized soil was marginally adequate according to the criteria that are applicable to rainfed conditions in the Mediterranean region (Ryan and Matar, 1992).

Despite significant differences in P uptake with fertilization, apparent P uptake values from the fertilizer were low and decreased with increasing P application rate. For example, in the first season (2002 - 2003), the apparent P % uptake values, or P efficiency, were 22.2, 18.8, 10.3, and 3.8% for the Adana-99 variety for the four P application rates. In the second year, despite yields being lower due to poor rainfall distribution, the respective efficiencies for the same variety (Adana-99) were 18.8, 10.6, 7.7, and 4.4% following a similar pattern as in the favorable year. Though indicating low efficiency of utilization, these values are within the range indicated by Manske et al. (2000) for wheat.

Given that wheat can vary in its responsiveness to P fertilization depending on the genotype (Schulthess et al., 1997; Egle et al., 1999; Manske et al., 2000, 2001; Ozturk et al., 2005; Gunes et al., 2006), the trial added another dimension to P fertilization studies as it demonstrated genetic differences in relation to P responses in a field study in the Mediterranean region. However, in terms of differences between wheat varieties, the effect was not as pronounced as expected since there were significant differences in interactions between genotypes for P concentrations in the plant tissue and the grain only in the first year, and not for either grain yield or uptake in the second cropping year. As this field study was a progression from the green house experiment by Korkmaz et al., (2009), which included some of the same wheat varieties, it is pertinent to consider the differences in observations between the two related experiments. In the greenhouse, soils with low levels of available could be chosen as in the case of six soils used by Korkmaz et al., (2009), while environ mental conditions allowed for maximum genetic growth and P uptake potential of the crop varieties. The deficiencies in the P response data highlight the difficulties of finding appropriate sites with low levels of availability. The low and variable rainfall that is characteristic of the Mediterranean region imposes such crop growth constraints that neither the growth potential of wheat varieties nor their response to P is maximized, thus – limiting the expression of interactions between P and

Table 4. Effect of P application rates on grain P concentrations of five wheat genotypes in a 2-year field trial.

Year	Genotype	P rate (kg P ha^{-1})				
		0	9	17	35	70
		% P				
2002-2003	Genc-99	0.15	0.16	0.14	0.13	0.12
	Balatilla	0.14	0.18	0.15	0.13	0.12
	Adana-99	0.08	0.13	0.15	0.14	0.13
	Golia	0.12	0.14	0.13	0.12	0.11
	Panda	0.11	0.14	0.11	0.11	0.09
F-test	P rate	***				
	Genotype	***				
	Rate x genotype	***				
2003 - 2004	Genc-99	0.19	0.23	0.19	0.22	0.22
	Balatilla	0.20	0.22	0.24	0.22	0.22
	Adana-99	0.20	0.23	0.22	0.22	0.22
	Golia	0.23	0.25	0.23	0.20	0.20
	Panda	0.16	0.22	0.22	0.22	0.21
F-test	P rate	***				
	Genotype	NS				
	Rate x genotype	NS				

*** Indicates significances at p <0.001 and NS = non-significance.

Table 5. Effect of P application rates on grain P uptake of the genotypes in a 2-year field trial.

Year	Genotype	P rates (kg P ha^{-1})				
		0	9	17	35	70
		kg P ha^{-1}				
2002-2003	Genc-99	5.3	6.1	5.4	5.4	5.5
	Balatilla	5.1	7.1	6.2	5.4	5.1
	Adana-99	3.0	5.0	6.2	6.6	5.7
	Golia	3.7	4.8	4.4	4.7	4.2
	Panda	3.5	4.5	4.2	4.9	3.3
F-test	P rate	***				
	Genotype	***				
	Rate × genotype	***				
2003-2004	Genc-99	2.8	4.5	4.6	5.5	5.9
	Balatilla	3.4	4.8	5.2	5.1	4.8
	Adana-99	4.1	5.7	5.7	6.9	5.0
	Golia	3.9	4.6	4.7	5.5	4.6
	Panda	3.3	5.0	6.0	6.3	4.1
F-test	P rate	***				
	Genotype	NS				
	Rate × genotype	NS				

*** Indicates the significances at p < 0.001 and NS= non-significance.

genotypes. Although the rainfall was higher in 2003 - 2004 than in 2002 -2003, its distribution was skewed with little rain in the period of active crop growth, thus eliminating the interaction effect between P and varieties. As environmental constraints are minimal during the early part of the Mediterranean cropping season, genetic differential to or genotype differences are easily expressed in P concentrations in the early growth plant tissue. Correlation coefficients ($r= 0.301^{**}$) indicated a significant relationship between leaf P concentration and grain yield. Thus, as shown by other studies on wheat (Rashid et al. 2005), P in the flag leaves can be a good predictor of ultimate yield. Notwithstanding, the potential of crops to vary in terms of their growth response to P fertilizer, and to vary in the efficiency with which they use available soil P, it is likely that most modern cereal varieties that are bred for yield and resistance to biotic and abiotic stresses are also efficient at using P as a nutrient. Where varieties are believed to vary in relation to P use, greenhouse screening would be an efficient cost-effective way of ascertaining such differences given the constraints of conducting such evaluations in the field under Mediterranean conditions.

ACKNOWLEDGMENTS

The authors wish to thank the World Phosphate Institute (IMPHOS), Casablanca, Morocco and Cukurova University Research Foundation Adana, Turkey, for their financial support.

REFERENCES

Alves VMC, Parentoni SN, Vasconcellos CA, Bahia Filho AFC, Pitta GVE and Schaffert RE (2001). Mechanisms of phosphorus efficiency in maize. *In* W J Horst et al. (Eds) Plant Nutrition-Food Security and Sustainability of Agroecosystems Kluwer Academic Publ Dordrecht The Netherlands. pp. 566-567.

Blair G (1993). Nutrient efficiency-what do we really mean? *In* Genetic aspects of plant mineral nutrition (Eds Randall PJ, Delhaize E, Richards RA and Munns R) Kluwer Academic Publ Dordrecht, The Netherlands. pp. 204-213.

Egle K, Manske G, Römer W, Vlek PLG (1999). Improved phosphorus efficiency of three new wheat genotypes from CIMMYT in comparison with an older Mexican variety J. Plant. Nutr. Soil. Sci., 162: 353-358

Fohse D, Claassen N, Jungk A (1991) Phosphorus efficiency of plants II significance of root radius root hairs and cation anion balance for phosphorus influx in seven plant species. Plant Soil., 132: 262-271.

Gill AA, Sadana US, Samal D (2005). Phosphorus influx and root-shoot relations as indicators of phosphorus efficiency of different crops. Comm. Soil Sci. Plant Anal., 36: 2315-2327.

Gahoonia TS, Nielsen NE (1997). Variation in root hairs of barley cultivars doubled soil phosphorus uptake. Euphytica. 98: 177-182.

Gerloff GC (1977). Plant efficiencies in the use of N, P and K in plant adaptation to mineral stress in problem soils. Ed. M. J. Wright pp. 161-174. Cornell University Press New York

Gunes A, Inal A, Alpaslan M, Cakmak I (2006). Genotypic variation in phosphorus efficiency between wheat cultivars grown under greenhouse and field conditions, Soil. Sci. Plant. Nutr., 52: 470–478.

Ibrikci H, Ryan J, Ulger AC, Buyuk G, Cakır B, Korkmaz K, Karnez E, Ozgenturk G, Konuskan O (2005). Maintenance of phosphorus fertilizer and residual phosphorus effect on corn production. Nutr Cycl Agroecosyst. 72: 279–286.

Kassam A (1981) Climate and land resources in Wet Asia and North Africa. Plant. Soil., 58: 1-28.

Korkmaz K, Ibrikci H, Karnez E, Buyuk G, Ryan J, Ulger AC, Oguz H (2009) Phosphorus use efficiency of wheat genotypes grown in calcareous soils. J. Plant. Nutr.. 32: 2094–2106.

Lynch JP (1995) Root architecture and plant productivity. Plant. Physiol., 109: 7-13.

Manske CGB, Ortiz-Monasterio JJ, Van Ginkel M, Gonzalez RM, Rajaram S, Molina E, Vlek PLG (2000). Traits associated with improved P-uptake efficiency in CIMMYT's semi-dwarf spring bread wheat grown on an acid Andisol in Mexico. Plant Soil., 221: 189-204.

Manske GGB, Ortiz-Monasterio JJ, Van Ginkel M, Gonzalez RM, Fischer RA, Rajaram S, Vlek PLG (2001). Importance of P uptake efficiency versus P utilization for wheat yield in acid and calcareous soils in Mexico. Eur. J. Agron .,14: 261–274.

Matar A, Torrent J, Ryan J (1992). Soil and fertilizer phosphorus and crop responses in the dry land Mediterranean zone. Adv. Soil. Sci., 18: 81-146.

Murphy J, Riley JP (1962). A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta., 27: 31–36.

Neumann G, Massonneau A, Martinoia E, Romheld V (1999). Pysiological adaptations to phosphorus deficiency during proteoid root development in white lupin. Planta. 208: 373-382.

Ozturk L, Eker S, Torun B, Cakmak I (2005). Variation in phosphorus efficiency among 73 bread and durum wheat genotypes grown in a phosphorus-deficient calcareous soil. Plant Soil, 269: 69-80.

Rashid A, Awan ZI, Ryan J (2005). Diagnosing phosphorus deficiency in spring wheat by plant analysis: proposed critical concentration ranges. Commun. Soil. Sci. Plant Anal., 36: 609-622.

Ryan J, Curtin D, Cheema MA (1985a). Significance of iron oxides and calcium carbonate particle size in phosphate sorption by calcareous soils. Soil. Sci. Soc. Am. J., 49: 74-76.

Ryan J, Hassan H, Bassiri M, Tabbara HS (1985b). Availability and transformation of applied phosphorus in calcareous soils. Soil Sci. Soc. Am. J., 51: 1215-1220.

Ryan J, Matar A (1992). (Ed) Fertilizer use efficiency under rainfed agriculture. Proceedings Fourth Regional Soil Test Calibration Workshop Agadir Morocco May 5–11, 1991 ICARDA Aleppo Syria. p. 286.

Ryan J, Ibrikci H, Masri S, Korkmaz K, Buyuk G, Karnez E (2008). Soil depth and moisture in relation to barley and chickpea growth and uptake responses to applied phosphorus, Basic. Appl. Dryland. Res., 2: 23-33.

Schjorring JK, Nielsen NE (1987). Root length and phosphorus uptake by four barley cultivars grown under moderate deficiency of phosphorus in field experiments, J. Plant. Nutr., 10: 1289-1295.

Schulthess U, Feil B, Jutzi SC (1997). Yield-independent variation in grain nitrogen and phosphorus concentration among Ethiopian wheats. Agron. J., 89: 497-506.

Sims TJ, Sharpley AN, Pierzynski GM, Westermann DT, Cabrera ML, Powell ML, Daniel TC, Withers PJA (2005). Phosphorus: agriculture and the environment. Agron Monograph Am Soc Agron/Crop Madison WI USA, Sci. Soc. Am. Soil Sci. Soc. Am., p.46.

Stewart WM, Dibb DW, Johnston AE, Smyth TJ (2005). The contribution of commercial fertilizer nutrients to food production. Agron. J., 97: 1-6

Tang X, Li J, Ma Y, Hao X, Li X (2008). Phosphorus efficiency in long term (15 years) wheat-maize cropping systems with various soil and climate conditions. Field. Crops. Res., 108: 231-237.

Wittenmayer L, Merbach W (2005). Plant responses to drought and phosphorus deficiency: contribution of phyto-hormones in root-related processes, J. Plant. Nutr. Soil. Sci., 168: 531-540.