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RESEARCH PAPER

Phosphorus and iron interaction: Effects on dry matter yield, nutrient uptake and quality of maize (*Zea mays* L.)

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Abstract A study in light-textured and heavy-textured soil was conducted to explore the impact of phosphorus (P) and iron (Fe) application on maize, focusing on their effects on dry matter yield, nutrient uptake (nitrogen, phosphorus, potassium, and iron) and protein content at Screen house of College of Agriculture, Hisar. Based on our study it was concluded that, in light-textured soil, the highest dry matter yield and N uptake was observed in $P_{40}Fe_{10}$ treatment. The highest Phosphorus and K uptake was observed in $P_{40}Fe_{5}$ treatment. The highest Fe uptake was observed $P_{40}Fe_{10}$ while highest protein content was observed with $P_{40}Fe_{1\%spray}$. Whenever in heavy-textured soil, the highest dry matter yield, N uptake, P uptake, K uptake and protein content were observed in $P_{30}Fe_{10}$ treatment. The highest Fe uptake was observed in $P_{20}Fe_{10}$ treatment. In the case of light textured soil P × Fe interaction was found significant only in the case of dry matter yield and protein content. On the other hand, P × Fe interaction was significant in all the parameters except Fe uptake.

Keywords: Maize · P × Fe interaction · Yield · Nutrient uptake · Protein content

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Introduction

Maize (*Zea mays* L.) is one of the most widely grown cereals in the world and has great significance as human food, animal feed and raw material for industrial products. Maize has high production potential especially under irrigated conditions when compared to any other cereal crop. In India during 2022-23, 10.2 m ha of maize were cultivated and produced 35.9 mt of maize with a productivity of 3.6 t/ha. In Haryana, the total maize area is 4.81 thousand ha, with production 16.01 thousand tons and productivity is 3.3 t/ha (MoF and FW, 2022-23). The productivity of maize largely depends on its nutrient requirement and management. Soil P exists in four different pools based on its accessibility and extractability such as soil solution P; surface-adsorbed P; strongly-bonded or absorbed P; and very strongly-bonded or inaccessible or mineral or precipitated P (Syers *et al.*, 2008). In the soil solution, P is immediately available for uptake by plant roots. Researchers in India (Tandon, 1994) also recognize the existence of different pools of P in the soil and their accessibility to crops.

Amongst micronutrients, iron (Fe) is an essential plant nutrient, the lack of which causes chlorosis and is responsible for a significant decrease in yield and quality of plants. Although soils may contain adequate total iron, amounts that are available to plants might be inadequate depending on various soil factors such as very high or low soil temperature, high humidity, poor soil aeration and compaction, high pH, HCO_3^- and $CaCO_3$ contents. Its availability is lower in soils of arid and semi-arid regions as forage and grains had lower Fe content in these areas and showed more chlorosis compared to those grown in soils of humid and sub-humid regions. Nutrient interaction in crop plants is probably one of the other most important factors affecting yields of annual crops. Nutrient interaction can be positive, negative, or neutral (Fageria *et al.,* 1997). All three interactions among essential plant nutrients have been reported. However, most interactions are complex. A nutrient interacting simultaneously with more than one nutrient may induce deficiencies, toxicities, modified growth responses, and/or modified nutrient composition. Since these interactions modify the nutrition of crop plants, there is an imminent need to consider and understand them adequately. Because of the foregoing consideration, a pot experiment was planned to investigate the status of various P fractions under light and heavy textured soils.

Materials and methods

A bulk surface sample (0-15 cm) of light and heavy textured soil was collected from village Balsamand and Lalauda of Hisar and Fatehabad districts, respectively to conduct the experiments in screen house and laboratory conditions at the College of Agriculture, Hisar. The soils were air-dried, then passed through a 2 mm sieve and mixed thoroughly. The processed soil samples were used for laboratory and screen house studies. Some of the relevant physico-chemical characteristics of soil and macro and micronutrients status along with the methods used for analysis are mentioned in Table 1.

Imposition of treatments

The processed soil was filled in five kg capacity plastic pots and placed in a completely randomized way in the screen house. The plastic pots were used mainly to avoid the leaching of soil solution and the interaction of metals with the pot surface. All, 96 pots were filled with 4 kg of thoroughly mixed air-dried soil. The processed soil was artificially spiked with P using potassium dihydrogen phosphate (KH_2PO_4) as a source of P and with Fe using Iron (II) sulphate heptahydrate ($FeSO_4.7H_2O$) as a source of Fe. An 8000 ppm P solution was prepared with KH_2PO_4 and a dose of 10, 15 and 20 ml per pot, of this solution was supplied to apply phosphorus at 40, 60 and 80 kg ha^{-1} or 20, 30 and 40 mg kg^{-1}, respectively. Likewise, 2000 ppm Fe solution was prepared with $FeSO_4.7H_2O$ and a dose of 10 and 20 ml per pot, of this solution was supplied to apply iron at 10 and 20 kg ha^{-1} (or 5 and 10 mg kg^{-1}), respectively. In addition to this, 1% $FeSO_4$ solution was also prepared and foliar spray of this solution was made on maize plants at 30 days after sowing (DAS) to achieve the fourth iron treatment.

Basal application of the recommended dose of nitrogen, potassium and Zn at 150, 62.5 and 25 kg ha^{-1} was supplied through urea, KH_2PO_4 and $ZnSO_4.7H_2O$, respectively in solution form at 200 ml in each pot separately. Each soil sample was spread uniformly over the plastic sheet and thoroughly mixed for proper equilibration and uniform enrichment of soil with added P and Fe, respectively. Ten seeds of maize were sown in each pot. Thinning was done to 4 plants per pot on 7th day of seeding and plants were allowed to grow up to 45 days from the date of sowing. The pots were irrigated with de-ionized water as and when required. The crop was harvested at 45 DAS. Plant samples were

Table 1. Initial physico-chemical characteristics of experimental soils

Characteristic	Soil type		Method used
	Light textured	Heavy textured	
Sand (%)	70.6	44.7	International pipette method (Piper, 1966)
Silt (%)	12.8	22.9	
Clay (%)	16.6	32.4	
Textural class	Sandy loam	Clay loam	USDA system of soil classification for textural class
pH (1:2)	7.9	7.5	Glass electrode pH meter (Jackson, 1973)
EC (dS m^{-1})	1.05	0.14	Conductivity bridge meter (Richard, 1954)
Organic carbon (%)	0.18	0.62	Walkley and Black (1934)
Calcium carbonate (%)	0.5	Nil	Puri (1949)
Available N (kg ha^{-1})	78	166	Subbiah and Asija (1956)
Available P (kg ha^{-1})	13	47	Olsen *et al.* (1954)
Available K (kg ha^{-1})	194	249	Flame photometrically (Jackson, 1958)
DTPA- Fe (mg kg^{-1})	4	56	Lindsay and Norvell (1978)

ground in a stainless-steel grinder and stored in polyethylene bags separately for further chemical analysis.

The experimental data so obtained was statistically analyzed by the methods of analysis of variance (ANOVA) as described by Panse and Sukhatme (1985). The significance of treatment effects was computed with the help of 'F' (variance ratio) test and to judge the significance of differences between the means of two treatment, critical differences (CD) was worked out as described by Cochran and Cox (1959) and Gomez and Gomez (1983).

Results and discussion

Effect of P and Fe application on dry matter yield

Dry matter yield: Dry matter yield of maize increased with increasing levels of phosphorus (Table 2) but a significant increase in yield was recorded only with higher levels (at 30 and 40 mg P kg^{-1}) of P application over control in light-textured soil. A similar trend was observed in the case of Fe application and dry matter yield increased with increasing level of Fe up to its highest level. A foliar spray of 1% Fe also increased dry matter yield but was statistically at par as compared to the control. The interaction between phosphorus and iron was also found to be significant; the lowest yield was recorded under the treatment P_0Fe_0 whereas the highest yield was noticed with the treatment combination of $P_{40}Fe_{10}$.

In heavy textured soil, there was a significant increase in yield with an increasing level of P (Table 2) but only up to the level of 30 mg P kg^{-1} over control then it decreased significantly with further increase in P level from 30 to 40 mg P kg^{-1}. Concerning iron application, the dry matter yield also increased significantly with increasing levels of Fe up to its highest level of 10 mg kg^{-1} over control. Significant increase in dry matter yield was also recorded under 1% foliar spray of Fe over control. The yield levels obtained in light textured soil were much lower than in heavy textured soil with various treatments of phosphorus and iron applications. Rehm and Albert (2006) found that Fe application and foliar sprays enhanced wheat grain yield and protein content. Bameri *et al.* (2012) reported significant wheat yield improvement with micronutrient application. Abbas *et al.* (2012) noted the positive effects of Fe and P application on wheat grain yield and components. In the case of chickpea, Pingoliya *et al.* (2014) observed increased growth and yield attributes with higher P and Fe levels, particularly in the 40 kg P_2O_5 ha^{-1} with 5 kg Fe ha^{-1} treatment.

Effect of P and Fe application on nutrient uptake

Nitrogen uptake: Nitrogen uptake by maize plants in light-textured soil increased to the increasing level of P application (Table 3) but a significant increase was noticed

Table 2. Effect of P and Fe application on dry matter yield of maize in different textured soil.

Nutrient level (mg kg^{-1})	Dry matter yield (g pot^{-1})				Mean
	Fe_0	Fe_5	Fe_{10}	$Fe_{spray\ 1\%}$	
Light textured soil					
P_0	0.78	0.83	0.87	0.80	0.82
P_{20}	0.88	0.92	0.97	0.90	0.92
P_{30}	0.93	1.00	1.10	0.98	1.00
P_{40}	2.07	2.53	2.83	2.40	2.46
Mean	1.17	1.32	1.44	1.27	-
CD (p=0.05)	P: 0.11; Fe: 0.11; P x Fe: 0.22				
Heavy textured soil					
P_0	7.67	8.03	9.97	7.77	8.36
P_{20}	13.07	15.67	16.03	14.83	14.90
P_{30}	11.47	16.53	18.30	13.80	15.03
P_{40}	10.73	13.93	15.27	11.03	12.74
Mean	10.73	13.54	14.89	11.86	-
CD (p=0.05)	P: 0.46; Fe: 0.46; P x Fe: 0.91				

Table 3. Effect of P and Fe application on NPK uptake by maize plants in light textured soil

Nutrient level	Light textured soil					Heavy textured soil				
(mg kg^{-1})	Fe_0	Fe_5	Fe_{10}	$Fe_{spray\ 1\%}$	Mean	Fe_0	Fe_5	Fe_{10}	$Fe_{spray\ 1\%}$	Mean
N uptake (mg pot^{-1})										
P_0	7.49	8.38	10.53	9.44	8.96	72.87	94.75	128.61	96.35	98.15
P_{20}	9.86	11.41	12.22	11.34	11.21	162.07	211.55	221.21	231.35	206.54
P_{30}	10.88	12.60	15.84	14.41	13.43	147.96	228.11	290.97	182.16	212.30
P_{40}	25.05	32.64	40.75	36.72	33.79	136.27	185.27	224.47	165.45	177.86
Mean	13.32	16.26	19.84	17.98	-	129.79	179.92	216.32	168.83	-
CD (p=0.05)	P: 2.44; Fe: 2.44; P x Fe: NS					P: 16.91; Fe: 16.91; P x Fe: 33.81				
P uptake (mg pot^{-1})										
P_0	0.86	1.08	1.22	0.96	1.03	15.34	14.45	16.95	15.54	15.57
P_{20}	1.58	1.56	1.46	1.44	1.51	32.68	37.61	32.06	32.63	33.74
P_{30}	1.86	2.00	1.87	1.86	1.90	34.41	36.37	38.43	33.12	35.58
P_{40}	5.18	5.82	5.66	5.28	5.48	34.34	33.43	36.65	29.78	33.55
Mean	2.37	2.62	2.65	2.39	-	29.19	30.47	31.02	27.77	-
CD (p=0.05)	P: 0.51; Fe: NS; P x Fe: NS					P: 2.90; Fe: 2.90; P x Fe: 5.80				
K uptake (mg pot^{-1})										
P_0	13.26	16.77	13.92	14.56	14.63	215.5	234.5	309.1	211.3	242.6
P_{20}	19.62	20.79	20.56	19.71	20.17	364.7	498.3	514.6	422.7	450.0
P_{30}	24.74	23.60	25.74	21.95	24.01	347.5	547.1	602.1	427.8	481.1
P_{40}	57.75	73.12	72.45	65.04	67.09	382.0	500.1	571.1	448.9	475.5
Mean	28.84	33.57	33.17	30.32	-	327.4	445.0	499.2	377.7	-
CD (p=0.05)	P: 4.63; Fe: NS; P x Fe: NS					P: 43.23; Fe: 43.23; P x Fe: 86.46				

only at higher P levels i.e., 30 and 40 mg P kg^{-1} over control treatment. Similarly, the Fe application also enhanced the N uptake and significant improvement was recorded with increasing level of basal application as well as a foliar spray of Fe over control. The P x Fe interaction was found insignificant and the highest N uptake was recorded under $P_{40}Fe_{10}$ treatment.

In heavy textured soil, N uptake by maize was increased significantly with increasing level of P application up to 30 mg kg^{-1} over control, thereafter with further increase in P level i.e., from 30 to 40 mg kg^{-1}, N uptake decreased significantly over 30 mg kg^{-1} treatment (Table 3). Significant improvement in N uptake was recorded with increasing level of soil application of Fe over control and 1% foliar spray of iron also enhanced the N uptake significantly over control treatment. The phosphorus and iron interaction was found to be significant and the highest N uptake was recorded under $P_{30}Fe_{10}$ treatment.

Singh *et al.* (1995) reported increased N uptake in French bean with up to 5 kg Fe ha^{-1}. Sharma *et al.* (2012) saw rising wheat nitrogen uptake with phosphorus, peaking at 60 kg P_2O_5 ha^{-1}, with levels significantly differing. In chickpea, Khan *et al.* (2014) observed the highest N content and uptake with 2 kg ha^{-1} Fe for both genotypes, affecting nodulation, nitrogen fixation, and yield.

Phosphorus uptake: The uptake of P by maize plants in light textured soil was increased with increasing level of P application over control treatment (Table 3) but significant increase was recorded at higher levels i.e. 30 and 40 mg kg^{-1} over control. The different Fe treatments did not influence the P uptake significantly; only a numerical increase in P uptake was recorded over control treatment. The P and Fe interaction was also found non-significant. The highest amount was noticed with the $P_{40}Fe_5$ treatment.

In heavy textured soil, the phosphorus uptake was increased significantly over control up to 30 mg P kg^{-1}, whereas, it was found to decrease with further increase in P application level but decrease was statistically insignificant (Table 3). With respect to Fe application, there was insignificant improvement in P uptake with increase in Fe application but significant reduction was noticed under the treatment of 1% foliar spray of Fe when compared with control. The P x Fe interaction was found significant and the highest amount of P uptake was recorded under the combined effect of $P_{30}Fe_{10}$. Islam *et al.* (2008) also observed that the phosphorus content of *japonica* and *indica* rice varieties increased progressively with an increase of applied P levels.

Potassium uptake: In light textured soil, K uptake was increased significantly with increasing level of P application (Table 4) over control treatment. In case of Fe application, K uptake did not vary significantly and also the interaction between P and Fe was insignificant. The highest K uptake (73.12 mg pot^{-1}) was recorded under the combined effect of $P_{40}Fe_5$ treatment.

In heavy textured soil, K uptake was also found to be increased significantly with increasing level of P application over control, however, there was reduction in K uptake at 40 mg P kg^{-1} when compared with 30 mg P kg^{-1} but the reduction was statistically non-significant (Table 9). Both, soil application of Fe as well as 1% foliar spray increased K uptake significantly with respect to control treatment. The P and Fe interaction was also found to be significant and the highest K uptake was noticed with $P_{30}Fe_{10}$ treatment.

Modak and Chavan (1999) found that adding 20 ppm $FeSO_4$ with NPK increased N, P, and K uptake significantly compared to NPK alone. Total nutrient uptake varied significantly with phosphorus levels, with higher and lower levels yielding the highest and lowest values. This increase in nutrient uptake was linked to increased nutrient availability from soil and fertilizer (Shankarlingappa *et al.*, 2000). Potassium uptake in grain and straw was notably enhanced with 60 kg P_2O_5 ha^{-1} (Sharma *et al.*, 2012). Abbas *et al.* (2012) reported increased K uptake and soil concentration with Fe application in their study on wheat yield.

Iron uptake: In light textured soil, P application did not influence the Fe uptake up to 30 mg P kg^{-1} level concerning control treatment (Table 4), thereafter; it was increased significantly at 40 mg P kg^{-1} over control as well as other phosphorus levels. Application of Fe increased Fe uptake at both 5 and 10 mg kg^{-1} levels over control, whereas, foliar spray of iron also enhanced Fe uptake significantly over control. The highest amount of Fe uptake was recorded with $P_{40}Fe_{10}$ treatment.

In the case of heavy textured soil, there was no definite trend concerning P application on Fe uptake by maize plants and it was found to be non-significant when compared with control (Table 4). Numerically, it increased at 20 and 30 mg P kg^{-1} level as compared to control but at 40 mg P kg^{-1} level, it was observed to be decreased when compared to lower levels of P applications. About Fe application, Fe uptake was increased significantly with increasing level of soil application of Fe and 1% foliar

Table 4. Effect of P and Fe application on Fe uptake by maize plants in light textured soil

Nutrient level (mg kg^{-1})	Fe uptake (mg pot^{-1})				Mean
	Fe_0	Fe_5	Fe_{10}	$Fe_{spray\ 1\%}$	
Light textured soil					
P_0	0.25	0.47	0.49	0.49	0.42
P_{20}	0.26	0.49	0.54	0.49	0.45
P_{30}	0.21	0.44	0.56	0.47	0.42
P_{40}	0.39	1.06	1.21	1.02	0.92
Mean	0.28	0.61	0.70	0.62	-
CD (p=0.05)	P: 0.15; Fe: 0.15; P x Fe: NS				
Heavy textured soil					
P_0	2.86	3.37	4.95	4.14	3.83
P_{20}	3.80	5.26	6.69	5.92	5.42
P_{30}	3.04	4.72	5.50	5.04	4.58
P_{40}	2.52	3.35	3.84	2.99	3.18
Mean	3.06	4.18	5.25	4.52	-
CD (p=0.05)	P: NS; Fe: 0.82; P x Fe: NS				

Table 5. Effect of P and Fe application on protein content of maize plants in light textured soil

Nutrient level (mg kg^{-1})	Protein content (%)				Mean
	Fe_0	Fe_5	Fe_{10}	$Fe_{spray\ 1\%}$	
Light textured soil					
P_0	6.00	6.31	7.56	7.38	6.81
P_{20}	7.00	7.75	7.88	7.88	7.63
P_{30}	7.31	7.88	9.00	9.19	8.34
P_{40}	7.56	8.06	9.00	9.56	8.55
Mean	6.97	7.50	8.36	8.50	-
CD (p=0.05)	P: 0.72; Fe: 0.72; P x Fe: 1.44				
Heavy textured soil					
P_0	5.94	7.38	8.06	7.75	7.28
P_{20}	7.75	8.44	8.63	9.75	8.64
P_{30}	8.06	8.63	9.94	8.25	8.72
P_{40}	7.94	8.31	9.19	9.38	8.70
Mean	7.42	8.19	8.95	8.78	-
CD (p=0.05)	P: NS; Fe: NS; P x Fe: 1.57				

spray of iron also increased the Fe uptake significantly over control. Moosavi and Ronaghi (2011) noted that a 1% iron sulfate foliar spray improved plant Fe content without negatively affecting shoot dry matter yield. Gomaa *et al.* (2015) demonstrated that a mixed foliar application of micronutrients (Zn+Fe) significantly increased Fe uptake in wheat grain compared to the control.

Effect of phosphorus and iron application on protein content

Protein content: The protein content of maize plants in light textured soil (Table 5) increased significantly with an increasing level of P application up to its highest level over control. Concerning Fe application, a significant increase in protein content was noticed at soil application at 10 mg Fe kg^{-1} and 1% foliar spray of Fe over control. There was significant interaction between P and Fe for protein content and the highest value for protein content was recorded with $P_{40}Fe_{spray1\%}$ treatment. The protein content of maize plants was increased by 12.0, 22.5 and 25.6% with the application of P at 20, 30 and 40 mg P kg^{-1}, respectively over control. About Fe application, it was increased by 7.6, 19.9 and 22.0% when Fe applied at 5, 10 mg Fe kg^{-1} and 1% foliar spray of iron, respectively over control.

In heavy textured soil, the protein content of maize plants was observed to increase numerically with the increasing level of P application, but P application did not influence the protein content significantly (Table 5). Similarly, Fe application as soil or foliar spray did not reveal any significant improvement in protein content; however, numerically it was higher under the treatment of 10 mg Fe kg^{-1} followed by 1% foliar spray of Fe. The P x Fe interaction was found to be significant and the highest protein content was recorded under the combined effect of $P_{30}Fe_{10}$ treatment. The protein content of maize plants was increased by 18.7, 19.8 and 19.5% with the application of P at 20, 30 and 40 mg P kg^{-1}, respectively over control. With regard to Fe application, it was increased by 10.4, 20.6 and 18.3% at 5, 10 mg Fe kg^{-1} and 1% foliar spray of iron, respectively over control. This observation also attests to earlier reports by several authors in various crops (Mekkei *et al.*, 2014; Pingoliya *et al.,* 2014).

Conclusion

The phosphorus and iron interact negatively with each other but this phenomenon has been observed in heavy textured soil only due to higher levels of phosphorus and iron availability in these soils. In conclusion, increasing levels of phosphorus and iron application significantly enhanced dry matter yield in maize, particularly at higher concentrations. Nitrogen, phosphorus, and potassium uptake were also positively influenced by phosphorus and iron application, with significant interactions observed between these nutrients. Iron uptake was notably affected by both phosphorus and iron application levels. Moreover, protein content increased significantly with higher levels of phosphorus and iron application in light-textured soil, while in heavy-textured soil, the increase was observed numerically but not statistically significant. Overall, phosphorus and iron application showed promising effects on maize growth and nutrient uptake, with implications for improving yield and protein content.

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