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Research Communication

Response of alley-cropped pearl millet (*Pennisetum glaucum*) to nitrogen and zinc schedules under semi-arid regions

KAMLESH VERMA[1], S.K. PRASAD[2], M.K. SINGH[3] AND PRASHANT SHARMA[4]

Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh 221 005

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ABSTRACT

Realizing the importance of tree-based cropping system and scheduling of nitrogen (N) and zinc (Zn) in the semi-arid region, an on-field trial was conducted with pearl millet [*Pennisetum glaucum* (L.) R. Br.] during the rainy season of 2017 at RGS Campus of Banaras Hindu University, Mirzapur, Uttar Pradesh. The trial was laid out in factorial randomized block design with 4 N and 4 Zn treatment applications in different schedules. The results revealed that, N scheduled at ¼ [basal] + ½ (3rd visible leaf (VL) + ¼ panicle extended in flag-leaf sheath (PEFLS) produced the most synergetic effect on growth and yield of pearl millet. The grain yield increased up to 65% compared to no N application. Conversely, Zn schedules did not significantly influence the growth parameters (except dry-matter), while Zn application at 2.5 kg/ha (basal) + 0.25% panicle initiation (PI) + 0.25% PEFLS recorded about 37% more grain yield, than no Zn application. Additionally, the maximum biological and straw yields recorded with 2.5 kg/ha (basal) + 0.25% panicle emergence (PE) + 0.25% milk stage (MS) Zn application compared to the other treatments. Moreover, N and Zn interacted significantly to produce synergetic effect on the dry-matter, test weight, grain, straw, and biological yields. The maximum grain yield was observed with conjunctive application of N at ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS] and Zn at 2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS], whereas the maximum biological and straw yields were recorded with application of the N at ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS] and Zn at 2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS].

***Key words*:** Alley cropping, N fertilizer, Pearl millet, Phenophase, Zn fertilizer

Pearl millet [*Pennisetum glaucam* (L.) R. Br.] is a major crop of semi-arid region, with high degree of tolerance to various abiotic (heat, drought, and salinity) and biotic stresses (pest and disease) (Pattanashetti *et al.,* 2016). Globally, pearl millet is widely cultivated as coarse cereal, and more than 90 million people depends on pearl millet for food and livelihood, in addition to its significant contribution as livestock fodder (Bamboriya *et al.,* 2017). Generally, pearl millet is grown as a monocrop; however, there is an opportunity if pearl millet is grown as alley crop with the fruit trees, especially custard apple (*Annona squamosa* L.), which is an important fruit tree of the dry region, at least during the initial year of tree establishment. The association of the woody perennial with annual crops in the semi-arid region can boost the associated crop yield, soil carbon, nutrient and water as well as improve the soil biology. Conventionally, the pearl millet is grown in nutrient-stress conditions of semi-arid region, where soils are inherently low in fertility (Bana *et al.,* 2016). Simultaneously, continuous excessive application of nitrogen (N) caused a widespread deficiency of micronutrients in pearl millet (Choudhary *et al.,* 2016), especially zinc (Zn). However, the combined application of N and Zn is known to produce the synergetic effect on the pearl millet growth and yield (Prasad *et al.,* 2014). Since the N is the building block of proteins, it has an imperative role in plant growth and optimum yield (Bana *et al.,* 2015). Similarly, Zn has a vital role in the various physiological processes, including disease resistance and it is fourth-most powerful yield-limiting nutrient, and has a definite role in enhancing the quality of produce (Prasad *et al.,* 2014).

It is well known fact that, timely application of the fertilizers maximizes the crop yield (Dar and Ram, 2016). Significant work has been done to optimize the N and Zn

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[3]**Corresponding author's Email:** manoj.agro@bhu.ac.in

[1]Ph.D. Scholar (Forestry), ICAR-Central Soil Salinity Research Institute, Karnal, Haryana 132 001; [2,3]Associate Professor, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh 221 005; [4]Assistant Professor, Department of Silviculture and Agroforestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh 173 230

application rate in the pearl millet; however, the scheduling of N and Zn did not receive appropriate attention and confined to other staple cereal crops*,* viz. rice (Meena *et al.,* 2017) or wheat (Ranva *et al.,* 2022). In the view of the above facts, the present field experiment was carried out.

The field experiment conducted at the Agriculture farm of Rajiv Gandhi Sourth Campus, Mirzapur, (25º 03'N, 82º 35'E, 169 m above mean sea-level) of the Banaras Hindu University, Uttar Pradesh, India during the rainy (*kharif*) season of 2017. The experiment site is typically semi-arid climatic condition. During the crop-growth period, the weekly mean maximum and minimum temperature varies from 28.9ºC to 33.11ºC and 20.4ºC to 29.0ºC. Total rainfall was 455.6 mm, and the average duration of bright sunshine was 3.2 hour/day, whereas the maximum and minimum relative humidity varies from 83–93 and 38–85%, respectively. However, most of the rainfall (>90%) concentrated during the first 4 weeks of the crop establishment. The soil of experiment site was sandy clay loam soil (Typic Ustochrept; Order Inceptisols) having slightly acidic *p*H (5.9), low in the organic carbon (0.37%), N (185.6 kg/ha) and Zn (0.40 ppm), whereas medium in available P (12.2 kg/ha) and K contents (187.3 kg/ha). The experiment was laid down in a 10-year-old custard apple (*Annona squamosa* L.) orchard (spacing 5 m × 5 m) on 1 August 2017, in a factorial randomized block design having 4 levels each of nitrogen, i.e. no N; ½ [basal] + ½ [3rd visible leaf (VL)]; ¼ [basal] + ½ [3rd VL] + ¼ [panicle extended in flag-leaf sheath (PEFLS)]; ½ [basal] + ¼ [3rd VL] + ¼ [panicle visible (PV)]} and zinc scheduling, i.e. no Zn; 2.5 kg/ha [basal] + 0.25% [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)], replicated thrice. The plots of 3.6 m × 3.0 m size were made between the alleys of custard apple.

Pearl millet (cultivar 'Kaveri Super Boss') was sown manually with a seed rate of 5 kg/ha, at a spacing of 45 cm × 15 cm. The recommended doses of phosphorus (P_2O_5 40 kg/ha) and potassium (K_2O: 40 kg/ha) were applied basal through diammonium phosphate and muriate of potash respectively. The recommended dose of the N (RDN) (N: 60 kg/ha) was applied in the form of urea, whereas Zn in the form of zinc sulphate ($ZnSO_4$) as per the scheduled treatments. Except at basal stage, Zn was applied as foliar spray, as per treatments. The crop was grown with recommended package of practices and 2 hand-weedings were done at 15 and 30 days after sowing to control weed infestations, while only 1 irrigation provided during the critical growth period, i.e. during the initiation of flowering. The crop was harvested on 20 October 2017. The growth parameters (plant height, tiller count, internode count, internode length, dry-matter accumulation), yield parameters (ears/plant, panicle length, 1,000-seed weight) and yield (grain, straw and biological yield) of each plot was recorded at harvesting as per the methodology suggested by Prasad *et al.* (2014).

Scheduling of recommended dose of nitrogen (RDN) at different growth and development stages of crop leads to reduced gaseous N loss, leaching, denitrification, volatilization, and runoff (Ali, 2010), thus extend the period of N availability to the crop. Therefore, in the present study, the RDN scheduling significantly affected the growth, yield attributes, and yield of the pearl millet. In fact, except for no N application, all 3 RDN scheduling produced the statistically at par results for the plant height, tiller count, internode count, internode length, ears/plant and panicle length (Table 1). It indicates that differential scheduling of N were equally good and saves N for the optimum growth and development as well as maximizing the N utilization through reducing losses of applied N (Ali, 2010) as compared to no-N application. Besides at par results, trends clearly reflect that highest plant height recorded in RDN applied at ½ [basal] + ¼ [3rd VL] + ¼ [PV], as the stem elongation continues to increase even after the flowering (Bamboriya *et al.,* 2017) and helps increase the plant height. Likewise, the maximum tiller counts recorded with RDN in 2 splits; ½ [basal] + ½ [3rd VL], as the higher N availability (½ at sowing) during the early vegetative phase helped in the build-up of vegetative growth and increasing the numbers of tillers/plant. In fact, tiller buds are formed before the panicle-development phase (Faiz *et al.,* 2022), thus N applied in the later stages has no significant impact in tillers production.

Moreover, elongation of the internode begins after panicle initiation, maximize during the flag-leaf stage, and thereafter increases slowly (Ullah *et al.,* 2020), so the application of RDN at ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS] recorded more internodal length and count as compared to ½ [basal] + ½ [3rd VL]; however, the differences were not statistically significant. Likewise, panicle rapidly increased during PEFLS, and the application of the last split N during PEFLS recorded the most significant results. Additionally, there was a progressive increase in the dry-matter accumulation; maximum dry-matter accumulation was recorded when ¼ of the RDN was applied at PV stage (Table 2). Indeed, dry-matter accumulation is a function of the leaf growth, stem elongation, and panicle. Nevertheless, the leaf growth completed by the time of the flowering; however, the stem elongation and panicle continue to increase even after the flowering (Khairwal *et al.,* 2007), thus contributes in increasing the dry-matter and straw yield of the pearl millet. Likewise, the N scheduling positively affected the grain and biological yields and maximum recorded when the last split of ½ RDN was applied at PEFLS as compared to the PV (Table 2). Actually, up to the PEFLS, the panicle development already completed, only grain dry weight increases from the milk to dough stages (Ullah *et al.,* 2020). Wu *et al.,* (2022) argued that, the application of the N after boot stage did not affect grain number but may increase individual grain weight. Contrary, in our study, even the maximum test weight also recorded in the RDN at ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS].

Simultaneously, Zn scheduling did not significantly influence the growth parameters as well as ears/plant, except the dry-matter accumulation (Tables 1 and 2). Prasad *et al.,* (2014) also reported that, Zn rates do not influence plant height; however, influence the tiller count, internode length but not the dry-matter accumulation. The maximum dry matter, straw and biological yields (Table 2) recorded in the 2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS] and this may be owing to increment of the N accumulation with Zn application (Grzebisz *et al.,* 2008). Thus, Zn spray in the later growth stages helped in increasing N accumulation and simultaneously increased the dry matter, straw, and biological yields. Apart from no Zn application, rest of-Zn scheduling treatments did not influence significantly the panicle length and test weight. Although, Zn schedules at 2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS] recorded about 20 and 16% more panicle length and test weight, respectively, than no-Zn application. Scheduling of Zn at 2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS] resulted in the maximum grain yield. This might be owing to fact that, initially Zn has rapid binding in the root cell-walls, but the slower linear transport phase (Hawkesford and Barraclough, 2011). Moreover, in pearl millet, the grain dry weight increases from the milk to dough stages (Khairwal *et al.,* 2007), therefore the Zn applied during the PEFLS has ample time to reach the sink (grain) to increase grain production. Similarly, Meena *et al.,* (2017) also reported that, application of Zn during the anthesis stage increases the grain yield of rice as compared to the later stages (MS or dough stage). Furthermore, N and Zn scheduling interacts positively and leads to progressive increase in dry-matter (Table 2). The maximum dry matter was achieved when the last split of N and Zn was applied during the PV and MS respectively. Prasad *et al.,* (2016) were also view that, N and Zn interacts positively; in fact, Zn leads to a higher rate of the N accumulation (Grzebisz *et al.,* 2008). Interaction between scheduling of N at ½ [basal] + ¼ [3rd VL] + ¼ [PV] and Zn at 2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS] revealed that, split application of N and Zn at this stage was optimum for enhancing the dry-matter accumulation. Similar trend was followed by biological and straw yield (Table 2); however, there was no progressive increase in the biological and straw was noticed with the N and Zn interaction. Application of N in 3 splits (last split either in PEFLS or PV) with Zn at 2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS] recorded the maximum

Tables 1. Nitrogen and zinc scheduling affecting growth and yield attributes of pearl millet

Treatment	Plant height (cm)	Tiller count (No./ plant)	Internode count (No./plant)	Internode length (cm)	Ears/ plant	Ear length (cm)
Scheduling of nitrogen (N) †						
No N-application	129.5 b	0.19 b	5.72 b	10.47 b	1.14 b	17.5 b
½ [basal] + ½ [3rd VL]	227.3a	0.78 a	9.81 a	15.70 a	1.61 a	23.7 a
¼ [basal] + ½ [3rd VL] + ¼ [PEFLS]	228.4 a	0.67 a	9.94 a	15.90 a	1.69 a	25.5 a
½ [basal] + ¼ [3rd VL] + ¼ [PV]	228.7 a	0.69 a	9.56 a	15.40 a	1.64 a	25.2a
SEm±	5.90	0.10	0.31	0.40	0.13	0.69
CD (P=0.05)	17.04	0.28	0.89	1.17	0.36	2.00
Scheduling of zinc (Zn)						
No Zn-application	198.5	0.39	8.03	13.79	1.33	20.3 b
2.5 kg/ha [basal] + 0.25 [PI]	200.3	0.58	9.08	14.64	1.53	23.9 a
2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS]	208.9	0.75	9.06	14.77	1.64	24.4 a
2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS]	206.3	0.61	8.86	14.26	1.58	23.3 a
SEm±	5.90	0.10	0.31	0.40	0.13	0.69
CD (P = 0.05)	NS	NS	NS	NS	NS	2.00
N × Zn	NS	NS	NS	NS	NS	NS

†= Recommended dose of nitrogen (60 kg/ha); PEFLS, panicle extended in flag-leaf sheath; PI, panicle initiation; PV, panicle visible; PE, 50% panicle emergence; MS, milk stage; VL, visible leaf; NS, non-significant Treatment means of N and Zn are compared with alphabet a and b; Treatment showing similar alphabet are statistically at par

Table 2. Effect of nitrogen and zinc scheduling on dry-matter accumulation, test weight, and yield of pearl millet under alley cropping

Treatment	Scheduling of nitrogen (N) †				
	No-N application	½ [basal] + ½ [3rd VL]	¼ [basal] + ½ [3rd VL] + ¼ [PEFLS]	½ [basal] + ¼ [3rd VL] + ¼ [PV]	Mean
Scheduling of Zn (Zn)					
		Dry-matter accumulation (g/plant)			
No Zn-application	11.33^{h}	12.38^{h}	24.29^{fg}	26.99^{efg}	18.75^{r}
2.5 kg/ha [basal] + 0.25 [PI]	18.41^{gh}	35.29^{cde}	38.95^{cd}	31.01^{def}	30.92^{q}
2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS]	21.72^{g}	38.97^{cd}	32.65^{def}	49.68^{b}	35.76^{p}
2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS]	24.05^{fg}	25.09^{fg}	44.32^{bc}	62.64^{a}	39.02^{p}
Mean	18.88^{z}	27.93^{y}	35.05^{x}	42.58^{w}	
SEm±	N and Zn = 1.57	N × Zn = 3.14			
CD (P=0.05)	N and Zn = 4.53	N × Zn = 9.07			
		1,000-grain weight (g)			
No Zn-application	4.82^{g}	7.81^{bcd}	8.05^{bc}	6.41^{ef}	6.77^{q}
2.5 kg/ha [basal] + 0.25 [PI]	5.69^{fg}	7.15^{cde}	8.87^{ab}	8.88^{ab}	7.65^{p}
2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS]	6.84^{def}	7.81^{bcd}	9.7^{a}	7.18^{cde}	7.88^{p}
2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS]	7.2^{cde}	7.11^{cde}	8.08^{bc}	8.41^{b}	7.70^{p}
Mean	6.14^{y}	7.47^{x}	8.68^{w}	7.72^{x}	
SEm±	N and Zn = 0.21	N × Zn = 0.41			
CD (P=0.05)	N and Zn = 0.59	N × Zn = 1.19			
		Grain yield (t/ha)			
No Zn-application (control)	1.21^{g}	1.30^{g}	1.70^{f}	1.81^{def}	1.50^{r}
2.5 kg/ha [basal] + 0.25 [PI]	1.22^{g}	1.75^{ef}	2.31^{abc}	2.07^{cde}	1.84^{q}
2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS]	1.73^{f}	1.95^{def}	2.56^{a}	2.00^{cdef}	2.06^{p}
2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS]	1.27^{g}	2.09^{bcd}	2.40^{ab}	2.12^{bcd}	1.97^{pq}
Mean	1.36^{z}	1.77^{y}	2.25^{w}	2.00^{x}	
SEm±	N and Zn = 0.056	N × Zn = 0.114			
CD (P=0.05)	N and Zn = 0.163	N × Zn = 0.330			
		Biological yield (t/ha)			
No Zn-application (control)	7.22^{cd}	5.89^{fg}	6.68^{def}	6.08^{efg}	6.47^{r}
2.5 kg/ha [basal] + 0.25 [PI]	6.95^{de}	7.31^{cd}	7.66^{cd}	7.21^{cd}	7.28^{pq}
2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS]	5.15^{gh}	8.17^{bc}	7.10^{de}	7.64^{cd}	7.02^{q}
2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS]	4.75^{h}	7.21^{cd}	9.33^{a}	9.08^{ab}	7.59^{p}
Mean	6.02^{y}	7.14^{x}	7.69^{w}	7.50^{wx}	
SEm±	N and Zn = 0.180	N × Zn = 0.361			
CD (P=0.05) of N × Zn	N and Zn = 0.521	N × Zn = 1.04			
		Straw yield (t/ha)			
No Zn-application (control)	6.02^{abc}	4.60^{def}	4.98^{cdef}	4.27^{fgh}	4.97^{q}
2.5 kg/ha [basal] + 0.25 [PI]	5.73^{bc}	5.55^{bcde}	5.35^{bcdef}	5.14^{bcdef}	5.44^{pq}
2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS]	3.42^{h}	6.22^{ab}	4.54^{efg}	5.63^{bcd}	4.95^{q}
2.5 kg/ha [basal] + 0.25% [PE] + 0.25% [MS	3.48^{gh}	5.12^{cdef}	6.93^{a}	6.95^{a}	5.62^{p}
Mean	4.66^{x}	5.37^{w}	5.45^{w}	5.50^{w}	
SEm±	N and Zn = 0.189	N × Zn = 0.377			
CD (P=0.05) of N × Zn	N and Zn = 0.545	N × Zn = 1.09			

†= 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.

Treatment means of N and Zn compared with alphabet w, x, y, z and p, q, r respectively; whereas the interaction between the treatment is compared by using alphabet a, b, c……..h. Treatment showing similar alphabet are statistically at par biological and straw yields. Further, the maximum 100-grain weight was recorded when the last split of both N and Zn was applied at PEFLS, this might be because late application of N and Zn helps in better translocation of nutrients to the sink (grain) up to the MS when grain dry weight starts increasing (Khairwal *et al.,* 2007 Likewise, Zn scheduling clearly reflects higher grain yield obtained with Zn application over no Zn. Further, as compared to Zn application in 2 splits, 3 splits resulted in higher grain yield, preferentially given at PEFLS. As, N along with Zn, improves physiological and molecular mechanism within the plant that increases grain yield (Cakmak *et al.,* 2010), especially when N and Zn were applied at the proper stage, i.e. at PEFLS.

Thus, scheduling of N and Zn fertilizers plays a significant role in improving the productivity of pearl millet in semi-arid regions. Specifically, for better growth and yield, both N and Zn should be scheduled in the 3 splits, i.e. RDN applied as ¼ [basal] + ½ [3rd VL] + ¼ [PEFLS], whereas Zn as 2.5 kg/ha [basal] + 0.25% [PI] + 0.25% [PEFLS]. Moreover, dry matter and yield would increase significantly with interaction between N and Zn applied in 3 splits.

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