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Direct and residual effects of phosphorus and zinc fertilization on productivity of wheat *(Triticum aestivum)*-pearl millet *(Pennisetum glaucum)* cropping system

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ABSTRACT

A field experiment, carried out from winter 2001-02 to rainy season 2003 at Navgaon (Alwar) on sandy loam soil revealed that application of 60 kg P_2O_5/ha significantly improved the growth and yield attributes as well as grain (43.95 q/ha) and straw yield (68.61 q/ha), harvest index (39.13%), protein content (10.72%) and P uptake (40.92 kg/ha) by wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] over no-use of P (control), while Zn uptake increased only up to 30 kg P_2O_5/ha and thereafter decreased significantly. Agronomic efficiency decreased up to 90 kg P_2O_5/ha. Recovery of P was higher at 60 kg P_2O_5/ha (21.63%) and thereafter decreased sharply. Similarly, application of 6 kg Zn/ha significantly increased all the growth and yield attributes (except test weight), protein content and Zn uptake by wheat over no-use of Zn (control). Application of graded levels of zinc up to 9 kg Zn/ha, remained at par with12 kg Zn/ha, significantly increased Zn uptake by wheat crop over other levels. Application of 6 kg Zn/ha increased the grain and straw yields by 19.4 and 16.8% over the no-use of Zn (control). Agronomic efficiency (115.3 kg/kg) and apparent Zn recovery (1.87%) were also higher at 6 kg Zn/ha. Available P status of soil increased and Zn status decreased significantly with the increase in phosphorus level up to 90 kg P_2O_5/ha. However, P status decreased and Zn status increased significantly with the increase in zinc level up to 12 kg Zn/ ha. Application of 60 kg P_2O_5/ha and 6-9 kg Zn/ha to wheat significantly improved the growth and yield attributes, yield, protein content and P uptake in succeeding pearl millet [*Pennisetum glaucum* (L.) R. Br. emend. Stuntz] over control, while application of P @ 90 kg P_2O_5/ha decreased Zn and zinc @ 12 kg Zn/ha improved Zn uptake by pearl millet significantly over lower levels.

Key words : Direct effect, Residual effect, Phosphorus, Zinc, Wheat, Pearl millet, Yield

Intensification of cropping without balanced fertilization had led to depletion of soil fertility to a great extent (Musande and Palaskar, 1997). Wheat-pearl millet cropping system, a most important cereal-based cropping system followed in north-east part of Rajasthan, is of no exception. This will result in decline in yield of both the crops. Among various nutrients, phosphorus and zinc play a crucial role in wheat-pearl millet production. In sequential cropping, first crop hardly utilizes 10-20% of the applied phosphorus and zinc (Sharma and Chandra, 1997). Since information on direct and residual effects of phosphorus and zinc in wheat pearl millet cropping system is meagre, a field experiment was conducted to study the direct and residual effects of phosphorus and zinc fertilization on productivity of this cropping system.

MATERIALS AND METHODS

A field experiment was conducted from winter season 2001-02 to rainy season 2003 at Agricultural Research Station, Navgaon (Rajasthan). The soil was sandy loam, alkaline (pH 8.2), low in initial available N (161.73 kg/ha) and zinc (0.526 ppm) and medium in available P_2O_5 (22.15 kg/ha) and K_2O (179.09 kg/ha), with EC 1.18 dS/m. The experiment comprising 20 treatment combinations of 4 levels of phosphorus (0, 30, 60 and 90 kg P_2O_5/ha) and 5 levels of zinc (0, 3, 6, 9 and 12 kg Zn/ha) was laid out in randomized block design with 3 replications. Wheat 'Raj 3077' was sown in the last week of November during both the years at a row spacing of 20 cm using seed rate of 100 kg/ha. A uniform dose of 90 kg nitrogen and 30 kg potassium/ha was applied through urea + diammonium phosphate and muriate of potash, respectively. Phosphorus through diammonium phosphate and zinc through zinc oxide were applied to wheat only as per treatments. One-third of nitrogen and full doses of phosphorus, potassium and zinc were drilled basally at the time of sowing. Remaining N was applied in 2 equal splits at the time of first and second irrigation. The crop was raised with recom-

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mended package of practices.

After harvesting of wheat, pearl millet 'HHB 67' was sown in the last week of June using seed rate of 5 kg/ha at a spacing of 40 cm × 15 cm apart. Half of the recommended dose of nitrogen (45 kg/ha) and full of potassium (30 kg K_2O/ha) were applied at the time of sowing. Remaining half dose of N (45 kg/ha) was applied 1 month after sowing. The crop was raised with recommended package of practices. The protein content in grain was calculated by multiplying nitrogen percentage in grain with a factor of 6.25. Multiplying the respective nutrient concentration determined with standard procedures with the grain and straw or stover yield and then adding both grain and straw or stover uptake gave total uptake. After harvesting, separate soil samples were collected from each plot for estimation of available P and Zn in soil by standard methods. The data of 2 years were pooled and analysed.

RESULTS AND DISCUSSION

Direct effect on wheat

Growth attributes : Application of P up to 60 kg P_2O_5/ha significantly increased plant height by 10.5 and 5.4% and dry matter by 37.7 and 16.4% over no-use of P (control) and 30 kg P_2O_5/ha, respectively and thereafter declined (Table 1). This could be attributed to effective utilization of nutrients through the extensive root system developed by crop plants under adequate P application. Similarly, application of 6 kg Zn/ha significantly increased the plant height by 9.5 and 4.6% and dry matter by 22.2 and 9.6% over no-use of Zn (control) and 3 kg Zn/ha, respectively and thereafter decreased (Table 1). Zinc plays a pivotal role in regulating the auxin concentration in plant and nitrogen metabolism and might have improved these growth attributes. These results are in close conformity with those of Dewal and Pareek (2004).

Yield attributes : Phosphorus fertilization up to 60 kg P_2O_5/ha significantly increased the effective tillers/m^2 by 10.0 and 5.0%, grains small's spike by 16.7 and 4.9%, spikelets/spike by 15.5 and 7.4% and spike length by 19.3 and 9.0% over no use of P (control) and 30 kg P_2O_5/ha, respectively and thereafter decreased with the further increase in P level at 90 kg P_2O_5/ha. While application of 60 kg P_2O_5/ha significantly improved the test weight over no use of P (control) and 30 kg P_2O_5/ha by 9.2 and 5.3%, respectively. This favourable effect might be owing to the fact that P is well known for its role as 'Energy currency' and plays a key role in development and energy transformation in various vitally important metabolic processes in the plant. Vyas and Choudhary (2000) also reported similar results.

Wheat crop fertilized up to 6 kg Zn/ha significantly increased the effective tillers/m^2 by 8.2 and 4.2%, spike length by 13.1 and 7.8% and grains/spike by 17.1 and 6.5% over no-use of Zn (control) and 3 kg Zn/ha, respectively. While application of 6 kg Zn/ha significantly increased the spikelets/spike by 13.0 and 8.1% over no-use of Zn (control) and 3 kg Zn/ha, respectively. Application of zinc did not have significant effect on test weight of wheat. Further increase in zinc levels resulted in reduction in all the parameters except spikelets/spike at 9 kg Zn/ha. The increase in the yield attributes might be owing to role of zinc in biosynthesis of indole acetic acid (IAA) and especially due to its role in initiation of primordia for reproductive parts and partitioning of photosynthates towards them, which resulted in better flowering and fruiting. Sharma *et al.* (2000) also reported similar results.

Yield, apparent recovery and agronomic efficiency: Application of 60 kg P_2O_5/ha increased the grain yield by 28.6 and 10.3% and straw yield by 20.6 and 9.7% over no use of P (control) and 30 kg P_2O_5/ha, respectively. Application of 90 kg P_2O_5/ha recorded significant reduction in yield from just 60 kg P_2O_5/ha. Application of P up to 30 kg P_2O_5/ha significantly improved the harvest index by 3.7% over no-use of P (control). The significant increase in grain yield of wheat was largely a function of improved growth and the consequent increase in different yield attributes as mentioned above. Singh *et al.* (2000) also recorded similar results. The P recovery was also higher at 60 kg P_2O_5/ha (21.63%) and thereafter decreased abruptly at higher level of P application. Agronomic efficiency decreased with the increase in P levels but the sharp decline was observed after 60 kg P_2O_5/ha application.

Significant improvement in grain and straw yields were observed with every increasing level of zinc up to 6 kg Zn/ha. The response due to 6 kg Zn/ha was 19.4 and 9.0% in grain yield and 16.8 and 7.2% in straw yield over no-use of Zn (control) and 3 kg Zn/ha, respectively (Table 1). Further application of zinc reduced the yields. Application of zinc could not bring significant increase in harvest index. The increase in the yield may be attributed to the fact that the initial status of available zinc in the experimental soil was low. Under such a situation an increase in the yield was expected. Further, increased grain yield is the manifestation of increase in all the yield attributes. Sharma *et al.* (2000) and Dewal and Pareek (2004) reported increase in wheat yield with the application of zinc. Apparent Zn recovery (1.87%) and agronomic efficiency (115.3 kg/kg) were also higher at 6 kg/ha and thereafter decreased with further increase in Zn levels.

The interaction between P and Zn was significant on grain yield of wheat (Table 2). At the same level of Zn, increase in dose of P up to 60 kg P_2O_5/ha significantly increased the grain yield of wheat except at $P_{60}Zn_9$ and

Table 1. Direct effect of phosphorus and zinc fertilization on the productivity and soil fertility status after harvest of wheat (pooled data of 2 years)

Treatment	Plant height (cm)	Dry mater (q/ha)	Effective tillers/ m^2	Grains/ spike	Spikelets/ spike	Spike length (cm)	Test weight (g)	Grain yield (q/ha)	Straw yield (q/ha)	Harvest index (%)	Proein content (%)	P uptake (kg/ha)	Zn uptake (g/ha)	Available P status after harvest (kg/ha)	Available Zn status after harvest (ppm)	Apparent recovery (%)	Agronomic efficiency (kg/kg)
Phosphorus (kg P_2O_5/ha)																	
0	78.42	92.88	432.2	33.04	13.12	8.44	36.08	34.18	56.91	37.63	9.48	27.94	279.17	15.59	1.217		
30	82.18	109.88	452.8	36.76	14.11	9.24	37.42	39.85	62.56	39.03	10.01	34.23	283.10	22.72	1.080	20.97	18.9
60	86.64	127.92	475.3	38.55	15.16	10.07	39.39	43.95	68.61	39.13	10.72	40.92	274.23	30.14	0.942	21.63	16.3
90	82.46	117.67	461.8	36.78	14.62	9.40	38.21	40.61	64.68	38.69	10.21	36.03	218.41	34.84	0.710	8.99	7.1
CD (P=0.05)	2.25	3.92	14.2	1.36	0.63	0.37	1.47	1.17	2.00	1.00	0.13	1.05	8.80	0.74	0.029		
Zinc (kg Zn/ha)																	
0	78.20	99.31	435.4	33.06	13.19	8.70	36.62	35.74	57.63	38.25	9.41	33.82	174.14	31.78	0.381		
3	81.87	110.71	452.1	36.36	13.79	9.13	37.54	39.15	62.75	38.54	9.90	35.77	224.01	28.58	0.789	1.66	113.7
6	85.66	121.36	471.3	38.72	14.91	9.84	38.67	42.66	67.29	38.88	10.64	37.49	286.09	25.73	1.058	1.87	115.3
9	83.97	118.84	466.2	37.76	14.96	9.55	38.46	41.51	65.47	39.90	10.53	34.92	312.34	22.91	1.271	1.54	64.1
12	82.42	110.23	452.9	35.53	14.41	9.22	37.58	39.18	62.82	38.53	10.04	31.90	322.06	20.13	1.438	1.23	28.7
CD (P=0.05)	2.51	4.38	15.9	1.52	0.70	0.41	NS	1.31	2.23	NS	0.15	1.18	9.84	0.83	0.032		

$P_{60}Zn_{12}$ levels and thereafter decreased significantly at higher level of P (P_{90}) with Zn_6, Zn_9 and Zn_{12} levels. Similarly, at the same lower levels of P (P_0 and P_{30}), grain yield improved up to 9 kg Zn/ha while at same higher levels of P (P_{60} and P_{90}), grain yield improved only up to 6 kg Zn/ha and thereafter decreased. The mean maximum (49.07 q/ha) and minimum (29.09 q/ha) grain yield was recorded at $P_{60}Zn_6$ and P_0Zn_0 treatment combinations respectively.

Table 2. Interaction effect of phosphorus and zinc on grain yield of wheat (q/ha)

Treatment	P_0	P_{30}	P_{60}	P_{90}
Zn_0	29.09	34.37	39.90	39.59
Zn_3	32.42	38.58	43.86	41.73
Zn_6	35.66	42.71	49.07	43.20
Zn_9	37.72	43.25	44.91	40.17
Zn_{12}	35.99	40.36	42.00	38.37
CD(P=0.05)		2.62		

The favourable effect of optimum level of P-Zn combination might be because P fertilization is likely to make the crop more responsive to Zn by increasing the growth. Addition of Zn with P may maintain a favourable balance between the applied nutrients in the plant for its optimum growth and Zn enhanced the utilization of P by its effect on metabolism. Similar results were also reported by Singh and Meena (1998).

Protein content : Increasing level of P up to 60 kg P_2O_5/ha significantly increased the protein content in wheat grain by 13.1 and 7.1% over no use of P (control) and 30 kg P_2O_5/ha respectively (Table 1). This may be attributed to increased N content in grain and its uptake by the crop and role of P in energy conservation and transformation. Khalil and El-Aref (1999) also reported similar findings. Successive increase in Zn level from 0 to 6 kg Zn/ha significantly increased the protein in wheat grain by 13.1 and 7.5% over no-use of Zn (control) and 3 kg Zn/ha, respectively, and thereafter declined it. Zinc enhances the cation-exchange capacity of the roots which in turn enhances the absorption of essential elements especially of N which is responsible for higher protein content of wheat grain. Malakouti (1998) also reported similar results.

Nutrient uptake: Phosphorus fertilization up to 60 kg P_2O_5/ha significantly increased P uptake by 46.5 and 19.5% over no-use of P (control) and 30 kg P_2O_5/ha, respectively, and thereafter decreased it significantly (Table 1). Increasing level of Zn up to 6 kg Zn/ha significantly increased the P uptake by 10.9 and 4.8% over no-use of Zn (control) and 3 kg Zn/ha, respectively (Table 1).

Application of increasing level of P up to 30 kg P_2O_5/ha increased the Zn uptake by wheat and thereafter decreased significantly up to 90 kg P_2O_5/ha (Table 1). Application of graded levels of Zn up to 9 kg Zn/ha, remained at par with 12 kg Zn/ha, significantly increased Zn uptake by wheat crop to the extent of 79.4, 39.4 and 9.2% over (control), 3 and 6 kg Zn/ha respectively.

Response study: The regression analysis revealed that wheat crop response to P and Zn were quadratic with highly significant R^2 of 0.965358 for P and 0.959777 for Zn. The equations obtained on the basis of pooled data of 2 years for P and Zn separately were:

$$Y=3388.45 + 30.3316\,P - 0.250343\,P^2 \text{ (For P)}$$
$$Y = 3549.22 + 184.5659\,Zn - 12.8115\,Zn^2 \text{ (For Zn)}$$

A mean P level of 55.23 kg P_2O_5/ha was found to optimum with grain yield of 43.00 q/ha and a mean response of 9.12 q/ha. Thus, the average response to optimum level of P was 16.51 kg grain/kg P. Similarly, the predicted grain yield of 41.67 q/ha could be realized at a mean optimum level of 5.28 kg Zn/ha which amounted to an average response of 116.92 kg grain/kg Zn applied.

Soil nutrient status: Available P status of soil improved and Zn status declined significantly with each increment in P level up to 90 kg P_2O_5/ha by 123.5 and 41.7% over no-use of P (control) respectively (Table 1). Successive increase in Zn up to 12 kg Zn/ha significantly decreased the available P status and improved Zn status of soil by 36.7 and 277.4% over no-use of Zn (control) respectively (Table 1).

Residual effect on pearl millet

Growth attributes : Maximum plant height and dry matter in pearl millet were recorded with 60 kg P_2O_5/ha applied to preceding wheat crop, and was significantly superior to lower levels and registered a mean increase of 8.6 and 4.9% in plant height and 14.2 and 7.4% in dry matter over no-use of P (control) and 30 kg P_2O_5/ha respectively (Table 3). Further increase in the level of P decreased both these parameters.

Residual effect of increasing level of Zn up to 6 kg Zn/ha significantly increased the plant height by 9.5 and 5.1% and dry matter by 15.2 and 6.8% over no-use of Zn (control) and 3 kg Zn/ha, respectively (Table 3). Further addition of Zn increased these parameters marginally at 9 kg Zn/ha and thereafter resulted in decreasing at 12 kg Zn/ha.

Yield attributes: Application of 60 kg P_2O_5/ha to the preceding wheat crop significantly increased effective tillers/m^2 by 11.6 and 5.4%, panicle length by 8.9 and 5.0% and test weight by 13.6 and 9.0% over no-use of P (control) and 30 kg P_2O_5/ha, respectively (Table 3). Beyond this level, all the parameters decreased marginally.

Residual effect of 6 kg Zn/ha, being at par with 9 kg Zn/ha, significantly increased the effective tillers/m^2 by 11.6 and 5.4%, panicle length by 8.4 and 5.6% and test weight by 14.3 and 7.5% over no-use of Zn (control) and 3 kg Zn/ha (Table 3). Further addition of zinc at 12 kg/ha to wheat crop decreased all the attributes.

Yield and harvest index: Grain and stover yields of pearl millet increased significantly up to the application of 60 kg P_2O_5/ha to previous wheat crop by 22.7 and 14.6% over no use of P (control), respectively, and thereafter, decreased with further addition of P (Table 3). However, the residual effect of 60 kg P_2O_5/ha resulted in significant increase in harvest index by 5.3% over no use of P (control). This may be ascribed to improvement in the status of available P of soil and its better absorption by the plants. The increased availability of P increased the growth and yield attributing characters which reflected in higher yield of pearl millet. Similar residual effects were also reported by Jat and Shaktawat (2003).

Residual effect of Zn up to 6 kg Zn/ha, remained at par with 9 kg Zn/ha, significantly increased the grain and stover yields of pearl millet by 20.4 and 9.1% and 12.4 and 5.6% over no-use of Zn (control) and 3 kg Zn/ha, respectively, while application of 6 and 9 kg Zn/ha to wheat significantly improved the harvest index over no-use of Zn (control) and registered a mean increase of 5.7 and 6.7%, respectively (Table 3). The beneficial effect of Zn application could be attributed to improved fertility status of the experimental field in terms of available Zn. Recovery of applied Zn during 1 season is not more than 10-15% so it remains in soil for successive crop (Sharma and Chandra, 1997). Thus, the response of pearl millet to the residual Zn was expected. Similar results were also reported by Sharma and Bhardwaj (1998).

Protein content: Application of 60 kg P_2O_5/ha to wheat crop significantly increased the protein content in pearl millet grain by 11.6 and 6.2% over no use of P (control) and 30 kg P_2O_5/ha, respectively and thereafter, decreased slightly (Table 3). This may be due to increase in N content and its uptake by grain as a result of residual P.

Residual effect of Zn up to 6 kg Zn/ha significantly improved the protein content in pearl millet grain by 12.9 and 6.5% over no-use of Zn (control) and 3 kg Zn/ha, respectively (Table 3). This may be attributed to significant role of Zn in protein synthesis and nitrogen metabolism in the plant.

Nutrient uptake: Phosphorus fertilization up to 60 kg P_2O_5/ha to wheat significantly increased P uptake by 54.2 and 22.8% over no-use of P (control) and 30 kg P_2O_5/, respectively and thereafter decreased it significantly (Table 3). Residual effect of 6 kg Zn/ha significantly improved the P uptake by 4.8% over no-use of Zn (control) (Table 3).

Application of P up to 90 kg P_2O_5/ha decreased the Zn uptake by 16.2, 12.6 and 10.9% over no-use of P (con-

Table 2. Residual effect of phosphorus and zinc fertilization on productivity of pearl millet (pooled data of 2 years)

Treatment	Plant height (cm)	Dry matter production (q/ha)	Effective tillers/ m^2	Panicle length (cm)	Test weight (g)	Grain yield (q/ha)	Stover yield (q/ha)	Harvest index (%)	Protein content (%)	Net returns of wheat-pearl millet (Rs/ha)	P uptake (kg/ha)	Zn uptake (g/ha)
Phosphorus (kg P_2O_5/ha)												
0	154.0	64.96	40.5	16.83	7.12	13.70	45.65	23.05	10.17	25,364	10.17	155.75
30	159.5	69.10	42.9	17.44	7.42	15.31	48.90	23.77	10.69	30,628	12.77	149.39
60	167.3	74.18	45.2	18.32	8.09	16.81	52.33	24.27	11.35	34,934	15.68	146.50
90	166.1	73.84	44.3	17.94	7.86	16.67	52.15	24.19	11.06	31,598	14.69	130.54
CD (P=0.05)	5.0	2.74	1.5	0.60	0.31	0.82	1.56	0.77	0.37	1,082	0.55	6.00
Zinc (kg Zn/ha)												
0	152.2	63.63	39.8	16.73	6.99	13.66	45.71	22.89	9.92	27,507	13.13	98.58
3	158.6	68.62	42.5	17.18	7.43	15.07	48.63	23.64	10.52	30,737	13.67	122.82
6	166.7	73.28	45.0	18.14	7.99	16.44	51.37	24.20	11.20	33,837	13.76	150.89
9	169.4	75.51	45.7	18.42	8.17	17.00	52.43	24.43	11.51	32,323	13.61	172.52
12	161.9	71.56	43.0	17.68	7.53	15.95	50.64	23.94	10.94	28,751	12.47	182.92
CD (P=0.05)	5.6	3.06	1.7	0.67	0.35	0.92	1.75	0.86	0.42	1,210	0.62	6.71

trol), 30 and 60 kg P_2O_5/ha, respectively (Table 3). Zn uptake increased significantly with each increment in Zn level up to 12 kg/ha applied to wheat to the tune of 85.6, 48.9, 21.2 and 6.0% over no-use of Zn (control), 3, 6 and 9 kg Zn/ha.

Economics: There was a significant increase in net returns from wheat-pearl millet cropping system with the successive increase in P level up to 60 kg P_2O_5/ha by 37.7% over the no-use of P, i.e. control (Table 3). Similarly, Significantly higher net returns were recorded at 6 kg Zn/ha, being was 23.0% higher over the no-use of Zn (control).

Thus, application of 60 kg P_2O_5/ha and 6 kg Zn/ha to wheat along with recommended doses of N (90 kg/ha) and potassium (30 kg K_2O/ha) to each crop be used for obtaining higher productivity of the wheat-pearlmillet cropping system.

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