Research Journal of Applied Sciences 4 (2): 85-93, 2009
ISSN: 1815-932X

Phosphorus Use Efficiency by Two Varieties of Corn at Different Phosphorus Fertilizer Application Rates

A.H.A. Hussein
Water Studies Center, King Faisal University, P.O. Box 420, Al-Hassa 31982, Saudi Arabia

Abstract: Corn varieties respond differently to phosphorus fertilization. Method of P application may influence the degree of responsiveness. In this study, two varieties of corn (Hageen Asgro and Hageen Niagra) were grown under different rates of phosphorus fertilizer (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) by two methods, soil mixing at sowing and fertigation at three doses. Grain yield, shoot fresh weight, shoot dry weight, weight of 100 kernel, P content and uptake were determined. The data obtained after crop harvest showed that increasing rates of P supply had significantly effect on grain and shoot fresh yield, P content and uptake. Application of P by either method increased grain and shoot fresh yield as well as P uptake over control. P application method×P interaction effect was also significant for yield, indicating higher yield response due to fertigation compared to soil mixing method of P application. Phosphorus application through fertigation technique was more beneficial and has high P efficiency of use and utilization by corn. Also, Hageen Niagra variety was superior over Hageen Asgro variety concerning the phosphorus efficiencies. Soil available p-values obtained at the end of growing period increased significantly with increasing rates of added P. Thus, application of phosphatic fertilizer by fertigation along with selection of an appropriate variety may contribute to improve P fertilizer efficiency and increase corn grain yield.

Key words: P application methods, P fertilizer efficiency, P fertigation, varietals differences, soil mixing, corn

INTRODUCTION

Maize (*Zea mays*, L.) is one of the most important cereal crops in Saudi Arabia 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 considered essential nutrient for plant growth and productivity. It is a component of nucleic acid, nucleic protein and energy-rich compounds such as Adenosine Triphosphates (ATP) through, which plants store energy to fuel other chemical processes. Also, P is a constituent of numerous carbohydrates and nitrogenous compounds and it is a part of certain coenzymes (Mengel and Kirkby, 1987). As Ozanne (1980) reported, P is one of the most yield limiting factors in many tropical and sub tropical 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) P 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*., 2007). 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.

It is estimated that P availability to plant roots is limited in two thirds of the cultivated soil in the world (Batjes, 1997). Phosphorus application is essential to minimize yield loss on the soil. However, most of the P applied to soil can be converted into unavailable forms that cannot be easily utilized by plants. Development of P efficient genotypes with a great ability to grow and yield in P deficient soil is, therefore, an important goal in plant breeding (Hash *et al*., 2002; Wissuwa *et al*., 2002; Yan *et al*., 2004). Release of P efficient genotypes in both high and low-input farming systems would reduce the production costs associated with P fertilizer applications, minimize environmental pollution and contribute to the maintenance of P resources globally (Cakmak, 2002; Vance *et al.*, 2003). Plant species and genotypes of a given species develop diverse adaptive responses to P deficiency. It is well documented that plant genotypes differ greatly in adaptive mechanisms to P deficiency. To improve growth under P-deficient conditions, P-efficient plants have evolved two major mechanisms: increasing P acquisition (root morphology, root exudation and P uptake mechanisms) and enhancing P utilization (internal mechanisms associated with conservable use of absorbed P at the cellular level) (Bates and Lynch, 2001; Vance *et al.*, 2003).

In addition, at high pH (>8.0) and free lime calcium carbonate, this adsorbs soil solution P and increases the precipitation of calcium phosphate compounds, resulting in reduced P availability. Calcareous soils rich in $CaCO_3$ and exchangeable Ca, therefore, phosphorus may be immobilized by any or all the following mechanisms: adsorption on active sites of $CaCO_3$, precipitation by Ca in the system and 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 availability of plant nutrients (FAO, 1984).

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). 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 (Fohse *et al.*, 1988). Phosphorus efficiency can arise in two ways: 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 (90% of maximum yield, Bhadoria *et al.* (2002); 80% of maximum yield, Föhse *et al.* (1988) and 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). This experiment was conducted to determine the differences in yield and P use efficiency of two corn varieties as influenced by different phosphorus fertilizer application rates.

MATERIALS AND METHODS

A field experiment was conducted in the Agricultural and Veterinary Training and Research Station of King Faisal University (KFU), Al-Hassa region, during 2006 growing season of corn (*Zea mays*, L.). Some physical and chemical characteristics of the experimental soil were determined at the beginning of the growing season. The analysis of soil samples collected from the plough layer (0-30 cm) was done according to the methods outlined by Carter (1993) (Table 1). Using calcium-superphosphate (15.5% P_2O_5) four P levels (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) were applied at sowing by soil mixing or by fertigation, at three equal doses to all plots, the first dose was applied with the first irrigation and the second and the third doses was applied 1 and 2 month later, respectively. Seeds of corn varieties Hageen Asgro and Hageen Niagra were used in this study. Planting took place on September 5th, 2006 and harvesting was done at January 26th, 2007. The experimental plot consisted of 5 rows; 5 m long and 0.7 m wide making an area of 17.5 m^2. Seeds were planted at 0.3 m apart within each row. The experimental design used was a split-split plot in Randomized Complete Block Design (RCBD) with 3 replicates, having P application method as main plots, P rates as sub-plots and varieties of corn as sub-sub plots (48 experimental plots). Nitrogen fertilization as ammonium nitrate (33.5% N) at rate of 78.5 kg N ha^{-1} was divided into two equal doses to all plots, the first dose was applied with the first irrigation and the second dose was applied one month later. Potassium fertilization was applied to all plots in the form of potassium sulphate (48% K_2O) at a rate of 150.0 kg K ha^{-1} at two equal doses, the first dose was applied with the first irrigation and the second dose was 1 month later.

At harvest, 10 plants (shoot system) from each plot were randomly collected from the three central rows to determine the corn yield. Each plant sample was divided into two portions; the first portion had washed with tap water, distilled water, air-dried, oven dried at 65°C for

Table 1: Some physical and chemical characteristics of the experimental soil

Sand (%)	Silt (%)	Clay (%)	Soil texture	pH	EC (dSm^{-1})	OM (%)	$CaCO_3$ (%)	N[1] (mg kg^{-1})	P[1] (mg kg^{-1})
57.5	16.2	26.3	Sandy clay loam	8.2	2.26	0.29	27.98	23.31	5.56

[1]Available N-NO_3^- and P

72 h and then ground in a stainless steel mill and stored for elemental analysis. The ground plant material was digested with concentrated sulphuric acid +30% hydrogen peroxide according to the method of Wolf (1982). In the digest, total phosphorus was determined calorimetrically according to the method of Murphy and Riley (1962). The second portion of plant sample (fresh sample) was used to determine the fresh weight of shoot system, dry weight, grain yield and weight of 100 kernels. At harvest, soil samples (0-30 cm surface layer) were collected, air-dried, ground, mixed thoroughly and sieved through a 2 mm mesh screen for determine available P. Soil available P was extracted using a 0.5 M $NaHCO_3$ solution (Olsen *et al*., 1954) and determined by ascorbic acid- molybdenum blue method at wavelength of 406 nm as described by Murphy and Riley (1962). The obtained data were tabulated and subjected to statistical analysis according to Steel and Torrie (1982). Correlation coefficient was done using the method described by Draper and Smith (1981).

The efficiency of phosphorus was calculated as follows (Dobermann, 2005):

$$\text{Phosphorus Use Efficiency (PUE)} = \frac{\text{Corn grain yield (kg ha}^{-1}\text{)}}{\text{Fertilizer applied (kg P}_2\text{O}_5\text{ ha}^{-1}\text{)}}$$

$$\text{Agronomic Efficiency (PAE)} = \frac{\text{(Yield (fertilized) - Yield (control)) (kg ha}^{-1}\text{)}}{\text{Fertilizer applied (kg P}_2\text{O}_5\text{ ha}^{-1}\text{)}}$$

$$\text{Recovery Efficiency (PRE)} = \frac{\text{(P total uptake (fertilized) - P total uptake (control)) (kg ha}^{-1}\text{)}}{\text{Fertilizer applied (kg P}_2\text{O}_5\text{ ha}^{-1}\text{)}}$$

$$\text{Utilization Efficiency (UE)} = \frac{\text{Corn grain yield (kg ha}^{-1}\text{)}}{\text{P total uptake (kg ha}^{-1}\text{)}}$$

RESULTS AND DISCUSSION

Grain yield and fresh weight: Application of P by either method significantly increased the shoot fresh weight, dry weight, grain yield and weight of 100 kernels where, high increase in yield parameters was occurred with fertigation compared to soil mixing method of P application (Table 2). Farooq *et al.* (1994), Latif *et al.* (1997) and Alam *et al.* (2002, 2003) also reported improved grain yield of wheat due to fertigation of P at first irrigation compared to its soil mixing at sowing. As regards the extent of varietals response to P application by different methods, it may be observed (Table 2) that the behaviors of the two varieties were almost similar for both methods of application. However, Hageen Niagra had relatively greater response than to Hageen Asgro that may be attributed to improved 100 grain weight of this variety at fertigated treatment.

Table 2 showed that addition of P significantly increased the shoot fresh weight, shoot dry weight, grain yield and weight of 100 kernels. Shoot fresh weight increased gradually as the application rate of P increased. It was increased for variety Hageen Asgro by 7.52, 12.95 and 16.33%, for rates of 30, 60 and 90 kg ha^{-1}, respectively, relative to the control treatment. The corresponding values for variety Hageen Niagra were 9.67, 16.29 and 18.98%, respectively. The same trend was found with the dry weight, where it was significantly increased with application of P at any rate. The increases for variety Hageen Asgro were 7.23, 12.52 and 15.87% relative to the control treatment, respectively. The corresponding values for variety Hageen Niagra were 8.89, 15.73 and 19.23%, respectively. The highest values of grain yield and weight of 100 kernel were attained at the highest level of P (90 kg ha^{-1}). The increases in grain yield for variety Hageen Asgro were 17.70, 27.80 and 42.39%, respectively relative to the control treatment. The corresponding values for variety Hageen Niagra were 40.91, 47.57 and 61.04%, respectively. Also, the weight of 100 kernel, behaved the same trend because of the total seed yield is correlated with weight of seed.

Corn varieties differed significantly in shoot fresh weight, dry weight, grain yield and weight of 100 kernels. Mean highest of yield parameters was observed for Hageen Niagra followed by Hageen Asgro.

The obtained results are in close agreement with those found by Mahakulkar *et al.* (1992), Legere *et al.* (1994), Geelhoed *et al.* (1997), Hussein and Abdel-Nasser (2002) and Hussein and Khater (2003). Alam *et al.* (2003) found that application of phosphorus significantly increased grain and straw yield and 1000 grain weight of wheat. Ezekiel and Adigun (2005) showed that application of different levels of phosphorus fertilizer increased growth parameters (plant height, number of leaves and leaf area) of pepper and okra plant.

Interaction effects of the treatments were significant with dry weight and grain yield. In which, it increased with increasing P fertilization rate.

Shoot and grain phosphorus contents: The data presented in Table 3 showed that there are significant increases in shoot and grain P content with P fertigation method than soil mixing. The same trend was noticed with P uptake and total P uptake. Also, the results showed significant increases in P contents due to increasing the P application rate from 0-90 kg P_2O_5 ha^{-1}. These results

Table 2: Effect of method and rates of P application on growth and grain yield of two corn varieties

Method of application	P rate ($kg\ P_2O_5\ ha^{-1}$)	Varieties	Fresh weight ($t\ ha^{-1}$)	Dry weight ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Weight of 100 kernels (g)
Soil mixing at sowing	0 (Control)	Hageen Asgro	25.75	4.79	2.83	19.65
		Hageen Niagra	26.70	4.97	2.29	21.96
	30	Hageen Asgro	27.68	5.16	3.43	20.83
		Hageen Niagra	28.25	5.24	3.74	21.58
	60	Hageen Asgro	28.54	5.34	3.94	21.77
		Hageen Niagra	29.92	5.56	4.07	22.31
	90	Hageen Asgro	29.84	5.53	3.96	21.88
		Hageen Niagra	30.34	5.69	4.15	22.75
Fertigation	0 (Control)	Hageen Asgro	27.08	5.06	3.11	21.34
		Hageen Niagra	27.28	5.12	3.27	21.86
	30	Hageen Asgro	29.12	5.41	4.15	22.3
		Hageen Niagra	30.94	5.75	4.94	23.57
	60	Hageen Asgro	31.13	5.75	4.29	24.09
		Hageen Niagra	32.85	6.11	5.02	23.95
	90	Hageen Asgro	31.61	5.89	5.21	22.75
		Hageen Niagra	33.88	6.34	5.77	24.39
Mean effect of P application Method (M)						
Soil mixing at sowing			28.38	5.28	3.55	21.59
Fertigation			30.49	5.68	4.47	23.03
$LSD_{(0.05)}$			1.07*	0.03**	0.05**	0.80*
Mean effect of P application Rate (R) ($kg\ P_2O_5\ ha^{-1}$)						
0			26.70	4.99	2.87	21.20
30			29.00	5.39	4.07	22.07
60			30.61	5.69	4.33	23.03
90			31.42	5.86	4.77	23.32
$LSD_{(0.05)}$			1.20**	0.12**	0.10**	0.97**
Mean effect of corn Varieties (V)						
Hageen Asgro			28.84	5.37	3.87	21.83
Hageen Niagra			30.02	5.60	4.16	22.80
$LSD_{(0.05)}$			0.75**	0.05**	0.04**	0.35**
Interaction effects ($LSD_{(0.05)}$)						
M×R			ns	ns	0.14**	ns
M×V			ns	0.06**	0.05**	ns
V×R			ns	0.09*	0.07**	ns
M×R×V			ns	0.13*	0.10*	ns

NS: Not Significant

are in agreement with Elwan (1991), Hussein and Abou El-Seoud (1999), Hussein and Abdel-Nasser (2002), Alam *et al*. (2003) and Ezekiel and Adigun (2005). Also, P uptake in shoot and grain of corn significantly increased as a result of increasing P application rate. It is clear from the result that the concentration of P in shoot system and grain of corn was higher in Hageen Asgro while, it was lower in Hageen Asgro. Total phosphorus taken up by plants was also significantly higher in Hageen Niagra while, it was lower in Hageen Niagra. Increased phosphorus uptake due to P application may be attributed to increased yield rather than its concentration.

Interaction effects of the treatments were significant with shoot and grain P uptake. This means that all treatments have a significant effect on studied parameters.

The data showed that there are a significant correlation between applied of phosphorus and some parameters of corn plant (Table 4). Method of application had significant and positive effect on yield, phosphorus content of corn and P uptake, where high yield; high phosphorus content and high uptake of P was occurred in fertigation compared to soil mixing method of application. While, significant method×P interaction effect indicated increased P uptake to occur in fertigation compared to soil mixing method of application (Ranjhe and Mehdi, 1992). They concluded that immediate use of irrigation water after P application was the key factor in improving P fertilizer efficiency. In fact, when monocalcium phosphate is added to alkaline calcareous soil, the immediate reactions products are Di-Calcium Phosphate Dehydrate (DCPD) and Di-Calcium Phosphate Anhydrate (DCPA). The conversion of these two reactions product is moisture dependent. Fertilizer P when applied at seeding may be converted more to DCPA due to less moisture and hence, would be less available. At higher moisture content the conversion is towards DCPD. This product is more effective in replenishing P solution and stays for longer time before conversion to DCPA (Sauchilli, 1965). Moreover, the crown root growth at tillering has already developed close to the soil surface and crowns have been found to absorb P (Tisdale *et al*., 1985). The demand for P at this stage of growth is also much higher compared to other stages of growth (Romer and Schilling, 1986). Therefore, provision of readily available P through fertigation to the developing roots is more likely to meet the high P demand for a longer

Table 3: Effect of method and rates of P application on corn shoot and grain elemental content and uptake

Method of P application	P rate ($kg\ P_2O_5\ ha^{-1}$)	Varieties	P content (%) Shoot	P content (%) Grain	P uptake ($kg\ ha^{-1}$) Shoot	P uptake ($kg\ ha^{-1}$) Grain	Total P uptake ($kg\ ha^{-1}$) Shoot + Grain
Soil mixing at sowing	Control	Hageen Asgro	0.21	0.09	10.07	0.25	10.32
		Hageen Niagra	0.21	0.12	10.44	0.27	10.71
	30	Hageen Asgro	0.37	0.12	19.09	0.40	19.49
		Hageen Niagra	0.38	0.15	19.90	0.55	20.45
	60	Hageen Asgro	0.41	0.14	21.91	0.53	22.44
		Hageen Niagra	0.45	0.18	25.04	0.71	25.75
	90	Hageen Asgro	0.45	0.17	24.89	0.65	25.54
		Hageen Niagra	0.47	0.20	26.74	0.80	27.54
Fertigation	Control	Hageen Asgro	0.24	0.14	12.15	0.42	12.57
		Hageen Niagra	0.25	0.18	12.80	0.56	13.36
	30	Hageen Asgro	0.41	0.19	22.18	0.76	22.94
		Hageen Niagra	0.42	0.22	24.15	1.04	25.19
	60	Hageen Asgro	0.46	0.22	26.44	0.89	27.33
		Hageen Niagra	0.49	0.25	29.94	1.22	31.16
	90	Hageen Asgro	0.49	0.25	28.86	1.22	30.08
		Hageen Niagra	0.54	0.27	34.22	1.49	35.71
Mean effect of P application Method (M)							
Soil mixing at sowing			0.37	0.15	19.76	0.52	20.28
Fertigation			0.41	0.22	23.84	0.95	24.79
$LSD_{(0.05)}$			0.04*	0.03**	0.66**	0.03**	0.24**
Mean effect of P application Rate (R) ($kg\ P_2O_5\ ha^{-1}$)							
0			0.23	0.13	11.37	0.38	11.74
30			0.40	0.17	21.33	0.69	22.02
60			0.45	0.20	25.83	0.84	26.67
90			0.49	0.22	28.68	1.04	29.72
$LSD_{(0.05)}$			0.03**	0.03**	1.28**	0.04**	1.22**
Mean effect of corn Varieties (V)							
Hageen Asgro			0.38	0.17	20.70	0.64	21.34
Hageen Niagra			0.40	0.20	22.90	0.83	23.73
$LSD_{(0.05)}$			0.01**	0.01**	0.30**	0.02**	0.30**
Interaction effects $LSD_{(0.05)}$							
M×R			ns	ns	ns	0.06**	1.73**
M×V			ns	ns	0.42**	0.03**	0.43**
V×R			ns	ns	0.60**	0.04**	0.61**
M×R×V			ns	ns	0.85**	ns	0.86**

Table 4: Correlation coefficients between P application methods and some parameters of corn plant

Method of application	Varieties of corn	Fresh weight	Dry weight	Grain yield	P Conc. Shoot	P Conc. Grain	P uptake Shoot	P uptake Grain
Soil mixing at sowing	Hageen Asgro	0.99	0.98	0.95	0.92	0.99	0.94	0.99
	Hageen Niagra	0.98	0.99	0.88	0.93	0.99	0.95	0.97
Fertigation	Hageen Asgro	0.97	0.99	0.96	0.93	0.99	0.95	0.98
	Hageen Niagra	0.96	0.98	0.95	0.96	0.98	0.97	0.98

period of time and thereby result in improved P use efficiency. In an earlier study, consistent improvement of DMY and P uptake in plants sampled at different times of growth clearly showed the increased efficiency of fertigated P compared to soil mixing P at sowing (Alam *et al*., 1999).

Phosphorus efficiency: Phosphorus efficiencies of the two corn varieties were calculated for different methods and rate of application (Table 5). Fertigation method of P application resulted in improving P Use Efficiency (PUE), Phosphorus Agronomic Efficiency (PAE), Phosphorus Recovery Efficiency (PRE) and phosphorus Utilization Efficiency (UE) over soil mixing method. The increases were 25.42, 27.08, 16.67 and 6.98%, respectively. The increasing rate of phosphorus application was found to be decreased all above mentioned efficiencies. This is true because the utilization of nutrients decreased as increasing the rate of nutrient application as stated by the law of limiting factors (Blackman, 1905) and Liebig's law of the minimum (Liebig, 1840). On the other hand, Hageen Asgro variety was superior to Hageen Niagra variety concerning the phosphorus efficiencies. The increases were 12.07, 64.12, 16.67 and 37.19% for PUE, PAE, PRE and UE, respectively.

The response of crops to added P is generally affected by soil factors such as pH, EC and $CaCO_3$ content. Thus, poor efficiency of applied P may partially be attributed to alkaline or calcareous nature of soil, which favours P fixation by revering the applied P to less

Table 5: Phosphorus efficiencies of two corn varieties as affected by methods and rates of P application

Method of application	P rate (kg P_2O_5 ha^{-1})	Varieties of corn	PUE (kg kg^{-1}) P_2O_5	PAE (kg kg^{-1}) P_2O_5	PRE (kg kg^{-1})	UE (kg kg^{-1})
Soil mixing at sowing	Control	Hageen Asgro	-	-	-	274.22
		Hageen Niagra	-	-	-	213.82
	30	Hageen Asgro	114.33	20.00	0.306	175.99
		Hageen Niagra	124.67	48.33	0.325	182.89
	60	Hageen Asgro	65.67	18.50	0.202	175.58
		Hageen Niagra	67.83	29.67	0.251	158.06
	90	Hageen Asgro	44.00	12.56	0.169	155.05
		Hageen Niagra	46.11	20.67	0.187	150.69
Fertigation	Control	Hageen Asgro	-	-	-	247.41
		Hageen Niagra	-	-	-	244.76
	30	Hageen Asgro	138.33	34.67	0.346	180.91
		Hageen Niagra	164.67	55.67	0.394	196.11
	60	Hageen Asgro	71.50	19.67	0.246	156.97
		Hageen Niagra	83.67	29.17	0.279	161.10
	90	Hageen Asgro	57.89	23.33	0.195	173.20
		Hageen Niagra	64.11	27.78	0.248	161.58

Table 6: Effect of method and P application on available soil phosphorus (mg kg^{-1})

Method of P application	P rate (kg P_2O_5 ha^{-1})	Varieties of corn	Available P (mg kg^{-1})
Soil mixing at sowing	Control	Hageen Asgro	3.42
		Hageen Niagra	3.36
	30	Hageen Asgro	8.26
		Hageen Niagra	7.97
	60	Hageen Asgro	10.14
		Hageen Niagra	9.88
	90	Hageen Asgro	13.56
		Hageen Niagra	12.79
Fertigation	Control	Hageen Asgro	2.69
		Hageen Niagra	2.61
	30	Hageen Asgro	6.88
		Hageen Niagra	6.39
	60	Hageen Asgro	9.71
		Hageen Niagra	8.91
	90	Hageen Asgro	12.77
		Hageen Niagra	12.11
Mean effect of P application Method (M)			
Soil mixing at sowing			8.67
Fertigation			7.76
$LSD_{(0.05)}$			0.14**
Mean effect of P application rate (kg P_2O_5 ha^{-1})			
0			3.02
30			7.38
60			9.66
90			12.81
$LSD_{(0.05)}$			0.71**
Mean effect of corn Varieties (V)			
Hageen Asgro			8.43
Hageen Niagra			8.00
$LSD_{(0.05)}$			0.23**
Interaction effects $LSD_{(0.05)}$			
M×R			ns
M×V			ns
V×R			ns
M×R×V			ns

available calcium phosphate compounds (Rashid, 1994). Fixation of soil mixing P is much greater than the P fertigation technique. Therefore, P fertigation has performed most efficiently in many parts of the world (Twyford, 1994). The obtained results are in close agreement with those found by Alam *et al.* (2003). They found that the mean PUtE of five wheat varieties across four P sources varied in the order, Punjab-96>Pasban-90 = Pervaz-94 = Shahkar-95>Inqelab-91. Yaseen *et al.* (1998) also reported significant differences in PUtE among 20 wheat genotypes at deficient and adequate P levels. Alam *et al.* (2003) reported that application of phosphatic fertilizer by fertigation may contribute to improve P fertilizer efficiency and increase wheat grain yield.

Soil available phosphorus: The results in Table 6 indicated that P application methods have a significant effect on available soil P. Soil mixing method had significantly higher amounts of available P (8.67 mg kg^{-1}) than the fertigation method (7.76 mg kg^{-1}) (Table 6). This result can be explained on the basis that P concentration in shoot system and grain of two corn varieties was higher in fertigation method treatment while, it was lower in the soil mixing method. Thus, residual available P in soil was more in soil mixing method than fertigation method.

The amount of extractable P was increased significantly as the rate of P application increased. The increase in extractable P in soil was about 144, 219 and 324% for rates of 30, 60 and 90 kg ha^{-1}, respectively, relative to the control treatment. Also, the results showed that available P in soil cultivated with variety of corn (Hageen Asgro) was significantly higher than available P in soil cultivated with variety of corn (Hageen Asgro). This may be due to total phosphorus taken up by plants was significantly higher in Hageen Asgro while, it was lower in Hageen Asgro. So that, residual available P in soil was more in soil cultivated with variety of corn (Hageen Asgro), while, it lower in soil cultivated with variety of corn (Hageen Niagra).

These results were agreed with those obtained by Thompson and Troch (1982) and Ezekiel and Adigun (2005). Regression between P applications rates and available P in soil at each method of P application was

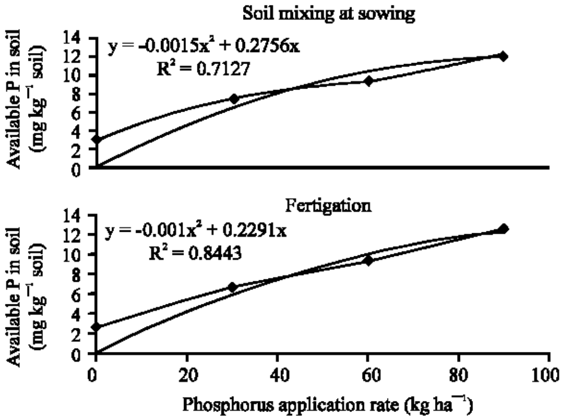

Fig. 1: Linear regression between phosphorus fertilization (kg P_2O_5 ha^{-1}) and available soil phosphorus (mg P kg^{-1} soil)

fitted. The inferred equations are shown in Fig. 1. A significant positive correlation was found between available P and P fertilizer rates at each method of P application. The correlation coefficient was 0.98 and 0.99 for soil mixing at sowing and fertigation, respectively.

CONCLUSION

The increasing costs and inaccessibility of chemical fertilizers to small and medium scale farmers in developing nations coupled with possible environmental pollution make it imperative that research efforts should focus on maximum production of good quality crops while, avoiding excessive and indiscriminate fertilizer use. The more the quantities of fertilizer used, the less the efficiency of the crops to use the nutrient element. It may be concluded that corn varieties differed significantly in shoot fresh weight, grain yield, P content in shoot system, P uptake and P use efficiency and may be ranked as Hageen Niagra>Hageen Asgro>. Hageen Niagra variety was, however, superior and Hageen Asgro was inferior in responding to P applied by either method. Phosphorus applied by fertigation resulted in improving the P efficiencies as compared to its soil mixing at sowing. Thus, application of phosphatic fertilizers by fertigation along with selection of an appropriate variety may contribute to improve P use efficiency and increase corn grain yield.

REFERENCES

Alam, S.M., S.A. Shah and M. Akthar, 2003. Varietal differences in wheat yield and phosphorus use efficiency as influenced by method of phosphorus application. Songklanakarin J. Sci. Technol., 25 (2): 175-181.

Alam, S.M., A. Latif and Z. Iqbal, 2002. Wheat yield and phosphorus use efficiency as influenced by method of phosphorus and zinc application. Pak. J. Sci. Ind. Res., 45: 117-119.

Alam, S.M., Z. Iqbal and A. Latif, 1999. Fertigation technology for improved phosphorus use efficiency in wheat. Pak. J. Sci. Ind. Res., 42 (6): 380-383.

Bates, T.R. and J.P. Lynch, 2001. Root hairs confer a competitive advantage under low phosphorus availability. Plant Soil, 236: 243-250. DOI: 10.1023/A: 1012791706800.

Batjes, N.H., 1997. A world data set of derived soil properties by FAOU/NESCO soil unit for global modeling. Soil Use Manage., 1: 9-16.

Bhadoria, P.S., B. Steingrobe, N. Claassen and H. Liebersbach, 2002. Phosphorus efficiency of wheat and sugar beet seedling grown in soils with mainly calcium, or iron and aluminum phosphate. Plant Soil, 246: 41-52. DOI: 10.1023/A:1021567331637.

Blackman, F.F., 1905. Optima and limiting factors. Ann. Bot., 19: 281-295.

Cakmak, I., 2002. Plant nutrition research: Priorities to meet human needs for food in sustainable ways. Plant Soil, 247: 3-24. DOI: 10.1023/A:1021194511492.

Caradus, J.R. and R.W. Snaydon, 1987. Aspects of phosphorus nutrition of white clover populations. I. Inorganic phosphorus content of leaf tissue. J. Plant Nutr., 10: 273-285. DOI: 10.1080/01904168709363572.

Carter, M.R., 1993. Soil Sampling and Methods of Analysis. 1st Edn. Canada Society of Soil Science, Lewis Publishers, Boca Raton, FL.

Dobermann, A., 2005. Nitrogen use efficiency-state of the art. IFA International Workshop on Enhanced-Efficiency Fertilizers, Frankfurt, Germany, June 28-30. http://soilfertility.unl.edu/Materials%20to%20include/Nitrogen%20use%20efficiency%20state%20of%20the%20art_Dobermann.pdf.

Draper, N.R. and H. Smith, 1981. Applied Regression Analysis. 2nd Edn. John Wiley, New York.

Egle, K., G. Manske, W. Römer and P.L.G. Vlek, 1999. Improved phosphorus efficiency of three new wheat genotypes from CIMMYT in comparison with an Mexican variety. J. Plant Nutr. Soil Sci., 162(3):353-358. DOI: 10.1002/(SICI)1522-2624(199906)162:3<353:AID-JPLN353>3.0.CO;2-A.

Elwan, I.M., 1991. Effect of P-fertilization and inoculation with VA-mycorrhizae on growth, phosphorus uptake by plants. Agric. Sci. Mansoura Uni., 16 (12): 3031-3037.

Ezekiel, A.A. and I.O. Adigun, 2005. Phosphorus-use efficiency by pepper (*Capsicum frutescens*) and okra (*Abelmoschus esculentum*) at different phosphorus fertilizer application levels on two tropical soils. J. Applied Sci., 5 (10): 1785-1791. DOI: 10.3923/jas.2005.1785.1791.

FAO, 1984. Fertilizer and plant nutrition Guide. FAO fertilizer and plant nutrition bulletin 9, Soil and water Development Division, Roma. ISBN: 9251021600 9789251021606.

Farooq, M., A. Ali, B.A. Ehsan and A.A. Doger, 1994. Economics of P application to wheat by fertigation. Abstract 5th Natl. Cong. Soil. Sci., Oct. 23-25, Peshawar, pp: 22.

Föhse, D., N. Claassen and A. Jungk, 1988. Phosphorus efficiency of plants. I. External and internal P requirement and P uptake efficiency of different plant species. Plant Soil, 110: 101-109. DOI: 10.1007/BF 02143545.

Geelhoed, J.S., W.H.V. Riemsdijk and G.R. Findenegg, 1997. Effects of sulphate and PH on the plant-availability of phosphate adsorbed on goethite. Plant Soil, 197: 241-249. DOI: 10.1023/A:1004228715984.

Gourley, C.J.P., D.L. Allan and M.P. Russelle, 1994. Plant nutrient efficiency: A comparison of definitions and suggested improvement. Plant Soil, 158: 29-37. DOI: 10.1007/BF00007914.

Hash, C.T., R.E. Schaffert and J.M. Peacock, 2002. Prospects for using conventional techniques and molecular biological tools to enhance performance of >orphan=crop plants on soils low in available phosphorus. Plant Soil, 245: 135-146. DOI: 10.1023/A: 1020627926131.

Hussein, A.H.A. and G. Abdel-Nasser, 2002. Influence of superphosphate and elemental sulfur on soil physical properties, growth, yield and nutrients status of sunflower. Two growth, yield, leaf water and nutrients contents. J. Adv. Agric. Res., 7 (2): 491-508.

Hussein, M.A. and M.A. Khater, 2003. Effect of superphosphate fertilizer type on yield and yield attributes of wheat plant growth in clay soil. J. Adv. Agric. Res., 8 (3): 487-499.

Hussein, A.H.A. and I.I.A. Abou El-Seoud, 1999. Effects of mycorrhizal fungus inoculation of organic fertilizer treated-soil on yield and elemental composition of cotton crop in relation to phosphorus fertilization. J. Adv. Agric. Res., 4: 813-826.

Latif, A., S.M. Alam, A. Hamid and Z. Iqbal, 1997. Relative efficiency of phosphorus applied through broadcast incorporation, top dressing and fertigation to crops. Pak. J. Soil Sci., 13: 15-18.

Legere, A., R.R. Simard and C. Lapierre, 1994. Response of spring barley and weed communities to lime, phosphorus and tillage. Can. J. Plant Sci., 74 (3): 421-428.

Liebig, J., 1840. Chemistry and its application to agriculture and physiology. Taylor and Walton, London.

Mahakulkar, B.V., S.S. Wanjari, V.B. Shekar, N.R. Potolukhe and A.M. Dhope, 1992. Yield of newly developed genotypes of rainfed sorghum (*S. bicolor*) under different levels of nitrogen and phosphorus. Ind. J. Agric. Sci., 62 (4): 274-248.

Marschner, H., 1995. Mineral Nutrition of Higher Plants. 2nd Edn. Academic Press, London, UK. DOI: 10.1016/ 0378-429096084669-7.

Mengel, K. and E.A. Kirkby, 1987. Principles of plant Nutrition. 4th Edn. International Potash Institute, Bern, Switherland. ISBN: 3906535037.

Murphy, J. and J.P. Riley, 1962. A modified single solution for the determination of phosphate in natural waters. Anal. Chem. Acta., 27: 31-36.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean, 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Agriculture, United States Department of Agricutlure in cooperation with the Colorado Agricutlural Experiment Station. Circular No. 939: 1-19.

Ozanne, P.G., 1980. Phosphate Nutrition of Plants a General Treatise. In: Khasawneh, F.F. and E.C. Sample (Eds.). The Role of Phosphorus in Agriculture, pp: 559-589. American Society of Agronomy, Madison.

Ranjha, A.M. and S.M. Mehdi, 1992. Effect of source and method of application of phosphorus on the growth of maize and wheat. In Proceeding, symposium on the role of phosphorus in crop production NFDC, Islamabad, pp: 259-264.

Rao, I.M., V. Borrero, J. Ricaurte, R. Garcia and M.A. Ayarza, 1997. Adaptive attribute of tropical forage species to acid soils. III Differences in phosphorus acquisition and utilization as influences by varying phosphorus supply and soil type. J. Plant Nutr., 20: 155-180.

Rashid, A., 1994. Phosphorus use efficiency in soils of Pakistan. In Proc. 4th Natl. Cong. Soil Sci. Islamabad, Pakistan, pp: 115-127.

Romer, W. and G. Schilling, 1986. Phosphorus requirement of wheat plants in various stages of its life cycle. Plant Soil, 91: 221-229. DOI: 10.1007/BF02181789.

Sattelmacher, B., W.J. Horst and H.C. Becker, 2007. Factors that contribute to genetic variation for nutrient efficiency of crop plants. Zeitschrift für Pflanzenernährung Und. Bodenkunde, 157: 215-224. DOI: 10.1002/jpln.19941570309.

Sauchilli, V., 1965. Phosphates in Agriculture Reinhold Publishing Corporation, New York, Chapman and Hall, Ltd., London.

Steel, R.G. and J.H. Torrie, 1982. Principles and Procedures of Statistics. 2nd Edn. Hill Book Company, New York, USA.

Thompson, L.M. and F.R. Troch, 1982. Soils and soil fertility. Pub. McGraw-Hill Inc., New York.

Tisdale, S.L., W.L. Nelson and J.D. Beaton, 1985. Soil Fertility and Fertilizers. 4th Edn. Macmillan Publishing Co., New York. ISBN-13:9780024208309.

Twyford, I.T., 1994. Fertilizer use and crop yield. In: Proc. 4th National Cong. Soil Sci., Islamabad, Pakistan, pp: 47-72.

Vance, C.P., C.U. Stone and D.L. Allan, 2003. Phosphorus acquisition and use: Critical adaptations by plants for securing a nonrenewable resource. New Phytologist, 157: 423-447. DOI: 10.1046/j.1469-8137.2003.00695.x.

Wolf, B., 1982. A comprehensive system of leaf analysis and its use for diagnosingcrop nutrient status. Comm. Soil Sci. Plant Anal., 13: 1035-1059.

Wissuwa, M., J. Wegner, N. Ae and M. Yano, 2002. Substitution mapping of Pup 1: A major QTL increasing phosphorus uptake of rice from a phosphorus-deficient soil. Theoret. Applied Genet., 105: 890-897. DOI: 10.1007/s00122-002-1051-9.

Yan, X., H. Liao, S.E. Beebe, M.W. Blair and J.P. Lynch, 2004. QTL mapping of root hair and acid exudation traits and their relationship to phosphorus uptake in common bean. Plant Soil, 265: 17-29. DOI: 10.1007/s 11104-005-0693-1.

Yaseen, M., M.A. Gill, M. Siddique, Z. Ahmad, T. Mahmood and H. Rahman, 1998. Phosphorus deficiency stress tolerance and phosphorus utilization efficiency in wheat genotypes. In: Proc. Symposium Plant Nutrition Management for Sustainable Agricultural Growth, NFDC, Islamabad, pp: 211-215.