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ASSESSMENT OF AGRONOMIC ZINC BIOFORTIFICATION OF ALLEY CROPPED PEARL MILLET

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Abstract

The availability of nitrogen (N) and zinc (Zn) at the specific plant growth stage is crucial for attaining the higher nutrient use efficiency (NUE) and uptake. An experiment was conducted, having 4-N scheduling [No N; ½[basal]+ ½[3rd visible leaf (VL)]; ¼[basal]+ ½[3rdVL]+ ¼[panicle extended in flag leaf sheath (PEFLS)]; ½[basal] + ¼[3rdVL]+ ¼[panicle visible (PV)], and 4-Zn scheduling [No Zn; 2.5 kg/ha [basal]+ 0.25% spray(*) [panicle initiation (PI)]; 2.5 kg/ha [basal]+0.25% [PI]*+ 0.25% [PEFLS]*; 2.5 kg/ha [basal]+ 0.25% [50% panicle emergence (PE)]*+ 0.25% [milk stage (MS)]*. Nitrogen schedule at ¼[basal]+ ½[3rdVL]+ ¼[PEFLS] recorded the maximum nutrient content, uptake, and NUE. Similarly, the maximum nutrient content, uptake, and nutrient use efficiency observed in the Zn at 2.5 kg/ha [basal]+0.25% [PI]*+ 0.25% [PEFLS]*. Moreover, N and Zn interacted significantly to increase the grain N and Zn content and uptake by grain.

Introduction

Pearl millet is staple cereal of semi-arid region, characterised by intense temperature and low nitrogen and zinc status. (Prasad *et al.* 2015). In such adverse environmental situation, nutrient management play crucial role not only for enhancing pear millet productivity but also efficient use of applied nutrient. Basically, nutrient use efficiency (NUE) is used to measure the efficiency of applied fertilizer (Cassman *et al.* 2002) and also to compare nutrient use efficiency in different environments under different management practices. However, the excess and deficient application of mineral nutrient not only affects nutrient use efficiency but also alter the nutrient concentration in grain.

Nitrogen and zinc an essential macro and micro nutrient, respectively and known to produce synergistic effect on growth, yield, and nutrient content of the pearl millet (Prasad *et al.* 2014). N plays an indispensable role in the synthesis of chlorophyll, protoplasm, vitamins, as well as amino acids synthesis, a building blocks of protein (Bauer *et al.* 2012). Zn is the fourth most crucial yield-limiting nutrient after N, phosphorus, and potassium (Khinchi *et al.* 2017). Zinc deficiency in the plant not only retard the development and maturation of the panicles but also significantly reduces the quality of the produce (Prasad *et al.* 2014). Moreover, nitrogen required in largest quantity for growth and development but excess application leads to low nitrogen use efficiency. At same time deficient soil zinc and low application leads to deficient zinc content in grain. Thus, for enhancing zinc content in grain, agronomic zinc biofortification is most suitable and low cost approach for enhancing zinc content in grain (Singh and Prasad 2014). A very confined study was made to the effect of N and Zn scheduling on Zn biofortification and NUE in pearl millet, but such response was widely studied in wheat (Layek *et al.* 2017, Meena *et al.* 2017) and rice (Meena

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et al. 2018). With the above given facts, an experiment was carried out to assess the agronomic zinc biofortification, nitrogen and zinc use efficiency under variable nitrogen and zinc scheduling of alley cropped pearl millet in semi-arid condition of Vindhyan region.

Materials and Methods

The field experiment was conducted at the Agriculture farm of Rajiv Gandhi South Campus-Banaras Hindu University (25º03'N, 82º35'E, 169 m above msl), Barkachha, Mirzapur, Uttar Pradesh, India during the *Rainy season* (*Kharif*) of 2017. The climate of the experiment site was typically semi-arid with weekly mean maximum and minimum temperature, ranges from 28.9 - 33.11^{0}C and 20.4 - 29.0^{0}C, respectively. The total rainfall received during the crop growing period was 455.6 mm, of which about 93% was received during the first four weeks of the crop establishment. The soil of experimental site was sandy clay loam (Order Inceptisol; Typic Ustochrept) having coarse sand 10.34%, fine sand 48.31%, silt 19.40%, and clay 21.95%. Additionally, the experiment soil has slightly acidic pH (5.9), low in the organic carbon (0.37 %), N (185.60 kg/ha) and Zn (0.40 ppm), while medium in available P (12.15 kg/ha) and K contents (187.26 kg/ha).

Pearl millet, was sown in the alleys of ten-year old custard apple (*Annonas quamosa* L.) orchard planted at 5 × 5 m distance. The experiment was laid out on 1st August 2017, in randomized complete block design (factorial), having 4-levels of nitrogen scheduling and 4-levels of zinc scheduling and replicated thrice (Table 1). In the plot size of 3.6 × 3.0 m, pearl millet (variety: Kaveri Super Boss) was sown manually in the opened furrow at a spacing 45 × 15 cm, having seed rate of 5 kg/ha. The recommended rate of phosphorus (40 kg/ha) and potassium (40 kg/ha) was applied basally at the time of sowing in the form of the single super phosphate and muriate of potash, respectively. For scheduling of N, the recommended dose of N i.e., 60 kg/ha was scheduled as per the treatment, in the form of urea. Likewise, Zn application was scheduled as per the treatment in the form of zinc (Zn). The crop was harvested on 20th October 2017.

Table 1. Details of treatments.

Treatments
Scheduling of Nitrogen (N)†
No N-application (control)
½ [basal] + ½[3rdVL]
¼ [basal] + ½ [3rdVL] + ¼ [PEFLS]
½ [basal] + ¼ [3rdVL] + ¼ [PV]
Zinc Scheduling (Zn)
No Zn-application (control)
2.5 kg/ha [basal] + 0.25% [PI]*
2.5 kg/ha [basal] +0.25%[PI]*+0.25%[PEFLS]*
2.5 kg/ha [basal] +0.25%[PE]* + 0.25% [MS]*

*= Zn foliar spray, †= Recommended dose of nitrogen (60 kg/ha), MS= Milk stage, PEFLS= Panicle extended in flag leaf sheath, PI=Panicle initiation, PE=50% Panicle emergence, PV = Panicle visible, VL= Visible leaf.

At physiological maturity, the grains harvested oven-dried, grinded in Wiley mill, and passed through a 30 mesh sieve for N and Zn content determination as per the procedure described by the modified Kjeldhal method (Jackson 1958) and Atomic Absorption Spectrophotometer (AAS) method (Jorhem 1993), respectively. N and Zn uptake estimated by multiplication of content with grain yield. The nutrient use efficiency *viz.*, partial factor productivity (PFP), agronomic efficiency (AE), crop recovery efficiency (CRE), and physiological efficiency (PE) of applied N and Zn was calculated as per the formula given by Dobermann (2005).

Data collected on the pearl millet were analyzed as per the standard procedure described by Gomez and Gomez (1984) to draw a valid conclusion. The significance of the treatment effect was judged with the help of 'F' test, and the treatments mean differences tested using critical difference at a 5 per cent level of probability.

Results and Discussion

Scheduling of nitrogen significantly influenced N and Zn content, uptake and agronomical indices of N and Zn. The maximum N and Zn content, uptake (Table 2) and agronomical indices of N and Zn was N scheduled at ¼ [basal] + ½ [3rd visible leaf (VL)] + ¼ [panicle extended in flag leaf sheath (PEFLS)]. Although, beyond PEFLS again decreased, but still more than ½ [basal] +½ [3rd VL]. Additionally, the N scheduling causes the continuous supply of the N, increases the synchrony between demand and supply of N (Tilman *et al.* 2002) in association with more efficient mobilization of N to the grain at the grain filling stage (Belete *et al.* 2018). This proposition is in consistent with the observation of Belete *et al.* (2018) reported higher N uptake in wheat grain when N applied as ¼ sowing + ½ tillering + ¼ booting.

Moreover, N scheduling leads decreased N losses and efficient utilization by the crop. Kara (2010) reported late-season N application effective in attaining higher N recovery and use efficiency in wheat, but in the present study only up to the PEFLS stage. Also, the nitrogen use efficiency indices except for AE_N range within the common value was specified by Dobermann (2005). AE_N more than common value recorded in ¼ [basal] + ½ [3rdVL] + ¼ [PEFLS], characterize this scheduled as a well-managed system. Higher NUE in present experiment signifies an efficiently managed system, since a similar rate of the N applied. Moreover, as compared to previous studies (Prasad *et al.* 2014) for the variable nitrogen rate, the present investigation revealed that even with similar N rate, higher N and Zn agronomic indices can be achieved by N scheduling at different growth and development stages. Moreover, the maximum N content in grain, and physiological efficiency (PE_N) recorded in ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS]. Although, except for the no-N application, the scheduling found at par result for the N content in grain, and PE_N. Similarly, Layek *et al.* (2017) also recorded at par impact of the N scheduling except the no-N application on grain N content in wheat.

Furthermore, Zn scheduling recorded the synergetic effect on N and Zn content and uptake, while maximum was observed in 2.5 kg/ha [basal] +0.25% spray (*) [PI] + 0.25% [PEFLS]* (Table 2). As, Zn has initial rapid binding in the root cell walls, but the slower linear transport phase (Hawkesford and Barraclough 2011). Therefore, Zn applied during the PEFLS has enough time to reach the sink (grain) to increase nutrient content, and uptake. Contrary to previous studies on wheat (Xi-Wen *et al.* 2011), where the application of Zn foliar spray during the milk and dough stage increase the Zn concentration.

Likewise, the maximum NUE indices recorded in 2.5 kg/ha[basal] +0.25% [PE]* + 0.25% [MS]* (Table 3). Although, the Zn scheduling recorded to have a variable effect on the NUE_{Zn} indices. The maximum partial factor productivity (PFP_{Zn}) recorded in the Zn at 2.5 kg/ha[basal] + 0.25[PI]* might be due to the two splits of the Zn as compared to the three splits where one extra

Table 2. Integrated effect of nitrogen × zinc scheduling on N and Zn content and uptake of pear millet grain under agri-horti system.

Zn Scheduling (Zn)	Scheduling of nitrogen (N)†				
	No-N (control)	½ [basal] +½ [3rd VL]	¼ [basal] + ½ [3rd VL] + ¼ [PEFLS]	½ [basal] + ¼ [3rd VL] + ¼ [PV]	Mean
			Nitrogen content (%) in grain		
No Zn-application (control)	1.05	1.42	1.34	1.63	1.36
2.5 Zn kg/ha [basal] + 0.25%[PI]*	1.13	1.62	1.96	1.64	1.59
2.5 Zn kg/ha [basal] + 0.25%[PI]*+0.25%[PEFLS]*	1.56	1.84	1.82	1.83	1.76
2.5 Zn kg/ha [basal] + 0.25%[PE]* + 0.25% [MS]*	1.53	1.51	1.57	1.54	1.54
Mean	1.32	1.60	1.67	1.66	
CD (P=0.05) of N & Zn			0.14		
CD (P=0.05) of N × Zn			0.28		
			Nitrogen uptake by grain (kg/ha)		
No Zn-application (control)	12.66	18.50	22.09	29.52	20.69
2.5 Zn kg/ha [basal] + 0.25%[PI]*	13.88	28.37	45.47	34.01	30.43
2.5 Zn kg/ha [basal] + 0.25%[PI]*+0.25%[PEFLS]*	26.8	35.82	46.61	36.63	36.49
2.5 Zn kg/ha [basal] + 0.25%[PE]* + 0.25% [MS]*	12.66	18.50	22.09	29.52	30.39
Mean	18.23	28.57	38.00	33.20	
CD (P=0.05) of N & Zn			3.09		
CD (P=0.05) of N × Zn			6.19		
			Zinc content (mg/kg) in grain		
No Zn-application (control)	5.09	14.25	12.65	14.50	11.62
2.5 Zn kg/ha [basal] + 0.25%[PI]*	7.23	15.12	17.23	16.77	14.09
2.5 Zn kg ha^{-1} [basal] + 0.25%[PI]*+0.25%[PEFLS]*	15.4d	16.84	24.60	18.14	18.75
2.5 Zn kg ha^{-1} [basal] + 0.25%[PE]* + 0.25% [MS]*	13.70	14.35	18.03	15.70	15.45
Mean	10.35	15.14	18.13	16.28	
CD (P=0.05) of N & Zn			1.20		
CD (P=0.05) of N × Zn			2.4		
		Zinc uptake by grain (g/ha)			
No Zn-application (control)	6.22	18.47	21.54	26.32	18.14
2.5 Zn kg/ha [basal] + 0.25%[PI]*	8.85	26.57	39.88	34.73	27.51
2.5 Zn kg/ha [basal] + 0.25%[PI]*+0.25%[PEFLS]*	26.75	32.72	62.87	36.28b	39.65
2.5 Zn kg/ha [basal] + 0.25%[PE]* + 0.25% [MS]*	17.39	30.11	43.41	33.31	31.05
Mean	14.80	26.97	41.93	32.66b	
CD (P=0.05) of N & Zn			3.58		
CD (P=0.05) of N × Zn			7.17		

*= Zn foliar spray, †= Recommended dose of nitrogen (60 kg/ha), MS= Milk stage, PEFLS= Panicle extended in flag leaf sheath, PI=Panicle initiation, PE=50% Panicleemergence, PV= Paniclevisible, VL= Visible leaf.

Tables 3. Nutrient use efficiency of applied N (NUE_N) and Zn (NUE_{Zn}) under nitrogen and zinc scheduling in pearl millet.

Treatments	Partial factor productivity (PFP) (kg/kg)		Agronomic efficiency (AE) (kg/kg)		Crop recovery efficiency (CRE)		Physiological efficiency (PE)	
	N (PFP_N)	Zn (PFP_{Zn})	N (AE_N)	Zn (AE_{Zn})	N (CRE_N) (kg/kg)	Zn (CRE_{Zn}) (g/kg)	N (PE_N) (kg/kg)	Zn (PE_{Zn}) (kg/g)
Scheduling of Nitrogen (N) †								
No N-application (control)	0.00	308.43	0.00	42.28	0.00	2.18	0.00	8.24
½ [basal] + ½[3rdVL]	29.55	423.40	6.89	137.72	0.28	4.90	22.45	23.94
¼ [basal] + ½ [3rdVL] + ¼ [PEFLS]	37.45	533.69	14.79	158.64	0.56	5.20	26.64	33.35
½ [basal] + ¼ [3rdVL] + ¼ [PV]	33.37	455.21	10.71	56.08	0.47	3.21	24.36	15.55
CD (P = 0.05)	2.64	43.48	3.09	55.09	0.08	1.64	9.23	16.52
Zinc Scheduling (Zn)								
No Zn-application (control)	20.04	0.00	4.94	0.00	0.20	0.00	16.33	0.00
2.5 Zn kg/ha [basal] + 0.25% [PI]*	25.59	602.74	10.28	110.26	0.34	3.44	23.64	23.70
2.5 Zn kg/ha [basal] + 0.25%[PI]*+0.25% [PEFLS]*	27.15	571.45	5.46	154.68	0.38	6.96	9.59	28.01
2.5 Zn kg/ha [basal] + 0.25% [PE]* + 0.25% [MS]*	27.59	546.54	11.70	129.78	0.39	5.09	23.89	29.37
CD (P = 0.05)	2.64	43.48	3.09	55.09	0.08	1.64	9.23	16.52

*= Zn foliar spray, †= Recommended dose of nitrogen, 60 kg/ha, MS= Milk stage, PEFLS= Panicle extended in flag leaf sheath, PI=Panicle initiation, PE=50% Panicle emergence, PV= Panicle visible, VL= Visible leaf, NS= Non significant, S = significant.

0.25 % Zn spray was applied and increases the total Zn applied. The maximum agronomic and crop recovery efficiency (AE_{Zn} and CRE_{Zn}) recorded in 2.5 kg/ha[basal] +0.25% [PI]*+ 0.25%[PEFLS]*, while the physiological efficiency (PE_{Zn}) in 2.5 kg/ha[basal] +0.25% [PE]* + 0.25% [MS]*. Present results (except PE_{Zn}) follow the finding of Layek *et al.* (2017), who suggested that in wheat PFP_{Zn}, AE_{Zn}, $CRE_{Zn,}$ and PE_{Zn} decreased as the Zn spray delayed. Moreover, our study recorded the maximum N and Zn use efficiency on Zn scheduling as compared to simply applying the different rate of the Zn (Prasad *et al.* 2015).

N and Zn scheduling significantly interacted to increase the N and Zn content and uptake positively (Table 2). The maximum N content in grain recorded in ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS] × 2.5 kg/ha [basal] + 0.25[PI]* while maximum N uptake, Zn content and uptake by grain recorded at ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS] × 2.5 kg/ha [basal] + 0.25% [PI]*+ 0.25% [PEFLS]*. Specifically, in a particular N schedule, the grain N and Zn content and uptake firstly increase from no-Zn application and attains maximum at 2.5 kg/ha [basal] + 0.25% [PI]*+ 0.25% [PEFLS]* and thereafter decreases. However, in the absence of Zn application, the maximum grain N and Zn content and uptake recorded in the ½ [basal] + ¼ [3rd VL] + ¼ [PV]. Contrary, in the absence of N, the maximum N and Zn content and uptake recorded in the 2.5 kg/ha [basal] + 0.25% [PI]*+ 0.25% [PEFLS]*. As, N and Zn have positive interaction (Kumar *et al.*1985), also Zn leads to a higher rate of the N accumulation (Grzebisz *et al.* 2008).

It may be concluded that there are new opportunities for managing the N and Zn fertilizers more judiciously and efficiently in pearl millet to increase the sustainability and livelihood of the farmers, especially in semi-arid regions. Three split of N (¼ [basal] + ½ [3rd VL] + ¼ [PEFLS]) has a positive influence on nutrient content, and uptake, NUE and ZnUE. Although, the application of the last split beyond the PEFLS stage again decreased the nutrient content, and use efficiency. Application of Zn at 2.5 kg/ha[basal] +0.25% [PI]*+ 0.25% [PEFLS]* is effective in maximizing the agronomic and crop recovery efficiency of Zn as well increased the Zn content and uptake. In contrast, maximum NUE, and physiological efficiency of Zn were found to be maximum in three Zn split and last two splits during 0.25% [PE]* + 0.25% [MS]*.

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