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Research Paper

Application of phosphorus and zinc improved the nutrient dynamics, productivity, and profitability of fenugreek (*Trigonella foenum-graecum*)–pearl millet (*Pennisetum glaucum*) cropping system

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ABSTRACT

A field experiment was conducted at Durgapura, Jaipur, (SKNAU, Jobner), Rajasthan during winter and rainy seasons of 2015–16 and 2016–17 to evaluate the effect of phosphorus (P) and zinc (Zn) application on yield, economics and energetics and nutrient dynamics in fenugreek–pearl millet cropping system. The experiment was consists of four levels of P as main-plot and six levels of Zn as sub-plot conducted in split plot design (SPD) replicated thrice. Results revealed that application of 60 kg P_2O_5/ha to fenugreek resulted in 42% higher pearl millet equivalent grain yield (PMEGY) along with the highest net returns and B: C ratio as compared to rest of the treatments. Similarly, among the different Zn treatments, 33% higher PMEGY and the highest net returns were obtained with the application of 5 kg Zn/ha + zinc solubilizer to fenugreek. Combined application of 60 kg P_2O_5/ha + 5 kg Zn/ha + zinc solubilizer, consumed the highest amount of energy but also gave the highest energy output. Overall, combined application of 60 kg P_2O_5/ha + 5 kg Zn/ha + zinc solubilizer improved the system productivity, profitability, energetics and nutrient (N, P, K and Zn) dynamics of fenugreek–pearl millet cropping system.

***Key words**:* Balance sheet, Economics, Energy productivity, Pearl millet equivalent grain yield

In arid region of Western India soils are developed from aeolian sand deposits. These are of coarse texture, very poor in fertility status, and alkaline in reaction having $CaCO_3$ concretion in subsoil. These areas have natural resources that are overexploited and predominantly characterized with agrarian base, is the highest density populated desert in the world (Dhir *et al.,* 2010). Further, more arid episodes lead to desiccation, decreased vegetation cover and mobilization of sands (Singhvi and Kar, 2004). Hence, the soils of these pockets are under tremendous pressure for food and fodder production. With the introduction of tractors, tillage practices are in excess both in terms of quantum and frequency which further aggravate the threat of soil erosion. The soils of these areas have low water holding capacity, organic matter, poor nutrient status and shallow depth (Jinger, 2017). Therefore, application of external input is prerequisite even for a moderate level of production. Among input application, nutrient management is one of the best management practices for improving the productivity and profitability of the crops under such kinds of soil (Jinger *et al.,* 2018; Gupta *et al.,* 2018).

Further, the pearl millet is the principal crop of the region that has to be sown as early as possible after the onset of the monsoon. Delay in sowing may reduce the crop yield to a great extent, because only insured availability of moisture will allow top dressing of nutrients. Besides, the farmers of these regions are very resource poor and they do not have the adequate surplus capital for purchasing of costlier inputs like fertilizers. However, farmers have started fertilizer application in the relatively high value winter season irrigated crops such as fenugreek with the recent coming of canal in the region.

Further, fenugreek is also an important winter season high value crop of the region. Application of P to legume crop like fenugreek in winter season is highly beneficial in improving the productivity of the legume and also of cereal crops grown in the succeeding rainy season (Raju *et al.,* 2005). Fenugreek and pearl millet both require high amount of Zn but the soils of the region are extremely deficient, therefore, it is indispensable to apply Zn to these

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crops in different modes of application (Jakhar *et al.,* 2013; Singh *et al.,* 2017). In this regard, the current study was hypothesized that P and Zn application will have instrumental role in enhancing the yield and economics of fenugreek-pearl millet. The objective of the study was to evaluate the effect of P and Zn in improving the productivity, nutrient dynamics, profitability and energetics of fenugreek–pearl millet cropping system.

MATERIALS AND METHODS

The field experiment was conducted at Rajasthan Agricultural Research Institute, Durgapur (SKNAU, Jobner), Rajasthan during winter and rainy seasons of 2015–16 and 2016–17. The soil of experimental site was loamy sand, low in available N (136 N kg/ha) and P (25 kg P_2O_5/ha), medium in K (181 kg K_2O/ha) and low in Zn (0.36 ppm). The soil pH was 8.2 and organic carbon content was 0.15%. Treatments comprised of twenty four treatment combinations consisting of four P levels (0, 20, 40 and 60 kg P_2O_5/ha) as main plot and six Zn levels (0, 2.5, 5.0 kg Zn/ha, Zn solubilizer (*Bacillus endophyticus*), 2.5 kg Zn/ha + Zn solubilizer and 5 kg Zn/ha + Zn solubilizer) as sub plot were tested in SPD with three replications. P and Zn as per treatment were drilled through di-ammonium phosphate and zinc sulphate (21%), respectively. To compensate the sulphur obtained from different levels of Zn compensatory dose of sulphur (S) applied through elemental S. Recommended dose of N (20 Kg/ha) was also applied to fenugreek. To assess the residual effect of P and Zn applied to fenugreek, succeeding crop of pearl millet (var. RHB 177) was raised during *kharif* seasons of 2016 and 2017 in same lay out. Recommended dose of N (90 kg/ha) was applied to pearl millet in two splits, half as basal and remaining half as top dressing at 30 days after sowing. Harvesting of pearl millet was done at 20% grain moisture. It was done by removing the ear heads and cutting down the plants later on. Ear heads were dried in sun before threshing. The grains were separated by beating the ear heads by sticks. Threshed grain were cleaned and dried in sun to bring the moisture content down to 14%. For harvest of fenugreek the entire plants is either pulled out of cut from the base with sickle when 70% of the pods turn yellow, and made into small bundles for drying them in sun. Grains were separated manually. The seed were dried up to 7–8% moisture, and cleaned through winnowing fan. PMEGY was calculated by converting the grain yield of fenugreek into the equivalent yield of pearl millet on the basis of market price. Nutrient content in soil were estimated by the standard methods. Energy input and output relationship (Table 1) was worked out using the energy requirements and the energy equivalents. Economics of the treatments were computed taking into account the prevailing market prices of inputs and crop outputs. Data were analyzed statistically in SAS @ version 9.3 for analysis of variance (ANOVA). Treatments were compared by computing the 'F-test'. The significant differences between treatments were compared by critical difference at 5% level of probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Fenugreek yield

Successive levels of P significantly increased the grain yield of fenugreek in comparison to control during both the years and on pooled basis (Table 2). The highest grain yield was recorded under application of 60 kg P_2O_5/ha that was significantly higher over control and 20 kg P_2O_5/ha and was statistically at par to that of 40 kg P_2O_5/ha. On pooled basis, the grain yield increased by 17, 31 and 37% over control with the application of 20, 40 and 60 kg P_2O_5/ha, respectively. It might be due P application significantly improved root area and number of root sites for biological fixation of N resulting in enhanced root and shoot growth of fenugreek and ultimately increased the grain yield (Raju *et al.*, 2005). It has been reported that P application significantly improved the grain yield of maize (Paramesh *et al.,* 2014) and aerobic rice (Jinger *et al.,* 2020) by enhancing root growth and nutrient uptake.

Significant improvement in grain yield of fenugreek was also recorded with the application of different Zn treatments. Significantly higher grain yield was obtained with 5 kg Zn/ha + zinc solubilizer and followed by 2.5 kg Zn/ha + Zn solubilizer remaining at par with the 5.0 kg Zn/ha + zinc solubilizer. On pooled basis, the per cent increase in grain yield of fenugreek recorded over control with the soil application of 2.5, 5.0, Zn solubilizer, 2.5 kg Zn/ha+ Zn solubilizer and 5 kg Zn/ha + Zn solubilizer was 10, 17, 7, 22 and 26 per cent, respectively. Nourishment with Zn

Table 1. Energy equivalents for various input and outputs

Particulars	Unit	Equivalent Energy (MJ)
Input		
Human labour		
Adult man	hour	1.96
Woman	hour	1.57
Animal Labour	hour	10.1
Diesel (including lubricant)	liters	56.31
Chemical Fertilizers Nutrients		
N	kg	60.60
P_2O_5	kg	11.10
Zn Sulphate	kg	20.90
Output		
Seed of fenugreek and pearl millet	kg	14.70
Straw / stover of fenugreek and pearl millet	kg	18.5

enhances chlorophyll synthesis that might have improved the photosynthesis and thus accumulation of dry matter accompanied with increased translocation efficiency and favorable dry matter partitioning towards sink resulted in significant improvement in yield (Gitte *et al.,* 2005). Customary application of inorganic Zn partially caters to the plant need, as 96–99% of applied Zn is converted into different insoluble forms (Goteti *et al.,* 2013) and become unavailable to plant, hence it is plausible that exploitation of native Zn by way of mineralizing and solubilizing through bacteria may aid in overcoming Zn deficiency and increasing availability of Zn to crops by solubilizing the complex zinc in soil.

Pearl millet yield

The grain yield of pearl millet increased significantly due to residual effect of P (Table 2). The increase in yield was significant with successive increase in levels of P. On the pooled basis, grain yield increased by 11, 34 and 52% over control owing to residual effect of 20, 40 and 60 kg P_2O_5/ha, respectively. Fenugreek being a deep rooted legume as preceding crop extracted native P from deeper layers, whereas pearl millet takes its most of P from upper layer. Besides, solubility of residual P also increased due to intermittent wetting and drying and higher temperature during the rainy season leading to increased solubility of Ca-P in calcareous soils and increased diffusivity factor of P (Raju *et al.,* 2005). It has been reported that higher grain yield of wheat was received with 90 kg P_2O_5/ha and found statistically similar with 60 kg P_2O_5/ha. The crop performed better under this treatment because residual P was released gradually and continuously throughout the whole crop growth cycle (Jinger *et al.,* 2021). These results are in consonance with those reported by Jat and Shaktawat (2003) in succeeding pearl millet under fenugreek–pearl millet cropping sequence. Residual effect of soil applied Zn also increased the grain yield of pearl millet. The highest grain yield was recorded with the residual effect of 2.5 kg Zn/ha + Zn solubilizer. However, it was found at par with that of 5 kg Zn/ha Zn solubilizer. However, on pooled basis, each level was significantly better to preceding levels and the magnitude of increase in grain yield over control was 12, 29, 9, 24 and 46% higher with the residual effect of 2.5, 5.0, Zn solubilizer, 2.5 kg Zn/ha + Zn solubilizer, and 5.0 kg Zn/ha + Zn solubilizer, respectively. Zn availability increased during rainy season due to increased temperature and intermittent wetting and drying (Adhikari and Ratan, 2002) and cereals require more Zn (Paramesh *et al.,* 2020).

Pearl millet equivalent grain yield

The pearl millet equivalent grain yield (PMEGY) increased significantly up to application of 60 kg P_2O_5/ha (Table 2). This implies that recurrent application of P leads to its accumulation in soil and requirement of further external application of P decreases (Choudhary *et al.,* 2011). PMEGY also increased significantly with the application of Zn and the highest yield was obtained with application of 5.0 kg Zn/ha + Zn solubilizer that was significantly supe-

Table 2. Effect of P and Zn fertilization on yield and economics of Fenugreek-pearl millet cropping system

Treatment	Grain yield (kg/ha)						Pearl millet equivalent grain yield (kg/ha)			Economics (pooled basis)		
	Fenugreek			Pearl millet								
	2015–16	2016–17	pooled	2016	2017	pooled	2015–16	2016–17	pooled	Gross Returns ($\times10^3$ ₹/ha)	Net Returns ($\times10^3$ ₹/ha)	Benefit: cost ratio
Phosphorus (P_2O_5 kg/ha)												
P_0	988	1,014	1,001	1,666	1,484	1,575	4,548	4,443	4,496	85.8	51.2	1.48
P_{20}	1,141	1,193	1,167	1,856	1,634	1,745	5,185	5,115	5,150	97.6	59.8	1.74
P_{40}	1,280	1,351	1,315	2,252	1,958	2,105	5,984	5,898	5,941	112.6	76.0	2.07
P_{60}	1,318	1,415	1,367	2,569	2,230	2,400	6,414	6,358	6,386	121.6	84.0	2.23
SEm±	27	24	18	46	41	31	89	72	57	–	–	–
CD (P=0.05)	92	82	55	158	143	95	307	249	176	–	–	–
Zinc (kg/ha)												
0.0	1,047	1,087	1,067	1,754	1,501	1,628	4,809	4,672	4,740	90.7	55.2	1.55
2.5	1,160	1,192	1,176	1,955	1,699	1,827	5,339	5,176	5,258	100.2	64.1	1.77
5.0	1,222	1,286	1,254	2,223	1,989	2,106	5,787	5,739	5,763	109.8	69.9	1.98
ZS	1,101	1,176	1,138	1,917	1,640	1,779	5,128	5,071	5,099	96.1	60.5	1.69
2.5 + ZS	1,261	1,338	1,300	2,161	1,887	2,024	5,841	5,788	5,815	110.2	74.0	2.04
5.0 + ZS	1,298	1,382	1,340	2,506	2,244	2,375	6,293	6,276	6,285	119.6	82.8	2.24
SEm±	16	16	11	53	44	35	77	65	50	–	–	–
CD (P=0.05)	45	46	32	153	126	97	219	185	141	–	–	–

ZS, Zinc solubilizer

rior over rest of the treatments followed by 2.5 kg Zn/ha + Zn solubilizer. The PMEGY increased significantly up to the highest level of Zn application, suggesting that Zn requirement of both the crops of the system is very high coupled with greater Zn fixation potential of the soil of experimental site. Under such conditions higher amount of Zn is needed and such application can be cost effective when it is applied on system basis (Sammauria and Yadav, 2010).

Economics

On the basis of pooled mean, the highest gross (121.6×10^3 ₹/ha), net returns (84×10^3 /ha), and benefit: cost (B: C) ratio (2.23) was obtained with 60 kg P_2O_5/ha. Amongst, Zn application 5 kg Zn/ha + Zn solubilizer fetched the highest gross (119.6×10^3 /ha), net returns (Rs 82.8×10^3 /ha), and benefit: cost (B: C) ratio (2.24) closely followed by 5.0 kg Zn/ha (Table 2). This might be due to higher grain and straw yield and their lucrative market price under these treatments which brought out maximum gross returns, net returns and benefit: cost (Choudhary *et al.,* 2016; Jat and Shekhawat, 2003). In order to improve utilization of the applied nutrients these should be applied on the system basis because a substantial portion of applied P and Zn remain in the soil on which succeeding crop may be raised profitably.

Nutrient-dynamics

The uptake of N, P, and K by fenugreek–pearl millet cropping system increased significantly with increasing levels of P (Table 3). The highest uptake of N, P, and K recorded with 60 kg P_2O_5/ha as compared to over lower levels of P during both the years. P fertilization led to an increase in root growth which finally proved effective in increasing the N uptake. It has been reported that more solubility of P in soil and balanced supply of P due to increased levels of P, which resulted in improved availability and uptake by crop in respective treatment (Kumar *et al.,* 2002). The enhancement in uptake was mainly because of the increased concentration of K in the sink as well as increased yield (Chanchareonsook *et al.,* 2002). Application of P reduced the uptake of Zn might be due to antagonistic interaction or dilution effect (Paramesh *et al.,* 2020). Similarly, different Zn treatments also significantly enhanced N, P, K, and Zn uptake by both the crops of the system. The significantly higher N, P, K, and Zn uptakes were recorded with 5 kg Zn/ha + Zn solubilizer that was significantly superior over rest of the Zn treatments during both the years. Further, available N and Zn status after the experiment was in positive balance due to application of different levels of P & Zn and magnitude of such improvement was of increasing trend corresponding with the in-

Table 3. Uptake and final status of available N, P, K and Zn (kg/ha) of soil as influenced by P and Zn fertilization to cropping system

Treatment	Nitrogen (kg/ha)				Phosphorous (P_2O_5 kg/ha)				Potassium (K_2O kg/ha)				Zinc (kg/ha)			
	Uptake		Final Status		Uptake		Final Status		Uptake		Final Status		Uptake		Final Status	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Phosphorous (P_2O_5 kg/ha)																
0.0	83.4	83.6	139	136	60.5	53.7	20.0	18.6	68.5	66.1	180	179	0.11	0.10	0.90	0.89
20	99.3	103	142	138	73.6	66.4	24.4	21.7	80.7	82.0	178	178	0.11	0.11	0.86	0.86
40	119	124	144	139	91.3	82.2	27.7	23.8	94.5	94.7	176	175	0.13	0.12	0.83	0.83
60	134	137	144	139	105	93.3	29.7	24.8	102	101	176	175	0.14	0.13	0.82	0.80
SEm±	1.00	1.41	1.5	1.3	0.74	0.42	0.30	0.29	1.96	1.37	5.4	4.2	0.01	0.01	0.04	0.03
CD (P=0.05)	3.46	4.89	NS	NS	2.57	1.47	1.05	1.02	6.77	4.73	NS	NS	0.02	0.02	NS	NS
Zinc (kg/ha)																
0.0	89.1	89.4	139	135	46.6	41.6	25.6	22.4	72.8	70.2	180	179	0.09	0.08	0.74	0.73
2.5	102	105	142	138	48.8	44.3	24.9	21.6	82.7	82.4	179	179	0.11	0.10	0.87	0.87
5.0	116	121	144	139	52.4	48.1	24.9	21.6	91.5	92.4	176	175	0.13	0.12	0.91	0.91
ZS	96.8	98.7	140	136	48.1	43.3	25.7	22.6	78.5	76.3	180	177	0.10	0.09	0.75	0.73
2.5+ ZS	117	122	144	140	52.8	49.0	25.8	22.5	92.9	93.3	176	176	0.13	0.13	0.91	0.91
5.0+ ZS	132	137	145	140	57.5	53.4	25.8	22.6	100.5	101.3	174	174	0.15	0.15	0.93	0.92
SEm±	1.66	1.25	1.70	1.34	0.85	0.69	0.50	0.47	1.39	0.97	3.7	3.1	0.01	0.01	0.04	0.04
CD (P=0.05)	4.74	3.57	NS	NS	2.42	1.98	NS	NS	3.96	2.78	NS	NS	0.03	0.03	0.13	0.13

ZS, Zinc solubilizer; NS, non-significant

Table 4. Energy input output ratio of fenugreek and pearl millet and of system (mean data of 2 years)

Treatment	Energy input (MJ)			Energy output (MJ)			Energy use-efficiency (%)			Energy productivity (g/MJ)		
	Fenugreek	Pearl millet	System	Fenugreek	Pearl millet	System	Fenugreek	Pearl millet	System	Fenugreek	Pearl millet	System
P0Zn0	10,656	7,537	18,193	36,804	82,416	119,220	3.45	10.94	14.39	972	2,466	3,438
P0Zn2.5	10,809	7,537	18,345	40,341	104,474	144,815	3.73	13.86	17.59	1,067	3,349	4,416
P0Zn5.0	10,961	7,537	18,497	43,110	110,874	153,984	3.93	14.71	18.64	1,128	3,659	4,787
P0Znsol	11,113	7,537	18,650	42,731	122,097	164,828	3.85	16.20	20.05	1,107	4,153	5,260
P0Zn2.5+sol	10,687	7,537	18,223	38,031	85,712	123,743	3.56	11.37	14.93	1,011	2,502	3,513
P0Zn5.0+sol	10,717	7,537	18,253	38,532	86,994	125,526	3.60	11.54	15.14	1,021	2,511	3,531
P20Zn0	10,879	7,537	18,415	46,017	115,430	161,447	4.23	15.32	19.55	1,195	3,577	4,771
P20Zn2.5	11,031	7,537	18,567	49,974	122,095	172,069	4.53	16.20	20.73	1,296	3,984	5,279
P20Zn5.0	11,183	7,537	18,720	49,191	125,741	174,932	4.40	16.68	21.08	1,257	4,127	5,384
P20Znsol	11,335	7,537	18,872	47,979	122,539	170,517	4.23	16.26	20.49	1,219	4,101	5,320
P20Zn2.5+sol	10,909	7,537	18,445	46,466	115,676	162,141	4.26	15.35	19.61	1,204	3,625	4,830
P20Zn5.0+sol	10,939	7,537	18,476	46,445	116,864	163,309	4.25	15.51	19.75	1,208	3,655	4,863
P40Zn0	11,101	7,537	18,637	46,124	132,916	179,040	4.15	17.64	21.79	1,186	4,219	5,405
P40Zn2.5	11,253	7,537	18,790	51,329	133,892	185,221	4.56	17.77	22.33	1,285	4,389	5,675
P40Zn5.0	11,405	7,537	18,942	52,935	142,922	195,857	4.64	18.96	23.61	1,334	4,708	6,042
P40Znsol	11,557	7,537	19,094	52,878	146,817	199,694	4.58	19.48	24.06	1,313	4,870	6,183
P40Zn2.5+sol	11,131	7,537	18,668	48,324	133,337	181,660	4.34	17.69	22.03	1,229	4,234	5,462
P40Zn5.0+sol	11,161	7,537	18,698	48,584	133,856	182,440	4.35	17.76	22.11	1,235	4,244	5,479
P60Zn0	11,323	7,537	18,860	46,227	145,455	191,682	4.08	19.30	23.38	1,172	4,738	5,910
P60Zn2.5	11,475	7,537	19,012	50,270	142,272	192,542	4.38	18.88	23.26	1,253	4,691	5,944
P60Zn5.0	11,627	7,537	19,164	54,737	147,972	202,709	4.71	19.63	24.34	1,355	4,943	6,297
P60Znsol	11,780	7,537	19,316	56,261	151,761	208,022	4.78	20.14	24.91	1,394	5,105	6,499
P60Zn2.5+sol	11,353	7,537	18,890	48,195	144,380	192,574	4.25	19.16	23.40	1,216	4,757	5,974
P60Zn5.0+sol	11,383	7,537	18,920	48,669	143,501	192,170	4.28	19.04	23.32	1,225	4,706	5,931

Sol, Zinc solubilizer

crease in P levels. Presence of crop residues of both the crops and production of organic acids under conditions of increased faunal activity due to decomposition of the stubbles also contributed in increasing available N and Zn in soil (Santiago, 2008). However, net gain thus obtained was statistically non-significant. Conversely, final status of available soil P and K after the experiment was in negative balance due to application of different levels of P & Zn. It might be due to fixation of some amount of P and K in the soil (Zhang *et al.,* 2009; Srinivasrao *et al.,* 2007).

Energetics

The highest energy input (19316 MJ/ha) was recorded with the combination of 60 kg P_2O_5/ha + Zn solubilizer (Table 4). It was further observed that fenugreek consumed more energy as compared to pearl millet because of higher seed rate, more number of irrigations and application of nutrients. Further, higher energy consumption due to conventional tillage has also been included in the energy consumption of fenugreek. The highest energy use efficiency (24.9) and energy productivity (6,499 g/MJ) was obtained with the nutrient combination of 60 kg P_2O_5/ha + Zn solubilizer in the system and similar trend in this respect was observed in the individual crops of the system. However, higher energy use efficiency and energy productivity was recorded with the pearl millet as compared to fenugreek. This was be due to increased production of energy output in terms of increased yield of grain and stover with less energy input for fertilizer nutrient namely P and Zn as pearl millet was raised on residual fertility. Singh *et al.* (2008) have also reported that the output–input energy ratio improves as intensity of tillage is reduced primarily due to energy saving.

CONCLUSION

Based on the result of the study it could be concluded that P and Zn fertilization had significant effect on fenugreek and pearl millet in terms of productivity, profitability, nutrient uptake and energetics. Results of the data recommend that P and Zn application should be accomplished to winter legume component in fenugreek–pearl millet cropping system for enhanced productivity and economics of the cropping system. Combined application of 60 kg P_2O_5/ha + 5 kg Zn/ha + zinc solubilizer could be a sustainable approach for obtaining better crop yield particularly under arid regions of Western India. Further, different kinds of Zn solubilizer could be evaluated with diverse cropping system and moisture regime under different land use.

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