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Moisture management and zinc fortification impacts on economics, quality and nutrient uptake of pearlmillet (*Pennisetum glaucum*) under rainfed conditions

G L CHOUDHARY[1], K S RANA[2], D S RANA[3], R S BANA[4], K PRAJAPAT[5] and MUKESH CHOUDHARY[6]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

A field study was conducted during *kharif* seasons of 2012 and 2013 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi to find out the effect of moisture management and zinc fortification on economics, quality and nutrient uptake of pearlmillet (*Pennisetum glaucum* L.) in pearlmillet-chickpea cropping system under rainfed conditions. Sowing of pearlmillet on flat bed with 5.0 tonnes/ha crop residue fetched significantly higher net returns of ₹ 25408/ha with production efficiency of ₹ 279.2/ha/day and protein content in grain during first year and B:C ratio during both the years as compared to flat bed without crop residue. However, in terms of net returns (₹ 30578/ha), production efficiency (₹ 397.1/ha/day) and protein content during second year and zinc content in both grain and stover and total uptake of N, P, K, Zn, Fe, Mn and Cu during both the years of study, flat bed with 5.0 tonnes/ha crop residue proved to be significantly superior over flat bed without crop residue as well as flat bed with 2.5 tonnes/ha crop residue and performed in statistically similar way to narrow bed and furrow with 2.5 tonnes/ha crop residue. Under zinc fortification treatments direct application of 2.5 and 5.0 kg Zn/ha being at par with each other and recorded significantly higher net returns, B:C ratio, production efficiency, protein content and total uptake of P, K and Cu during both the years and total uptake of Fe and Mn during second year over control. Content of Zn in both grain and stover and total uptake of N and Zn during both the years of study were improved significantly with increasing levels of zinc fortification up to 5.0 kg Zn/ha. Residual effect of zinc fortification was observed during second and showed significant response up to 5.0 kg Zn/ha on net returns, B:C ratio, production efficiency, Zn content in both grain and stover and total uptake of N, K and Zn and up to 2.5 kg Zn/ha on protein content and total uptake of P, Fe, Mn and Cu by pearlmillet.

Key words: Crop residue, Narrow bed and furrow, Net returns, Nutrient uptake, Protein content, Zinc content, Zinc use indices

Pearlmillet (*Pennisetum glaucum* L.) is an important crop of rainfed areas of Africa and India and serves as stable food for millions of people in the low productive soils of these areas. Among the coarse cereals it occupies pivotal position in arid and semi-arid zones of India. India ranks first in pearlmillet growing countries with planting area of 7.20 million hectares and producing 8.74 million tonnes with productivity of 1 214 kg/ha (GOI 2013). Pearlmillet is mainly grown on marginal and sub-marginal lands of Rajasthan, Uttar Pradesh, Gujarat, Haryana, Maharashtra and Karnataka. Out of these Rajasthan, Uttar Pradesh and Gujarat having 76.5 per cent acreages and producing 76.8 per cent of the total pearlmillet production of the country. From quality point of view, it is nutritionally better than many cereals as it is a good source of minerals (2.0-3.5%) particularly iron (284 mg/kg) and fat (4.0-8.0%). Pearlmillet grains possess higher protein content (10.5-14.5%) with higher levels of essential amino acids. The grains of pearlmillet possess a biological value similar to wheat and rice and impart substantial energy to the body. Pearlmillet survives in rainfed areas because of its drought escaping mechanism but still responds well to all inputs including fertilizers.

Indian agriculture is dominated by rainfed agriculture and it contributes to around 40 per cent of the national food grains production. Major part of dryland areas are confined to pearlmillet, sorghum, soybean and pulses. Therefore dryland areas are important for the economy of the country and will continue to be so in future. These areas are characterized by low crop productivity and high variation in yields from year to year mostly due to uncertainty and uneven distribution of rainfall. Moisture stress generally results in limited total nutrient uptake and their diminished tissue concentrations in crop plants. An

[1]Assistant Professor-cum-Junior Scientist (e mail: gopal.agron@gmail.com), Bihar Agricultural University, Sabour, Bhagalpur; [2]Professor and Head (e mail: ksrana04@yahoo.com), [3]Principal Scientist (e mail: dsrana55@yahoo.co.in), [4]Scientist (e mail: rsbana@gmail.com), [6]Ph D Scholar (e mail: selmukesh@gmail.com), Division of Agronomy; [5]Scientist (e mail: kp.agron@gmail.com), Indian Institute of Wheat and Barley Research, Karnal-132 001

important effect of water deficit is on the acquisition of nutrients by the root and their transport to shoots. Lowered absorption of the inorganic nutrients can result from interference in nutrient uptake and the unloading mechanism, and reduced transpirational flow (Garg 2003). Moisture conservation through organic residue application is a viable approach to retain soil moisture and nutrient under water scarcity situations (Tetarwal and Rana 2006, Sharma *et al.* 2010). Another problem associated with low productivity and poor quality of produce in dryland areas is occurrence of micronutrient deficiency especially zinc. Among the micronutrients Zn deficiency is occurring in both crops and human (White and Zasoski 1999). It is well known fact that zinc is now considered as fourth most important yield-limiting nutrient after nitrogen, phosphorus and potassium (Maclean *et al.* 2002). Light texture soils of arid and semi-arid regions with low CEC and organic matter contain low levels of zinc. Zinc plays a significant role in various enzymatic and physiological activities and performs many catalytic functions in plant system besides transformation of carbohydrates, chlorophyll and protein synthesis. Increasing zinc concentration in food crops, resulting better crop production and improved human health is an important global challenge. Bio-fortification through genetic approaches is time consuming and expensive, so agronomic fortification appears to be a rapid and simple solution to address the Zn deficiency in crop and human health. Therefore, use of moisture conservation practices along with fertilizers especially micronutrients are effective in increasing the profitability, productivity and quality of pearlmillet through efficient utilization of moisture and nutrients. Thus, keeping these facts in view, present study was undertaken to find out the effect of zinc fortification under different moisture management practices on economics, quality and nutrient uptake of pearlmillet in pearlmillet-chickpea cropping system under rainfed conditions.

MATERIALS AND METHODS

The field study was conducted at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi during *kharif* 2012 and 2013 to find out the effect of moisture management and zinc fortification on economics, quality, uptake of nutrients and zinc use indices of pearlmillet grown under rainfed conditions. The experimental farm is situated at 28°37' N latitude, 77°09'E longitude and 224 m above mean sea level. The total rainfall received during the cropping season was 416.0 and 928.6 mm, respectively, out of which 316.8 (76.1 per cent) and 401.9 mm (43.3 per cent) was effective. The experimental soil was sandy loam in texture (61.48% sand, 12.66% silt and 25.86% clay) and slightly alkaline in reaction (pH 7.7). The soil was low in organic carbon (0.40%) and available nitrogen (135.4 kg N/ha), medium in available phosphorus (12.8 kg P/ha), potassium (178.8 kg K/ha) and DTPA extractable Zn (0.63 mg/kg of soil). The experiment comprised of four treatments of moisture management (flat bed without crop residue, flat bed with 2.5 tonnes/ha crop residue, flat bed with 5.0 tonnes/ha crop residue and narrow bed and furrow with 2.5 tonnes/ha crop residue) as main plots and three treatments of zinc fortification (control, 2.5 kg Zn/ha and 5.0 kg Zn/ha) as sub plot to pearlmillet and as sub-sub plot to chickpea. The experiment was laid out in split plot design during first season and in split-split plot design during second year for study of residual effect of zinc fortification and replicated thrice.

The pearlmillet variety Pusa composite 443 was taken for experiment and sown at 50 cm × 15 cm spacing. Recommended dose of fertilizers (60 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha) were applied through urea, Diammonium phosphate (DAP) and muriate of potash (MOP). Half dose of nitrogen and full dose of phosphorus and potassium was applied as basal dose at the time of sowing and remaining half dose of nitrogen was as top dressing at 40 DAS. Chickpea residue was applied in main plots as per treatment just after sowing as moisture conservation treatments during both the years. The applied residue of chickpea contains 0.95 and 0.94% N, 0.20 and 0.21% P, 1.51 and 1.50% K, 37.2 and 39.5 ppm Zn, 220 and 221 ppm Fe, 44.9 and 44.7 ppm Mn and 18.8 and 19.0 ppm Cu during 2012 and 2013, respectively. Zinc was applied to sub-sub plots as per treatments through zinc sulphate ($ZnSO_4.7H_2O$) containing 21% zinc and 10% S at the time of sowing as basal dose. The amount of sulphur was adjusted through SSP in all the plots. The crop was grown with recommended package of practices. Need based application of pesticide was also followed to protect the crops from termites. The crop was sown on 12th and 13th July and harvested on 30 and 26 August during 2012 and 2013, respectively. Economics of different treatment was worked out by taking into account the cost of inputs and income obtained from output based on the prevailing market price. Production efficiency (PE) was expressed as the ratio of the net returns to total duration of the crop in days. The chemical analysis of plant samples for concentration of N, P, K and micronutrients (Zn, Fe, Mn and Cu) were done as per standard procedures. Statistical analysis of the data was carried out using standard analysis of variance (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Moisture management practices

Moisture management practices were brought significant effect on economics of pearlmillet (Table 1). Flat bed with 5.0 tonnes/ha crop residue remained at par to flat bed with 2.5 tonnes/ha cop residue and narrow bed and furrow with 2.5 tonnes/ha crop residue, proved significantly superior over flat bed without crop residue in terms of net returns and production efficiency during first year (2012) of study. During second year of experimentation flat bed with 5.0 tonnes/ha crop residue recorded significantly higher net returns of ₹ 30578/ha with production efficiency of ₹ 397.1/ha/day as compared to flat bed without crop

Table 1 Effect of moisture management and zinc fortification on economics of pearlmillet

Treatment	Grain yield (tonnes/ha)		Cost of cultivation (₹/ha)		Net returns (₹/ha)		B:C ratio		Production efficiency (₹/ha/day)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Moisture management										
Flat bed without crop residue	1.89	2.02	18771	19065	17771	21385	0.94	1.12	195.3	277.7
Flat bed + 2.5 tonnes/ha crop residue	2.25	2.42	20821	21115	22211	26649	1.06	1.26	244.1	346.1
Flat bed + 5.0 tonnes/ha crop residue	2.52	2.72	22471	22765	25408	30578	1.13	1.34	279.2	397.1
Narrow bed and furrow + 2.5 tonnes/ha crop residue	2.45	2.65	21421	21715	25318	30284	1.18	1.39	278.2	393.3
SEm±	0.06	0.05			962	946	0.05	0.04	10.57	12.28
CD (P=0.05)	0.19	0.17			3328	3272	0.16	0.15	36.57	42.50
Zinc fortification to pearlmillet										
Control	2.05	2.22	20362	20657	19320	23680	0.94	1.14	212.3	307.5
2.5 kg Zn/ha	2.33	2.51	20937	21232	23586	28191	1.12	1.32	259.2	366.1
5.0 kg Zn/ha	2.45	2.62	21312	21607	25125	29801	1.18	1.37	276.1	387.0
SEm±	0.04	0.04			697	654	0.03	0.03	7.66	8.49
CD (P=0.05)	0.12	0.13			2090	1961	0.10	0.09	22.97	25.47
Zinc fortification to chickpea										
Control		2.31		21165		24627		1.15		319.8
2.5 kg Zn/ha		2.49		21165		27785		1.30		360.8
5.0 kg Zn/ha		2.57		21165		29260		1.38		380.0
SEm±		0.03				521		0.02		6.76
CD (P=0.05)		0.09				1481		0.07		19.23

Market price of grain and stover were ₹12500 and 2000/tonnes during 2012 and ₹13250 and 2000/tonne during 2013 respectively

residue and flat bed with 2.5 tonnes/ha crop residue. Sowing of pearlmillet on narrow bed and furrow with 2.5 tonnes/ha crop residue gave statistically similar net returns to flat bed with 5.0 tonnes/ha crop residue. In terms of B:C ratio pearlmillet sown on narrow bed and furrow with 2.5 tonnes/ha crop residue recorded significantly higher B:C ratio (1.18 and 1.39) over control during both the years of study. Flat bed with 5.0 tonnes/ha crop residue fetched highest net returns but the B:C ratio was higher under narrow bed and furrow with 2.5 tonnes/ha crop residue, because of higher cost of residue under this treatment. The increase in net returns might be due to higher grain yield (2.52 and 2.72 tonnes/ha) obtained under flat bed with 5.0 tonnes/ha crop residue as compared to cost involved under this treatment. Similar findings were also reported in sorghum crop by Guled *et al.* (2011) and Thakur *et al.* (2011). Pearlmillet grown under flat bed with 5.0 tonnes/ha cop residue remained statistically similar to flat bed with 2.5 tonnes/ha cop residue and narrow bed and furrow with 2.5 tonnes/ha crop residue and recorded significantly higher protein content (10.84%) than flat bed without crop residue during 2012. However, during 2013 this treatment proved significantly superior over flat bed without crop residue and flat bed with 2.5 tonnes/ha crop residue (Table 2). The improvement in protein content has been observed in the present investigation was because of increased N content in seed which attributed to increased availability of nitrogen in the soil due to decomposition of crop residue. These results are in close conformity with the findings of Parihar *et al.* (2009).

Various moisture management practices did not influence the Zn content in grain as well as in stover of pearlmillet during first year of investigation, but significant variation was observed during second year (Table 2). Pearlmillet grown on flat bed with 5.0 tonnes/ha crop residue being at par to narrow bed and furrow with 2.5 tonnes/ha crop residue, registered significantly higher Zn content in grain (35.95 mg/kg) and stover (26.13 mg/kg) during second year over rest of the moisture management practices. Application of crop residue lowers down the soil pH through liberation of CO_2 and organic acid during decomposition and its decomposition products might gave rise natural complexing agents that solubilized the nutrients already present in soil and rendered zinc available to the plant (Prasad *et al.* 2010 and Kumari and Prasad 2014). Moisture management practices were also brought significant effect on total uptake of N, P and K by pearlmillet (Table 3). Flat bed with 5.0 tonnes/ha crop residue being at par to narrow bed and furrow recorded significantly higher total uptake of N (102.2 and 112.9 kg/ha), P (37.6 and 41.4 kg/ha) and K (137.5 and 149.7 kg/ha) than flat bed without crop residue and flat bed with 2.5 tonnes/ha crop residue during 2012 and 2013, respectively. This might be due to improved nutritional environment in the rhizosphere as well

Table 2 Effect of moisture management and zinc fortification on protein and zinc content of pearlmillet

Treatment	Protein content (%)		Zinc content (mg/kg)			
			Grain		Stover	
	2012	2013	2012	2013	2012	2013
Moisture management						
Flat bed without crop residue	10.01	10.22	32.11	31.33	23.06	22.49
Flat bed + 2.5 tonnes/ha crop residue	10.53	10.85	34.16	34.44	24.49	24.81
Flat bed + 5.0 tonnes/ha crop residue	10.84	11.24	35.21	35.95	25.39	26.13
Narrow bed and furrow + 2.5 tonnes/ha crop residue	10.66	11.00	34.47	34.98	24.72	25.14
SEm±	0.14	0.11	0.63	0.37	0.49	0.35
CD (P=0.05)	0.49	0.37	NS	1.27	NS	1.21
Zinc fortification to pearlmillet						
Control	10.19	10.46	29.68	29.39	21.25	21.10
2.5 kg Zn/ha	10.58	10.91	34.77	35.01	24.77	24.97
5.0 kg Zn/ha	10.75	11.11	37.52	38.12	27.23	27.86
SEm±	0.12	0.09	0.54	0.30	0.38	0.31
CD (P=0.05)	0.37	0.27	1.62	0.91	1.13	0.92
Zinc fortification to chickpea						
Control		10.59		31.39		22.52
2.5 kg Zn/ha		10.88		34.66		24.89
5.0 kg Zn/ha		11.01		36.48		26.52
SEm±		0.09		0.26		0.26
CD (P=0.05)		0.25		0.75		0.73

Table 3 Effect of moisture management and zinc fortification on total uptake of N, P and K by pearlmillet

Treatment	Total nutrient uptake (kg/ha)					
	N		P		K	
	2012	2013	2012	2013	2012	2013
Moisture management						
Flat bed without crop residue	72.1	77.9	26.4	28.1	96.8	104.1
Flat bed + 2.5 tonnes/ha crop residue	89.4	97.6	32.7	35.5	119.4	128.9
Flat bed + 5.0 tonnes/ha crop residue	102.2	112.9	37.6	41.4	137.5	149.7
Narrow bed and furrow + 2.5 tonnes/ha crop residue	98.1	107.2	35.9	39.1	131.3	141.7
SEm±	1.88	2.07	0.77	0.75	3.56	3.44
CD (P=0.05)	6.52	7.15	2.65	2.59	12.33	11.89
Zinc fortification to pearlmillet						
Control	80.0	87.7	31.3	34.3	110.4	119.5
2.5 kg Zn/ha	92.8	101.4	34.0	37.0	124.0	133.8
5.0 kg Zn/ha	98.6	107.5	34.2	36.9	129.4	140.0
SEm±	1.67	1.32	0.62	0.47	2.20	2.20
CD (P=0.05)	5.02	3.96	1.85	1.42	6.61	6.60
Zinc fortification to chickpea						
Control		91.6		34.8		123.7
2.5 kg Zn/ha		100.5		36.6		132.7
5.0 kg Zn/ha		104.5		36.8		136.9
SEm±		0.96		0.35		1.37
CD (P=0.05)		2.72		1.01		3.89

as in the plant system due to decomposition of crop residue leading to enhanced translocation of N, P and K in plant parts (Sharma *et al.* 2010 and Singh *et al.* 2011). The uptake of micronutrients by pearlmillet was also influenced significantly by various moisture management practices (Table 4). Pearlmillet grown under flat bed with 5.0 tonnes/ha crop residue remained at par with narrow bed and furrow with 2.5 tonnes/ha crop residue, resulted in significantly

Table 4 Effect of moisture management and zinc fortification on total uptake of micronutrients (Zn, Fe, Mn and Cu) by pearlmillet

Treatment	Total uptake of micronutrients (g/ha)							
	Zn		Fe		Mn		Cu	
	2012	2013	2012	2013	2012	2013	2012	2013
Moisture management								
Flat bed without crop residue	211.4	219.3	2020.4	2121.6	572.6	599.1	202.3	211.4
Flat bed + 2.5 tonnes/ha crop residue	260.6	279.8	2414.4	2572.0	683.7	728.0	244.3	260.1
Flat bed + 5.0 tonnes/ha crop residue	298.7	325.8	2727.1	2913.4	767.8	823.3	277.4	297.8
Narrow bed and furrow + 2.5 tonnes/ha crop residue	284.6	307.3	2635.9	2808.8	745.9	792.5	269.5	285.0
SEm±	7.50	7.04	71.23	46.60	18.57	12.83	5.22	6.86
CD (P=0.05)	25.95	24.35	246.49	161.27	64.28	44.39	18.08	23.75
Zinc fortification to pearlmillet								
Control	211.2	224.1	2328.1	2505.4	659.9	706.9	236.0	252.5
2.5 kg Zn/ha	271.8	291.0	2482.5	2638.4	702.6	745.1	252.2	267.0
5.0 kg Zn/ha	308.5	334.1	2537.7	2668.1	715.0	755.2	257.0	271.3
SEm±	6.73	5.28	57.32	35.30	15.67	9.99	4.98	4.15
CD (P=0.05)	20.17	15.83	NS	105.84	NS	29.95	14.92	12.43
Zinc fortification to chickpea								
Control		246.4		2524.7		712.0		254.9
2.5 kg Zn/ha		288.5		2619.1		740.3		265.4
5.0 kg Zn/ha		314.3		2668.1		754.9		270.4
SEm±		3.68		32.20		9.65		2.83
CD (P=0.05)		10.47		91.57		27.44		8.04

higher total uptake of Zn (298.7 and 325.8 g/ha), Fe (2727.1 and 2913.4 g/ha), Mn (767.8 and 823.3 g/ha) and Cu (277.4 and 297.8 g/ha) in comparison to flat bed without crop residue and flat bed with 2.5 t/ha crop residue during 2012 and 2013, respectively. It is well known fact that the uptake of nutrients is a function of their content in plant parts and yield, the higher content of Zn, Fe, Mn and Cu along with higher grain and stover yield resulted in higher uptake of these nutrients (Prasad *et al.* 2010 and Kumari and Prasad 2014). Zinc use indices (agronomic, recovery and physiological efficiencies and Zn harvest index) of pearlmillet were also improved linearly with increased amount of crop residue (Table 5). Flat bed with 5.0 tonnes/ha crop residue recorded the maximum agronomic efficiency (124.2 and 130.5 kg grain/kg Zn applied), recovery efficiency (3.50 and 2.63 per cent) and physiological efficiency (5 491 and 4 988 kg grain/kg Zn uptake) during 2012 and 2013, respectively. The same moisture management treatment was also recorded the maximum Zn harvest index of 29.9 per cent during 2012, however, during second year the maximum Zn harvest index of 30.4 per cent was observed under narrow bed and furrow with 2.5 tonnes/ha crop residue.

Zinc fortification to pearlmillet

Net returns and B:C ratio of pearlmillet were increased linearly with increasing levels of zinc up to 5.0 kg Zn/ha (Table 1). Application of 5.0 kg Zn/ha fetched significantly higher net returns of ₹ 25125 and 29801/ha with production efficiency of ₹ 276.1 and 387.0/ha/day and B:C ratio of 1.18 and 1.37, respectively during 2012 and 2013 cropping season as compared to control. This might be due to the cost involved under this treatment was comparatively lower than its additional income, which led to more returns under this treatment. Similar findings were also reported by Jakhar *et al.* (2006). Content of protein were also increased significantly by direct applied zinc fortification treatments (Table 2). Application of 5.0 kg Zn/ha remained at par with 2.5 kg Zn/ha, recorded significantly higher protein content (10.75 and 11.11 %) as compared to control during both the years of study. The increase in protein content by zinc fortification ascribed due to the role of Zn in nitrogen metabolism and protein synthesis. Jakhar *et al.* (2006) and Chauhan *et al.* (2014) were also reported similar findings. Direct application of 5.0 kg Zn/ha to pearlmillet recorded significantly higher Zn content in grain (37.52 and 38.12 mg/kg) and stover (27.23 and 27.86 mg/kg) over lower levels during both the years of experimentation (Table 2). The increased Zn content attributed to greater absorption of Zn by the crop owing to higher availability in soil due to direct addition of zinc; otherwise the soil was deficit in available Zn. The results of the present investigation are in accordance with the findings of Chaube *et al.* (2007). Fortification of pearlmillet with 5.0 kg Zn/ha registered significantly higher total uptake of N (98.6 and 107.5 kg/ha) during both the years of investigation (Table 3). The increase in concentration of N by zinc fortification might be due to the role of Zn in nitrogen metabolism which leads to increase in accumulation of nitrogen by plants and ultimately higher uptake of N. Phosphorus has antagonistic interaction with Zn, so application of zinc

Table 5 Effect of moisture management and zinc fortification on zinc (Zn) use indices of pearlmillet

Treatment	Agronomic efficiency (kg grain/kg Zn applied)		Recovery efficiency (%)		Physiological efficiency (kg grain/kg Zn uptake)		Zn harvest index (%)	
	2012	2013	2012	2013	2012	2013	2012	2013
Moisture management								
Flat bed without crop residue	63.3	49.4	2.77	2.16	2866	2147	29.0	29.4
Flat bed + 2.5 tonnes/ha crop residue	91.7	94.0	3.04	2.42	4212	4108	29.7	30.2
Flat bed + 5.0 tonnes/ha crop residue	124.2	130.5	3.50	2.63	5491	4988	29.9	30.1
Narrow bed and furrow + 2.5 tonnes/ha crop residue	109.1	116.4	3.31	2.54	4485	4454	29.8	30.4
Zinc fortification to pearlmillet								
Control							28.9	29.5
2.5 kg Zn/ha	113.9	115.1	2.42	2.68	4443	4510	29.9	30.3
5.0 kg Zn/ha	80.2	80.1	3.89	2.20	4084	3339	29.9	30.2
Zinc fortification to chickpea								
Control		97.0		2.22		4170		29.7
2.5 kg Zn/ha		110.2		2.57		4083		30.2
5.0 kg Zn/ha		85.5		2.53		3520		30.1

resulted in to reduction in P uptake at higher levels (Table 3). However, application of 2.5 and 5.0 kg Zn/ha found to be statistically similar with each other in terms of total uptake of P and proved statistically better as compared to control during both the years. In case of K, application of 5.0 kg Zn/ha recorded significantly higher total uptake of K (129.4 and 140.0 kg/ha) during both the years of study as compared to control, but remained at par with 2.5 kg Zn/ ha (Table 3). The increased concentration and uptake of K might be due to greater absorption of Zn by the crop owing to higher availability in soil. The result of the present study was in the line of the findings of Jain and Dahama (2005) and Jakhar *et al.* (2006).

Fortification of pearlmillet with 5.0 kg Zn/ha resulted into significantly higher total uptake of Zn (308.5 and 334.1 g/ha) during both the years as compared to lower levels (Table 4). The combined effect of increased zinc availability on yield and concentration finally reflected on total uptake of Zn (Jain and Dahama 2005 and Gupta and Sahu 2012). Though the content of Fe, Mn and Cu in pearlmillet were decreased with increasing levels of zinc due to antagonistic interaction, but the total uptake of these micronutrients were increased with increasing levels of zinc fortification (Table 4). Total uptake of Fe and Mn during 2012 did not influence significantly with zinc fortification treatments. However, application of 5.0 kg Zn/ha to pearlmillet being at par with 2.5 kg Zn/ha recorded significantly higher total uptake of Fe and Mn during second year and total uptake of Cu during first year over control. Whereas, total uptake of Cu during second year of study was increased significantly with increasing levels of zinc fortification up to 5.0 kg Zn/ha. Imtiaz *et al.* (2003) and Soleimani (2012) were also reported similar type of observation in terms of total uptake of Fe, Mn and Cu. Direct applied zinc fortification also respond differently on zinc use indices of pearlmillet (Table 5). Agronomic efficiency of Zn decreased with the increase in levels of zinc fortification. The highest agronomic efficiency (113.9 and 115.1 kg grain/kg Zn applied) was found with direct application of 2.5 kg Zn/ha. Recovery efficiency of Zn during first year of study was increased with increasing levels of zinc fortification and the highest efficiency (3.89 per cent) was observed under 5.0 kg Zn/ha. However, during second year recovery efficiency was decreased with increasing levels of zinc fortification and 2.5 kg Zn/ha observed highest recovery efficiency (2.68 per cent). Physiological efficiency of zinc was also followed the similar trend as observed with agronomic efficiency. Application of 2.5 kg Zn/ha to pearlmillet recorded maximum value of zinc harvest index (29.9 and 30.3 per cent). Use efficiencies of applied Zn were low at higher application rates because its rapid adsorption over soil organic matter and clay minerals and its subsequent slow desorption (Shivay *et al.* 2010). The reduction in zinc use efficiencies with successive increase in zinc levels might also due to that increase in levels of zinc did not bring corresponding increase in grain yield (Sammauria and Yadav 2010 and Chauhan *et al.* 2014).

Residual effect of zinc fortification

The residual effect of preceding zinc fortification treatments applied to chickpea was examined during second year of study and results were found to be significant on economics, quality and nutrient uptake of pearlmillet (Table 1, 2, 3 and 4). The residual effect of 5.0 kg Zn/ha fetched significantly higher net returns of ₹ 29260/ha with production efficiency of ₹ 380.0/ha/day over control and B:C ratio of 1.38 over control and 2.5 kg Zn/ha. Application of 5.0 kg Zn/ha recorded significantly higher protein content and total uptake of P, Fe, Mn and Cu as compared to control, but found statistically similar with 2.5 kg Zn/ha.

However, the same treatment recorded significantly higher total uptake of N (104.5 kg/ha) and K (136.9 kg/ha) in comparison to control as well as 2.5 kg Zn/ha. The residual effect of 5.0 kg Zn/ha resulted into significantly higher content of zinc in grain (36.48 mg/kg) and stover (26.52 mg/kg) as compared to lower levels of residual zinc fortification (Table 2). The improvement in content of Zn in grain and stover of pearlmillet with residual effect of zinc was also reported by Jain and Dahama (2005) and Singh *et al.* (2013).

Thus, on the basis of results of two years investigation, it could be concluded that sowing of pearlmillet either on flat bed with 5.0 tonnes/ha crop residue or narrow bed and furrow with 2.5 tonnes/ha crop residue and application of 2.5 kg Zn/ha were resulted significantly higher net returns along with higher B:C ratio and better quality of grain as compared to other treatments of moisture management and zinc fortification under rainfed conditions.

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