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Soil microbial properties, growth and productivity of pearl millet (*Pennisetum glaucum* L.) as influenced by moisture management and zinc fortification under rainfed conditions

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Pearl millet (*Pennisetum glaucum* L.) is an important crop in rainfed conditions and marginal land areas; it is grown under improper crop establishment and imbalanced fertilization. Proper moisture management with zinc fortification has potential to improve productivity, solve zinc malnutrition problem, maintain soil health and economic sustainability. The present study was conducted during 2012 and 2013 at IARI, New Delhi to find out the effect of moisture management and zinc fortification on soil microbial properties, growth and productivity of pearl millet under rainfed conditions. During both years, moisture management and zinc fortification treatments resulted in considerable improvement in soil microbial properties, growth and productivity of pearl millet. Flat bed with 5.0 t/ha crop residue recorded significantly higher dehydrogenase activity, microbial biomass carbon, plant height, dry matter accumulation and grain weight per ear head as compared to flat bed and flat bed with 2.5 t/ha crop residue. In terms of total number of tillers, number of ear heads and length of ear head flat bed with 2.5 and 5.0 t/ha crop residue and narrow bed and furrow with 2.5 t/ha crop residue remained statistically similar with each other. Significantly higher grain (2.52 and 2.72 t/ha), stover (8.21 and 8.65 t/ha) and biological yield (10.72 and 11.37 t/ha) were observed under flat bed with 5.0 t/ha crop residue during both years. Under zinc fortification treatments, application of 5.0 kg Zn/ha to pearl millet recorded significantly higher value of soil microbial properties over control and 2.5 kg Zn/ha. Application of 5.0 and 2.5 kg Zn/ha is at par with each other and proved significantly better over control in terms of growth parameters, yield attributes and yield of pearl millet. Residual effect of zinc fortification was also found to be significant in pearl millet. Soil microbial properties were improved significantly up to 5.0 kg Zn/ha. However, growth parameters and yield attributes were increased significantly only up to 2.5 kg Zn/ha. Application of 5.0 kg Zn/ha produced significantly higher grain (2.57 t/ha), stover (8.22 t/ha) and biological yield (10.78 t/ha) as compared to control. Final results revealed that pearl millet planting under flat bed with 5.0 t/ha crop residue or narrow bed and furrow with 2.5 t/ha crop residue and application of 2.5 kg Zn/ha to pearl millet or chickpea proved to be better.

Key words: Flat bed, crop residue, narrow bed and furrow, dehydrogenase, microbial biomass carbon, moisture management,root length, root volume, grain yield, pearl millet, Zn.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* L.) is the fifth most important cereal grain crop next to rice, wheat, maize and sorghum. The crop is cultivated for grain as well as fodder in the semi-arid tropical regions of Africa and Asia including India. In India, annual planting area is 8.69 million hectares producing nearly 10.05 million tonnes of grains (Anonymous, 2012). Today, it is getting more attention due to increasing evidence of less seasonal rainfall, terminal heat, frequent occurrence of extreme weather events coupled with scanty water resources (Singh et al., 2010). Pearl millet traditionally is an indis-pensable component of dry-farming system and it is consi-dered more efficient in utilization of soil moisture, and has a higher level of heat tolerance than even sorghum and maize. It is the food for millions of people in the poor regions of semi-arid tropics. 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 (284ppm) and fat (4.0-8.0%). Pearl millet grains possess higher protein content (10.5-14.5%) with higher levels of essential amino acids. The grains of pearl millet possess a biological value similar to wheat and rice and impart substantial energy to the body. It occupies a distinct position in the agricultural economy of the country. With the advent of pearl millet hybrids in mid-sixties, the pearl millet cultivation received a fillip. As a result, the productivity almost tripled from about 350 kg in mid-sixties to about 1156 kg in 2012. The crop is mostly confined to low fertile water deficit soils. Because of its remarkable ability to withstand and grow in harsh environment, reasonable and nearly assured harvests are obtained.

Dryland agriculture has a distinct place in Indian agriculture, occupying around 80 m ha area (58%) out of 141 m ha net cultivated area. This implies that the country will continue to grapple with the problems of rainfed agriculture. The main problem of rainfed areas is uncertainty and uneven distribution of rainfall and loss of water through runoff which leads to low and unstable productivity due to moisture stress at critical stages of crop growth. It is a well known fact that about 85% of annual rainfall is received during south-west monsoon season. In this period, knowledge of crop growth phases and moisture availability is more essential because the deficiency of rain water at any critical growth stage may affect the plant growth and yield. Moisture stress further affect the nutrient availability to the crop since nutrient mobility depends on optimum soil moisture. The risk factor can be minimized through *in situ* moisture conservation, adoption of suitable crops and their varieties (Munish Kumar et al., 2008). Residue application helps in maintaining proper growth and development of crop by conserving the moisture in soil profile and ultimately enhancing the productivity of crops (Singh et al., 2012; Tetarwal et al., 2012). 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 of the present scenario is zinc deficiency in soils. It is well a known fact that zinc is now considered as fourth most important yield-limiting nutrient after nitrogen, phosphorus and potassium (Maclean et al., 2002). Increasing zinc concentration in food crops, resulting to better crop production and improved human health is an important global challenge. Among the micronutrients, Zn deficiency is occurring in both crops and human (White and Zasoski, 1999). Zn deficiency reduces not only the grain yield, but also the nutritional quality of grain and ultimately nutritional quality of human diet. Zn is essential for both plants and animals because it is a structural constituent and regulatory co-factor in enzymes and proteins involved in many biochemical pathways. Besides improving photosynthesis and regulation of auxin concentration, Zn plays an important role in nitrogen metabolism and protein synthesis. It also involved in formation of chlorophyll and carbohydrate. Under dryland conditions reduced soil moisture in surface soil layer reduce zinc adsorption and may cause zinc deficiency. Cereal crops are generally the most susceptible to zinc deficiency and show a high response to zinc fertilization. Agronomic approaches such as application of Zn-containing fertilizers appear to be a rapid and simple solution to address the Zn deficiency in crop and human health. Biofortification of cereal grains through use of Zn fertilizers is required for keeping sufficient amount of available Zn in soil solution, maintaining adequate Zn transport to the seeds during reproductive growth stage and optimizing the success of biofortification of staple food crops with Zn through use of different approaches. Chaube et al. (2007) and Badiyala and Chopra (2011) reported that use of Zn increase the productivity as well as improve the fertility status of soil. Thus, keeping these facts in view, a research was undertaken to find out the effect of zinc fortification under different moisture management practices on soil microbial properties and performance of pearl millet in rainfed conditions.

MATERIALS AND METHODS

Climate and soil

A field experiment was conducted at the research farm of Indian Agricultural Research Institute, New Delhi during *kharif* 2012 and 2013 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 maximum and minimum temperature during the growing season (July-September) was 44.2 and 20.2°C during 2012 and 39.0 and 21.0°C during 2013, respectively. The total rainfall received during the cropping season was 416 and 928.6 mm, respectively, out of which 316.8 (76.1%) and 401.9 mm (43.3%) was effective (Figures 1 and 2). The region has typical semi-arid and sub-tropical climate with extremes of cold and hot situations (Sehgal et al., 1992). The experimental soil was sandy loam in texture

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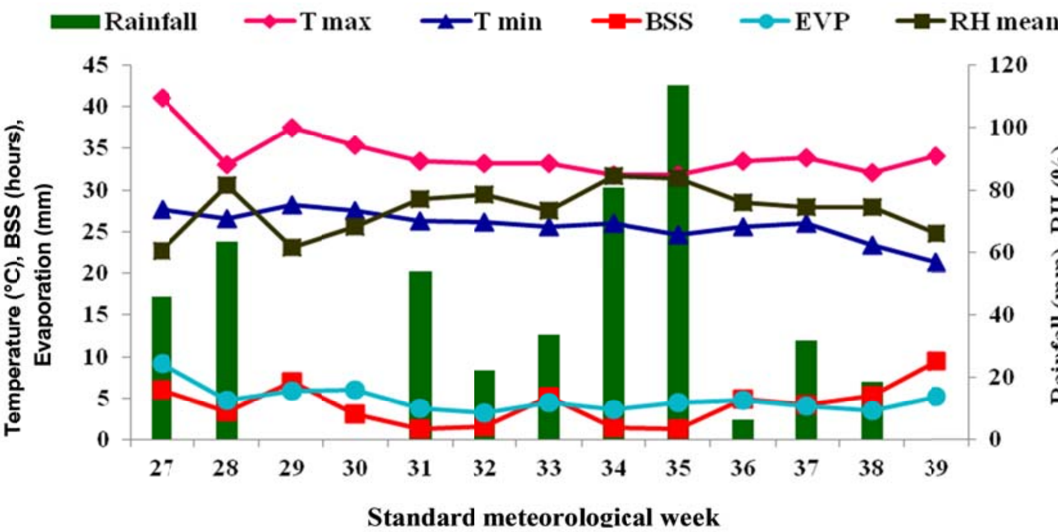

Figure 1. Weather parameters during *kharif* 2012.

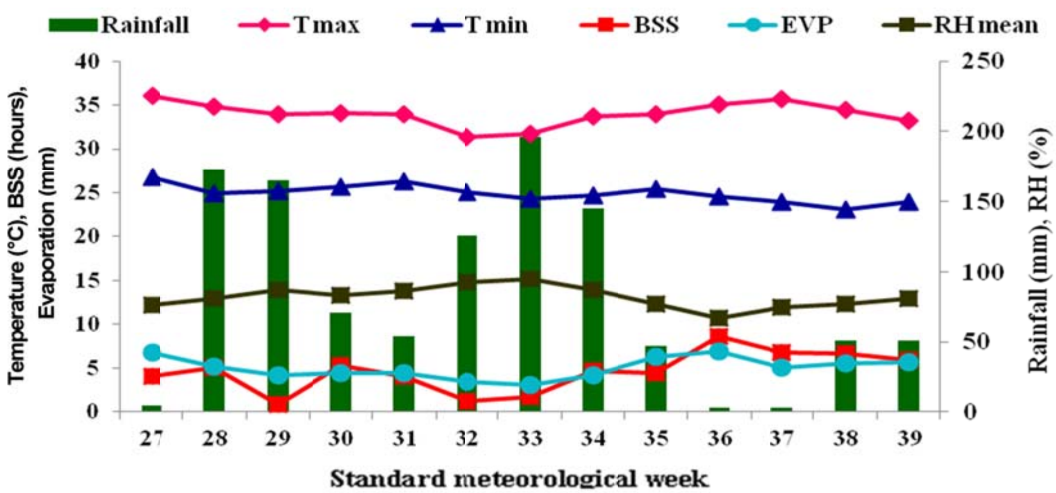

Figure 2. Weather parameters during *kharif* 2013.

having 61.48% sand, 12.66% silt and 25.86% clay contents. Chemical analysis of nutrients for the experimental soil were carried out by using the Modified Kjeldahl method (Jackson, 1958) for determination of available N, Olsen's method for available P (Olsen et al., 1954), Flame photometer method (Jackson, 1958) for available K, DTPA extraction method (Lindsay and Norvell, 1978) for available Zn and Walkley and Black's rapid titration method (Jackson, 1973) for organic carbon. The experimental soil was low in available nitrogen (135.4 kg N/ha), medium in available phosphorus (12.8 kg P/ha), potassium (178.8 kg K/ha) and Zn (0.63 mg/kg of soil) and low in organic carbon content (0.40%). The pH of the soil was 7.7 and determined in soil water suspension in the ratio of 1:2.5 with glass electrode pH meter.

Experimental set-up and management

The experiment comprised of four treatments of moisture management (Flat Bed, Flat Bed with 2.5 t residue/ha, Flat Bed with 5.0 t residue/ha and Narrow Bed and Furrow with 2.5 t residue/ha) in main plot and three treatments of zinc fortification (control, 2.5 kg Zn/ha and 5.0 kg Zn/ha) in sub plot to pearl millet and in sub-sub plot to chickpea. The experiment was laid out in split plot design during *kharif* 2012 and in split-split plot design from subsequent season and replicated thrice. The pearl millet variety 'Pusa composite 443' was taken for experiment and planted at 50 x 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, single super phosphate (SSP) or 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 of crop during both the years. Zinc fortification treatments were applied as per treatment 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 toke 81 and 77 days for completion of life cycle during 2012 and 2013, respectively.

Soil samples from surface depth (0-15 cm) and near plant roots were taken in small polythene bags from each plot by core sampler at 50% flowering stage. The soil samples were air-dried, ground and passed through 2 mm mesh-sieve, and analysed for microbial parameters *viz.*, microbial biomass carbon and dehydrogenase activity. Microbial biomass carbon was estimated by chloroform fumigation method (Nunan et al., 1998) and dehydrogenase activity was estimated as described by Casida et al. (1964). Five plants were selected randomly from each plot, tagged permanently and used for measurement of plant height. For dry matter accumulation, five plants from each plot were uprooted randomly from sample rows and after removal of root portion, the samples were first air dried for some days followed by drying in an electric oven at 65°C till constant weight. The weight was recorded and expressed as g/plant. The total number of tillers and number of earheads per metre row length were counted at harvest from three different spots from each plot and the average was worked out. Root samples were taken from the sample row at flowering stage 50 DAS. A root auger of 4.8 cm diameter and 10 cm height (core volume = 180.86 cm3) was used to take root samples up to 0-15 cm depth of soil profile. The root samples taken from each plot were thoroughly washed in running water to remove the dust particles. Then, root samples were put into polythene bag and used to measure root length and volume by scanning. Scanning and image analysis using RHIZO system was operated in a computer mounted with the scanner of RHIZO system. After taking root length and volume, root samples were put first and air dried for some days followed by drying in an electric oven at 65°C till constant weight. The weight was recorded and expressed as g/plant. Five earheads were randomly selected from each plot and the length of earhead was measured from the basal whorl of spikelet to the tip of earhead. The length of earhead was measured in centimetre and mean length was calculated. Same five earheads of pearl millet which were used to measure length were also used for recording grain weight. The weight of the thoroughly sun dried harvested produce from net area of each plot was recorded separately before threshing and expressed as biological yield in t/ha. After proper drying of harvested product, they were threshed separately. Grain yield from each net plot was recorded and computed as grain yield t/ha. The stover yield for each plot was worked out by subtracting grain yield from total biomass of each net plot and stover yield was expressed in t/ha. Statistical analysis of the data was carried out using standard analysis of variance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Moisture management practices

Soil microbial parameters *viz*., dehydrogenase activity and microbial biomass carbon were significantly influenced by moisture management practices (Table 1). Flat bed with 5.0 t/ha crop residue proved significantly superior over flat bed and flat bed with 2.5 t/ha cop residue in terms of dehydrogenase activity and it was found to be statistically similar with narrow bed and furrow with 2.5 t/ha crop residue. However, in terms of microbial biomass carbon flat bed with 2.5 t/ha cop residue proved significantly superior over all other moisture management practices. Addition of crop residue conserved soil moisture by reducing evaporation losses and also added organic carbon to the soil which results in the better aeration and microbial activity in the soil (Chakarabarti et al., 2000; Singh et al., 2009). Moisture management practices signi-ficantly influenced the plant height, dry matter accumulation and total number of tillers of pearl millet (Table 1). Flat bed with 5.0 t/ha crop residue recorded signi-ficantly higher plant height (271.0 and 273.3 cm) and total number of tillers per metre row length (20.0 and 20.1) during both years as compared to flat bed but it was found to be statistically at par with narrow bed and furrow with 2.5 t/ha crop residue and flat bed with 2.5 t/ha crop residue. However, dry matter accumulation per plant was significantly enhanced with flat bed with 5.0 t/ha crop residue by 35.9 and 12.7% in 2012 and 33.7 and 12.2% in 2013, respectively, over flat bed and flat bed with 2.5 t/ha cop residue. Under moisture stress conditions in search of moisture, the flat bed planted pearl millet recorded significantly higher value of rooting parameters (root length, root volume and root dry weight) as compared to crop residue applied treatments (Table 2). The improvement in growth parameters of pearl millet planted under residue applied moisture management practices might be due to the fact that residue cover helped to conserve soil moisture available through rainfall (Mulumba and Lal, 2008) and continuously provided t the needs of crops. Adequate availability of moisture to plants resulted in cell turgidity and eventually high meristematic activity, leading to more foliage development, greater photosynthetic activity and consequently higher growth and development. Moreover, applied residue as moisture management prac-tice also enhanced the nutrient supply through decom-position of organic residue coupled with favorable moi-sture condition creating conducive environment for plant growth and development (Parihar et al., 2012; Singh et al., 2012; Dass et al., 2013).

Moisture management practices also had significant effect on yield attributes and yield of pearl millet (Tables 3 and 4). Flat bed with 5.0 t/ha crop residue, narrow bed and furrow with 2.5 t/ha crop residue and flat bed with 2.5 t/ha crop residue remained at par with each other and proved significantly better over flat bed planted pearl millet in terms of number of earheads per metre row length and length of earhead. Flat bed with 5.0 t/ha crop residue being at par with narrow bed and furrow with 2.5 t/ha crop residue produces significantly higher grain weight per head (19.05 and 20.12 g), which was higher by 25.2 and 9.8% in 2012 and 25.1 and 9.8% in 2013 over flat bed and flat bed with 2.5 t/ha crop residue, respectively. However, there was no significant difference observed in test weight during both years. The favourable improvements in yield attributes was due to the favourable effect of moisture management practices on growth parameters, leading to greater nutrient uptake, efficient partitioning of metabolites and adequate accumu-lation and translocation of photosynthates. Adequate supply of moisture in general is known to enhance the growth and dry matter production of crops directly and indirectly by increasing the availability and utilization

Table 1. Effect of moisture management and zinc fortification on soil microbial properties and growth parameters of pearl millet.

Treatment	Dehydrogenase activity (µg TPF/g soil/day)		Microbial biomass carbon (µg C/g soil)		Plant height (cm)		Dry matter accumulation (g/plant)		Total number of tillers per metre row length	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Moisture management										
Flat Bed	23.6	23.8	62.8	64.7	235.0	238.9	59.58	65.46	17.3	17.4
Flat Bed + 2.5 t residue/ha	30.2	31.6	84.8	90.7	255.6	259.8	71.87	78.04	19.1	19.3
Flat Bed + 5.0 t residue/ha	35.1	36.8	97.7	105.6	271.0	273.3	80.97	87.53	20.0	20.1
NBF + 2.5 t residue/ha	33.0	34.5	88.6	95.6	263.2	267.4	77.43	83.93	19.7	19.8
Sem±	0.42	0.42	1.46	1.42	5.0	4.8	2.33	2.39	0.46	0.35
CD (P=0.05)	1.46	1.44	5.06	4.90	17.3	16.7	8.07	8.28	1.60	1.23
Zinc fortification to pearl millet (kg/ha)										
0	24.8	25.8	79.2	84.3	245.7	250.0	66.82	72.62	18.0	18.0
2.5	31.4	32.6	84.2	89.9	259.0	262.2	73.76	80.08	19.3	19.4
5.0	35.3	36.7	87.0	93.3	263.9	267.4	76.81	83.52	19.8	20.0
SEm±	0.26	0.39	0.46	0.70	4.1	2.6	1.82	1.33	0.33	0.29
CD (P=0.05)	0.78	1.17	1.39	2.10	12.1	7.7	5.46	3.99	0.99	0.88
Zinc fortification to chickpea (kg/ha)										
0	-	28.4	-	86.7	-	254.9	-	75.59	-	18.5
2.5	-	32.2	-	89.6	-	261.1	-	79.34	-	19.3
5.0	-	34.4	-	91.1	-	263.5	-	81.29	-	19.6
SEm±	-	0.25	-	0.50	-	1.9	-	0.87	-	0.21
CD (P=0.05)	-	0.70	-	1.42	-	5.4	-	2.46	-	0.59

Table 2. Effect of moisture management and zinc fortification on root length, volume and dry weight of pearl millet.

Treatment	**Root length per plant (cm)**		**Root volume per plant (cm^3)**		**Root dry weight per plant (g)**	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**
Moisture management						
Flat Bed	402.4	395.0	11.34	11.13	7.34	7.18
Flat Bed + 2.5 t residue/ha	352.4	348.0	10.10	9.96	6.52	6.42
Flat Bed + 5.0 t residue/ha	328.2	327.7	9.39	9.34	6.17	6.10
NBF + 2.5 t residue/ha	340.5	337.7	9.69	9.66	6.37	6.30
Sem±	11.70	10.12	0.30	0.24	0.22	0.15
CD (P=0.05)	40.49	35.01	1.03	0.82	0.76	0.52
Zinc fortification to pearl millet (kg/ha)						
0	330.7	322.2	9.41	9.18	6.06	5.96
2.5	362.8	360.6	10.29	10.21	6.70	6.62
5.0	374.1	373.5	10.69	10.67	7.03	6.92
SEm±	9.66	6.94	0.23	0.20	0.18	0.13
CD (P=0.05)	28.97	20.80	0.68	0.61	0.54	0.40
Zinc fortification to chickpea (kg/ha)						
0	-	337.1	-	9.62	-	6.24
2.5	-	355.9	-	10.11	-	6.56
5.0	-	363.4	-	10.34	-	6.70
SEm±	-	6.00	-	0.12	-	0.08
CD (P=0.05)	-	17.06	-	0.35	-	0.23

Table 3. Effect of moisture management and zinc fortification on yield attributes of pearl millet.

Treatment	Number of earheads per meter row length		Length of earhead (cm)		Grain weight per earhead (g)		1,000-grain weight (g)	
	2012	2013	2012	2013	2012	2013	2012	2013
Moisture management								
Flat Bed	11.8	12.1	25.6	26.7	15.21	16.08	7.76	7.87
Flat Bed + 2.5 t residue/ha	13.7	14.0	28.4	29.4	17.35	18.33	8.20	8.30
Flat Bed + 5.0 t residue/ha	14.6	15.0	29.4	30.6	19.05	20.12	8.41	8.54
NBF + 2.5 t residue/ha	14.3	14.7	29.1	30.1	18.34	19.38	8.28	8.40
Sem±	0.35	0.40	0.62	0.57	0.47	0.45	0.16	0.15
CD (P=0.05)	1.21	1.37	2.15	1.98	1.61	1.57	NS	NS
Zinc fortification to pearl millet (kg/ha)								
0	12.8	13.3	26.9	27.7	16.52	17.35	7.96	8.09
2.5	13.8	14.1	28.3	29.5	17.72	18.74	8.20	8.30
5.0	14.2	14.4	29.1	30.3	18.22	19.34	8.34	8.44
SEm±	0.22	0.18	0.39	0.41	0.32	0.33	0.11	0.10
CD (P=0.05)	0.65	0.53	1.18	1.23	0.96	1.00	NS	NS
Zinc fortification to chickpea (kg/ha)								
0	-	13.6	-	28.1	-	17.89	-	8.16
2.5	-	14.0	-	29.4	-	18.60	-	8.30
5.0	-	14.2	-	30.0	-	18.94	-	8.37
SEm±	-	0.12	-	0.32	-	0.21	-	0.07
CD (P=0.05)	-	0.35	-	0.91	-	0.59	-	NS

Table 4. Effect of moisture management and zinc fortification on yield and harvest index of pearl millet.

Treatment	Yield (t/ha)						Harvest index (%)	
	Grain		Stover		Biological			
	2012	2013	2012	2013	2012	2013	2012	2013
Moisture management								
Flat Bed	1.89	2.02	6.48	6.81	8.36	8.84	22.54	22.98
Flat Bed + 2.5 t residue/ha	2.25	2.42	7.44	7.83	9.69	10.25	23.25	23.63
Flat Bed + 5.0 t residue/ha	2.52	2.72	8.21	8.65	10.72	11.37	23.52	23.90
NBF + 2.5 t residue/ha	2.45	2.65	8.05	8.47	10.50	11.12	23.30	23.77
Sem±	0.06	0.05	0.20	0.19	0.23	0.22	0.50	0.296
CD (P=0.05)	0.19	0.17	0.68	0.65	0.80	0.77	NS	NS
Zinc fortification to pearl millet (kg/ha)								
0	2.05	2.22	7.04	7.44	9.09	9.66	22.54	23.11
2.5	2.33	2.51	7.68	8.07	10.01	10.58	23.28	23.64
5.0	2.45	2.62	7.91	8.32	10.36	10.94	23.65	23.96
SEm±	0.04	0.04	0.14	0.12	0.17	0.14	0.38	0.351
CD (P=0.05)	0.12	0.13	0.43	0.37	0.50	0.41	NS	NS
Zinc fortification to chickpea (kg/ha)								
0	-	2.31	-	7.60	-	9.91	-	23.28
2.5	-	2.49	-	8.01	-	10.50	-	23.63
5.0	-	2.57	-	8.22	-	10.78	-	23.79
SEm±	-	0.03	-	0.08	-	0.10	-	0.180
CD (P=0.05)	-	0.09	-	0.24	-	0.30	-	NS

of nutrients (Tetarwal et al., 2012).

Grain, stover and biological yield were significantly higher with flat bed with 5.0 t/ha crop residue over flat bed and flat bed with 2.5 t/ha crop residue but remained at par with narrow bed and furrow with 2.5 t/ha crop residue. Flat bed with 5.0 t/ha crop residue enhanced the grain yield of pearl millet by 33.3 and 12.0% in 2012 and 34.7 and 12.4% in 2013 over flat bed and flat bed 2.5 t/ha crop residue, respectively. Harvest index was increased linearly with moisture management practices but has no significant improvement. The increase in grain yield of pearl millet with flat bed with 5.0 t/ha crop residue might be due to the better availability of moisture and addition of organic matter. Rapid decomposition of organic residue helped in greater availability of nutrients, which led to increase in growth and yield attributes and finally the grain yield. High and well distributed rainfall in 2013 results in the better growth of crop due to adequate availability of moisture throughout the growing season and produced higher grain yield as compared to 2012. Similar findings were also reported by Kumar and Gautam (2004) and Parihar et al. (2012).

Zinc fortification to pearl millet

Zinc fortification treatments had significant effect on soil microbial properties *viz*., dehydrogenase activity and microbial biomass carbon as compared to the control (Table 1). Application of 5.0 kg Zn/ha reported significantly higher dehydrogenase activity (35.3 and 36.7µg TPF/g soil/day) and microbial biomass carbon (87.0 and 93.3 µg C/g soil) over control and 2.5 kg Zn/ha during both the years. More favourable condition results in higher soil microbial activities during the second year in comparison with first. Zinc is an important component of several enzymes especially dehydragenase and RNA polymerase which results in higher soil microbial activities. Growth parameters of pearl millet namely plant height, dry matter accumulation and total number of tillers were improved significantly due to application zinc. Application of 5.0 kg Zn/ha being at par with 2.5 kg Zn/ha significantly enhanced the plant height and dry matter accumulation by 7.0 and 15.0% in 2012 and 7.0 and 15.0% in 2013, respectively, over control. Root length, volume and dry matter were significantly higher under 5.0 kg Zn/ha as compared to control during both years of experiment (Table 2). The favourable influence of applied zinc on different growth parameters of pearl millet and chickpea is ascribed to its involvement in various metabolic activities, controlling auxin levels and nucleic acids (Marschner, 1995). Zinc is also an essential component of enzymes responsible for assimilation of nitrogen which helps in chlorophyll formation and plays an important role in nitrogen metabolism contributing towards increase in growth and development of plant (Jakhar et al., 2006; Badiyala and Chopra, 2011).

Yield attributes (number of earheads per metre row length, length of earhead and grain weight per earhead) and yield (grain, stover and biological) of pearl millet were enhanced significantly with zinc fortification treatments (Tables 3 and 4). Application of 5.0 kg Zn/ha to pearl millet significantly increased the number of earheads per metre row length by 10.9 and 8.3%, length of earheads by 2.2 and 2.6 cm and grain weight per earhead by 10.3 and 11.5%, respectively during 2012 and 2013, over control. Zinc fortification treatments failed to have any significant effect on test weight of pearl millet during both years of study. As already discussed in preceding paragraph, zinc plays an important role in nitrogen metabolism and formation of chlorophyll and carbohydrate, which leads to maintaining photosynthetic activity for longer period and finally results in increasing the yield attributes of the crop (Mehta et al., 2008; Ram Pratap et al., 2008).

Results further revealed that increasing levels of zinc linearly increased the grain, stover and biological yield of pearl millet but the response was significant only up to 2.5 kg Zn/ha. Application of 5.0 kg Zn/ha recorded significantly higher grain (2.45 and 2.62 t/ha), stover (7.91 and 8.32 t/ha) and biological yield (10.36 and 10.94 t/ha) and it enhanced the grain yield by 19.5 and 18.0%, stover yield by 12.4 and 11.8% and biological yield by 14.0 and 13.3%, respectively, in 2012 and 2013 over control. The effect of different treatments of zinc fortification remained non-significance on harvest index during both years of experiment. The cumulative beneficial effect of growth and yield attributing characters was finally reflected in grain yield of pearl millet. These results are in close conformity with that of Mehta et al. (2008) and Ram Pratap et al. (2008).

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 soil microbial properties. The residual effect of 5.0 kg Zn/ha recorded significantly higher dehydrogenase activity and microbial biomass carbon as compared to control and 2.5 kg Zn/ha. Growth parameters of pearl millet namely plant height, dry matter accumulation, total number of tillers and rooting characteristics were also influenced significantly with zinc treatments applied to preceding chickpea crop.

Application of 5.0 kg Zn/ha to chickpea crop significantly enhanced the plant height, dry matter accumulation per plant, total number of tillers per metre row length, root length, root volume and root dry weight by 3.4, 7.5, 5.9, 7.8, 7.5 and 7.4%, respectively, over control and was found to be statistically similar with 2.5 kg Zn/ha.

Yield attributes and yield of pearl millet were also influenced significantly by residual effect of zinc fortification.

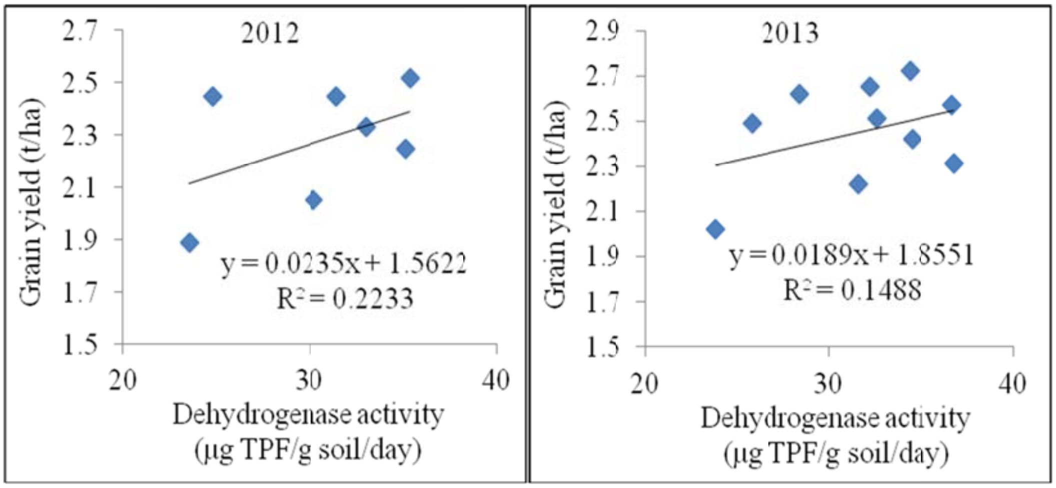

Figure 3. Correlation between pearl millet yield (y-axis) and dehydrogenase activity(x-axis) under moisture management and zinc fortification.

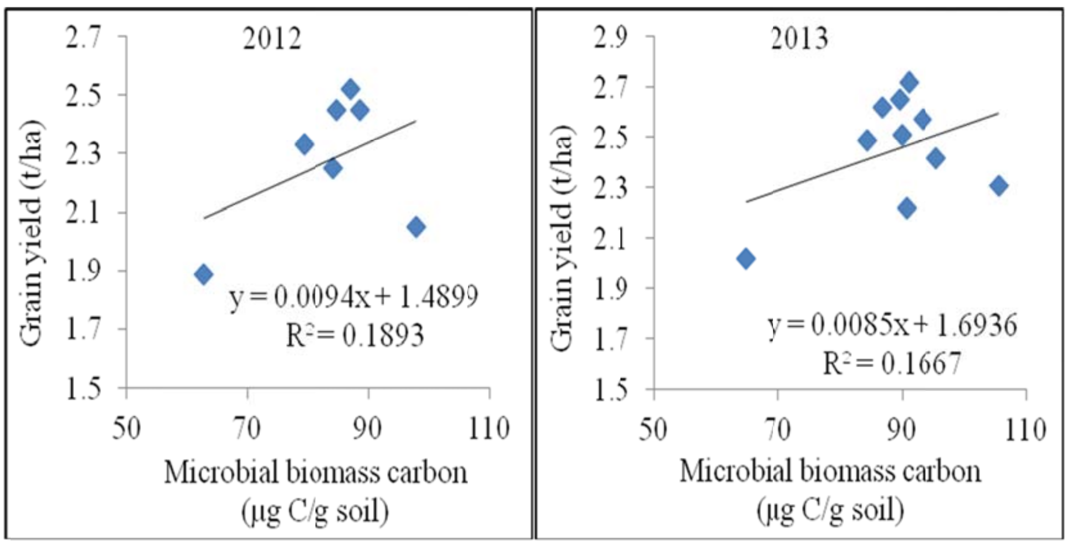

Figure 4. Correlation between pearl millet yield (y-axis) and microbial biomass carbon (x-axis) under moisture management and zinc fortification.

Wherein, application of 5.0 kg Zn/ha remained at par with 2.5 kg Zn/ha and produced significantly higher number of earheads per metre row length (14.2), length of earhead (30.0 cm) and grain weight per earhead (18.94 g) over control. Residual effect of 5.0 kg Zn/ha recorded significantly better grain (2.57 t/ha), stover (8.22 t/ha) and biological yield (10.78 t/ha), which were 11.3, 8.2 and 8.8% higher than the control. The application of zinc to chickpea crop improved the soil status of DTPA extractable zinc in the soil and increased supply and uptake by the succeeding pearl millet crop resulting in improvement in growth parameters and yield attributes. Thus, positive impact on these characters led to significant improvement in yield of succeeding pearl millet. Jain and Dahama (2005) and Sammauria and Yadav (2008) has also reported similar results with regard to residual effect of zinc.

Correlation studies

Regression analysis between yield and soil microbial properties of pearl millet showed positive but non-significant correlation (Figures 3 and 4). Whereas, regression analysis between yield and major yield attributes of pearl millet showed highly significant and positive correlation of pearl millet yield with number of earheads per metre row length, length of earhead and grain weight per earhead during both years of study (Figures 5 to 7).

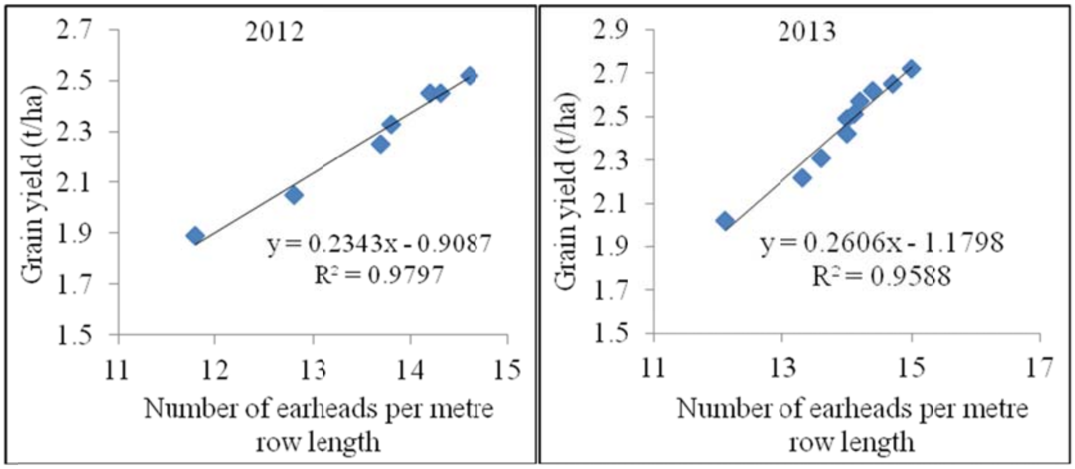

Figure 5. Correlation between pearl millet yield (y-axis) and number of earheads per metre row length (x-axis) under moisture management and zinc fortification.

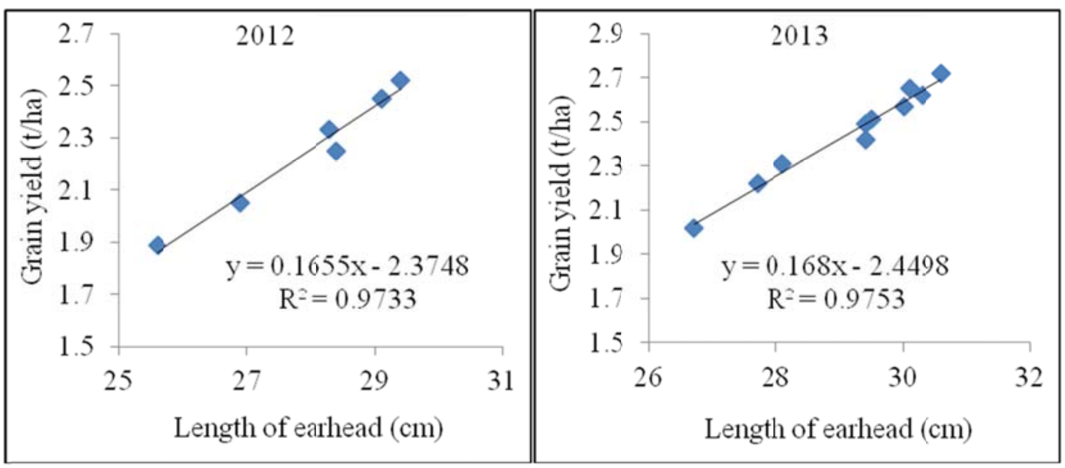

Figure 6. Correlation between pearl millet yield (y-axis) and length of earhead (x-axis) under moisture management and zinc fortification.

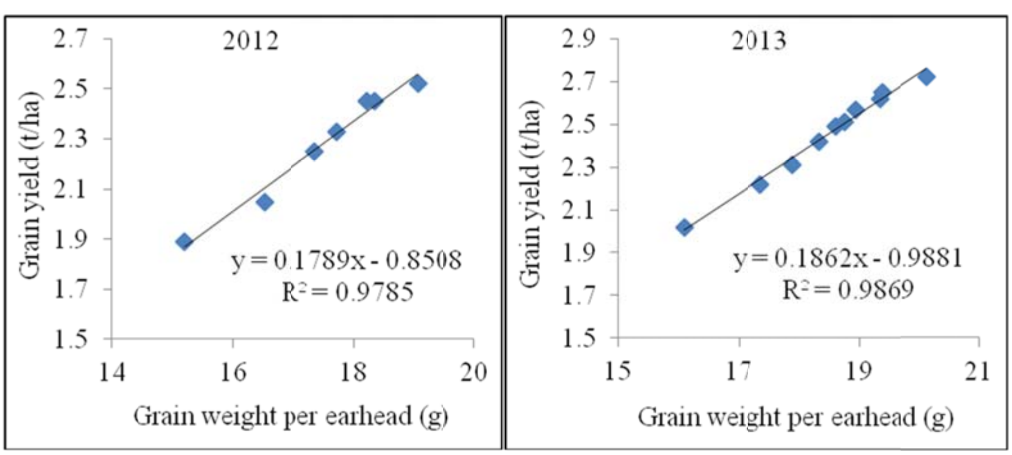

Figure 7. Correlation between pearl millet yield (y-axis) and grain weight per earhead (x-axis) under moisture management and zinc fortification.

Conflict of Interests

The authors have not declared any conflict of interests.

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