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AGRONOMY

Zinc biofortification and agronomic indices of pearl millet under semi-arid region

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ABSTRACT

Zinc deficiency is a global challenge and improving the grain Zn concentration of cereal crops is a high-priority research area. An investigation was conducted in 2011-12 to study the effects of nitrogen (N) and zinc (Zn) fertilizer on zinc biofortification in pearl millet. The experiment was laid out in a randomized block design (factorial), with four nitrogen rates (0, 20, 40 and 60 kg N/ha) and three rates of zinc (0, 5 and 10 kg Zn/ha) with three replication. The grain yield significantly increased 47.65% from 0 to 60 kg N/ha and 31.47 % from 0 to 10 kg Zn/ha. Nitrogen and zinc significantly interact and recorded highest zinc content (26.1 mg/kg) with 20 kg N with 5 kg Zn/ha. The agronomic efficiency, partial factor productivity and apparent recovery efficiency (nitrogen and zinc) diminished as nitrogen and zinc rates increased. An interaction was recorded with nitrogen and zinc fertilizer for partial factor productivity (nitrogen) with 20 kg N with 10 kg Zn/ha and for apparent recovery efficiency (Zn) with 20 kg N with 5 kg Zn/ha.

Highlights

- Pearl millet responded with nitrogen and zinc fertilizer and the grain yield significantly increased 47.65% from 0 to 60 kg N/ha and 31.47 % from 0 to 10 kg Zn/ha.
- Nitrogen and zinc fertilizer significantly interact and recorded higher zinc content in pearl millet grain at 20 kg N with 5 kg Zn/ha.

Keywords: Agronomic indices, biofortification, fertifortification, nitrogen x zinc interaction.

The arid and semi arid region covers more than 6.09 billion ha and supports the livelihood of 35% world population (van Ginkel *et al.*, 2013). In India, the arid and semi-arid area occupied more than 60% of the cultivated area and produced around 40% of the food (Gulati and Kelley 2000). The main features of these climatic regions are a short rainy season, intensive rainfall interspersed with unpredictable droughts, low soil fertility, poor and saline soils and lack of assured sources of irrigation. These harsh and fragile ecosystems have limited choice of cropping. Pearl millet is well adapted and widely cultivated staple cereal for majority of the poor smallholders and consumers (Nagaraj *et al.*, 2012) of semi arid region. It ranks first under the category of millets in India, in terms of area, production and productivity and contributing 8.89% to total production of coarse cereals (NRAA, 2012). Pearl millet also provide nutritional security as it has higher protein content (10.6%), more balanced amino acid profile, and contribute about one third of iron and zinc requirements (Manga and Kumar, 2011).

Intense temperature and low organic matter content in semi arid region leads to poor soil fertility (Rego *et al.*, 2003) and low nitrogen status. The deficient nutrient status decreases the availability of nutrient in food grain and ultimately reduces availability nutrient rich food to rural people. The reduce availability of nutrient in grain particularly micronutrient leads to increase micronutrient malnutrition. There are several approaches adopted to eliminate micronutrient malnutrition. The fertifortification of Zn is a promising and cost-effective measure to increase Zn concentration (agronomic biofortification) in cereal grain to address Zn malnutrition (Rakshit *et al.*, 2013; Singh and Prasad, 2014). Application of nitrogen fertilizer positively affect Zn concentrations in wheat grain and also reported that change in mineral status of soil which will affect the nutrient concentration of plant (Germ *et al.*, 2013). Nitrogen fertilization along with Zn not only increases the yield but also enhance zinc content in grain in pearl millet (Prasad *et al.*, 2014). Viewing the above circumstances, the study was conducted in order to examine the nitrogen and zinc fertilization on yield, zinc content and also to assess the nitrogen and zinc efficiencies in pearl millet under semi-arid region.

Material and Methods

The experiment was carried out during *kharif* season of 2011-12 at the Agronomy farm of Rajiv Gandhi South Campus (Banaras Hindu University), Barkachha, Mirzapur which is situated in Vindhyan region of district Mirzapur (25º 10'N, 82º 37'E, 427 m asl), India. The soil of the experimental site was sandy clay loam (Typic Ustochrept) (57.61, 19.39, 23.50% of sand, silt, clay, respectively), organic carbon (0.24%), pH (6.04), available N, P, K 179.45, 10.89, 190.40 kg/ha, respectively and DTPA available Zn 4.74 mg/kg. The pearl millet cultivar 'Kaveri Super Boss' was sown with 45 x 15 cm spacing on 20.08.2011. The experiment was laid out in randomized complete block design (factorial) with three replications. The

Table 1. Effect of nitrogen and zinc levels on yield, zinc content and uptake in grain and agronomic indices on pearl millet

Treatments	Grain			Indices					
				Nitrogen			Zinc		
	Yield (Kg/ha)	Zn content (mg/kg)	Zn uptake (Kg/ha)	AE (kg/kg)	PFP (kg/kg)	ARE (%)	AE (kg/kg)	PFP (kg/kg)	ARE (%)
Nitrogen levels (kg ha^{-1})									
0	1428.76	11.82	1.73	00.00	00.00	00.0	36.86	155.00	21.00
20	1760.77	15.78	2.67	16.60	88.00	64.3	26.56	182.00	20.20
40	1966.32	16.60	3.46	12.70	49.20	48.3	54.18	411.00	28.20
60	2109.70	17.81	3.80	11.30	35.20	42.5	29.35	217.00	23.50
Zinc levels(kg ha^{-1})									
0	1551.30	13.57	2.23	10.10	37.20	35.2	00.00	00.00	00.00
5	1858.28	16..34	3.02	7.43	43.30	37.3	61.39	519.00	36.40
10	2039.59	16.59	3.50	13.00	48.70	43.8	48.83	204.00	33.20
Significance									
Nitrogen	149.93	1.81	0.38	4.48	3.70	24.70	NS	NS	NS
Zinc	129.84	1.57	0.33	3.88	3.20	NS	26.12	256.06	14.00
NxZn	ns	**	**	ns	**	ns	ns	ns	**

** Significant at 0.05 level
ns: not significant

plots were fertilized with four nitrogen rates: 0, 20, 40 and 60 kg N/ha and three zinc rates: 0, 5 and 10 kg Zn/ ha with uniform application of phosphorus and potassium at the rate of 40 and 30 kg/ha, respectively. Crop was grown as per standard agronomic package of practices. Plants were sampled near physiological maturity to determine the maximum Zn content in grain. Zn content in grain was determined by AAS after ashing samples at 550°C and dissolving ash in 3.3% HCL. Zn uptake was calculated by multiplication of zinc content with grain yield. The crop from each plot was harvested separately, threshed and winnowed and grain yield was recorded and converted to kg/ ha. The observations recorded were subjected to statistical analysis as per procedure of Gomez and Gomez (1984). Differences among means and treatments were compared by the least significant differences (LSD) at $P<0.05$. Nutrient use efficiency was determined by calculating agronomic indices viz. agronomic efficiency; partial factor productivity and apparent recovery efficiency, as per the formula suggested by Dobermann (2007).

Table 2. Integrated effect of nitrogen and zinc levels on zinc content and uptake in pearl millet grain.

Treat-ments	Zinc content (mg/kg)				Zinc uptake (kg/ha)			
	Nitrogen levels (kg/ ha)				Nitrogen levels (kg/ ha)			
	0	20	40	60	0	20	40	60
Zinc levels (kg/ ha)								
0	8.6	17.3	11.3	17.1	1.03	2.68	2.01	3.21
5	11.8	26.1	13.2	14.3	1.82	4.53	2.77	2.95
10	15.0	4.0	25.3	22.1	2.35	0.81	5.60	5.25
LSD (0.05) of NxZn	2.27				0.58			

Nutrient Use Efficiency

Agronomic efficiency (AE):

$$AE = \frac{G_f - G_u}{N_a} = kg/kg$$

Where G_f is the grain yield in the fertilized plot (kg), G_u is the grain yield in the unfertilized plot (kg), and N_a is the quantity of nutrient applied (kg).

Partial factor productivity(PFP):

$$PEP = \frac{G_f}{N_a} = kg/kg$$

Where G_f is the grain yield in the fertilized plot (kg) and N_a is the quantity of nutrient applied (kg).

Apparent recovery efficiency (ARE):

$$ARE = \frac{Nf - Nu}{N_a} x100 = \%$$

Where, Nf is the nutrient accumulation by the total biological yield (straw plus grain) in the fertilized plot (kg), Nu is the nutrient accumulation by the total biological yield (straw plus grain) in the unfertilized plot (kg), and Na is the quantity of nutrient applied (kg).

Table 3. Integrated effect of nitrogen and zinc levels on partial factor productivity of nitrogen and apparent recovery efficiency of zinc

Treat-ments	Partial factor productivity (kg/kg)				Apparent recovery efficiency (%)			
	Nitrogen levels (kg/ ha)				Nitrogen levels (kg/ ha)			
	0	20	40	60	0	20	40	60
Zinc levels (kg/ ha)								
0	00.00	77.70	39.84	31.27	00.00	00.00	0.00	0.00
5	00.00	86.60	52.53	34.26	38.60	55.00	35.79	16.10
10	00.00	99.80	55.10	39.94	24.40	5.43	48.76	54.38
LSD (0.05) of NxZn	5.54				24.3			

Results and Discussion

Pearl millet showed a significant response to fertilizer N and Zn. Nitrogen and zinc fertilizer rate with 60 kg N/ha and 10 kg Zn/ha recorded maximum grain yield (Table 1). The grain yield was increased up to 47.65% from 0 to 60 kg N ha^{-1} and 31.47% from 0 to 10 kg Zn/ha. Pearl millet grain yield increased linearly with increased N rates (Maman *et al.*, 2006). Increasing the N supply increased the grain yield progressively due to positive effect of Zn in development of reproductive organs of pearl millet.

Zn content in grain was significantly varied with nitrogen and zinc rates and recorded maximum with 60 kg N/ha and 10 kg Zn/ha. However, nitrogen and zinc rate interact at 20 kg N/ha x 5 kg Zn/ha and recorded maximum zinc content (Table 2). The optimum availability of nitrogen and zinc at rhizosphere might be increased its content in grain. The positive effect of increasing N supply on the Zn concentration in the grain was due increasing plant growth and changing pH around the root zone (Shafea and Saffari, 2011) and also positively affected root uptake, shoot translocation and grain deposition of Zn (Cakmak, 2012). Nitrogen and zinc levels also interact and recorded maximum zinc uptake at 40 kg N/ha with 10 kg Zn/ha. The uptake of nutrient is a function of their content and yield. The increase in seed yield along with higher Zn content might have higher zinc uptake due to uptake of nutrient is a function of their content and yield. The Zn uptake rate was almost quadrupled when the N supply was increased (Erenoglu *et al.*, 2011)

Agronomic indices of both nitrogen and zinc were significantly influenced by nitrogen and zinc levels (Table 1). Agronomic efficiency represents the ability of the plant to increase yield in response to applied fertilizer and greatly dependent on meteorological situation of the growing season. Agronomic efficiency of nitrogen (AEn) decreases with increasing nitrogen levels. The maximum AEn recorded with 20 kg N/ha which was 30.70 and 31.92 per cent higher than 40 and 60 kg N/ha, respectively. The decrease in AEn with increased nitrogen levels might be due to proportionate less increase in grain production in respect to nitrogen rate. The increase of N loss by volatilization, and denitrification might be reduced in AEn (Hirel *et al.*, 2007). Partial factor productivity of nitrogen (PFPn) is an aggregate efficiency index that includes uptake of both indigenous and applied nutrients and the efficiency with which nutrient acquired by the plant is converted to grain yield (Dobermann, 2007). Maximum PFPn was recorded with 20 kg N/ha and was 78.86 to 150 per cent higher than 40 and 60 kg N/ha, respectively. PFPn showed significant interaction with nitrogen and zinc and recorded maximum at 20 kg N/ha and 10 kg Zn/ha (Table 3). This was might be due to zinc exerts a great influence on nitrogen metabolism and photosynthesis. Apparent recovery efficiency of nitrogen (AREn) was significant with nitrogen level but it was non-significant with zinc levels. Maximum AREn was recorded with 20 kg N/ha then decline with increasing nitrogen levels. The increment of AREn with 20 kg N/ha was 33.12 and 51.29 per cent higher than 40 and 60 kg N/ha, respectively.

Zinc levels showed significant influence on agronomic efficiency of zinc (AEzn), partial factor productivity of zinc (PFPzn) and apparent recovery efficiency of zinc (AREzn). AEzn, PFPzn and AREzn were showed decline trend with increasing zinc levels. The decrease in zinc use efficiency with increase in Zn rates was also due to progressive decline in grain yield or dry matter production at higher levels of Zn applied. Similar result was reported by (Muthukumararaja and Sriramachandrasekharan 2012). The AEzn and PFPzn was recorded 25.72 and 154.41 per cent higher with 5 kg Zn/ha than 10 kg Zn/ha. Nitrogen levels have no significant effect on AREzn although; they were significantly interacting with zinc levels (Table 3). The maximum AREzn (55.0 %) was recorded with 20 kg N with 5 kg Zn/ha. The interaction of nitrogen and zinc for AREzn might be due to Zn application increased N uptake and biomass yield.

Improving production the quality foods particularly zinc enriched cereals (pearl millet) in semi arid region to reduce mineral malnutrition and health problem is a fundamental challenge. On the basis experimental result and discussion it can be concluded that 60 kg N/ha and 10 kg Zn/ha was suitable and optimum for increasing yield, zinc uptake and content of zinc (biofortification) in pearl millet grain under semi arid region. The result indicated that the cultivation of pearl millet with nitrogen and zinc application not only increases food security but also improve the nutrition security of rural people. However, further more such investigation need to be conducted by applying adequate and suitable combination of nitrogen and zinc fertilizer for enhancing zinc content in pearl millet which enhance the food and nutritional security of rural people of semi arid.

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