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# Effect of Nitrogen Levels and Method of Fertilizer Application on Growth and Productivity of Finger Millet

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## Abstract

A field experiment was conducted at Dryland Agriculture project, UAS, GKVK, Bengaluru during *Kharif* 2021 and 2022 to study the effect of nitrogen levels and method of fertilizer application on growth and productivity of finger millet. The experiment was laid out in RCBD with factorial concept and replicated thrice. The experiment comprised 18 treatments with four levels of nitrogen ($A_1$: No nitrogen, $A_2$: 50 per cent RDN, $A_3$: 75 per cent RDN and $A_4$: 100 per cent RDN) and four methods of fertilizer application ($B_1$: Soil application of zinc, $B_2$: Foliar application of nano nitrogen @ 35 and 55 DAS, $B_3$: Foliar application of nano zinc @ 35 and 55 DAS and $B_4$: Foliar application of nano nitrogen and nano zinc @ 35 and 55 DAS) along with two control. For all the treatments, recommended phosphorus and potassium were applied as per standard recommendations. The results revealed that application of 100 per cent RDN along with spraying of nano-N and nano-Zn twice at 35 and 55 DAS recorded significantly higher growth parameters viz., number of tillers per hill, number of leaves per hill, total dry matter production and SPAD meter readings at all the growth stages. Similarly, significantly higher grain yield (3453 kg ha$^{-1}$) and straw yield (5048 kg ha$^{-1}$) were also recorded with application of 100 per cent RDN along with spraying of nano-N and nano-Zn and was on par with the application of 75 per cent RDN with spraying of nano-N and nano Zn twice (3449 kg ha$^{-1}$ and 5035 kg ha$^{-1}$, respectively). Greater mobility of nano fertilizers led to higher nitrogen use efficiency with the application of 75 per cent RDN along with spraying of nano-N and nano-Zn. Thus, application of 75 per cent RDN with spraying of nano-N and nano-Zn was found to be useful in enhancing the productivity of finger millet .

*Keywords* : Finger millet, Nano nitrogen, Nano zinc, Nitrogen use efficiency, RDN

Small millets are promoted as 'nutri-cereals' and climate smart crops because of their ability to withstand unfavorable consequences of climate change facilitating food and nutritional security for burgeoning population, especially in resource-poor and rainfed areas (Kumar *et al*., 2019). Among various small millets, finger millet (*Eleusine coracana* L. Gaertn), commonly known as 'ragi' is the most important crop in terms of its higher production and wider adaptability. Finger millet is referred as neutraceutical crop and has been perceived as a potential 'super cereal' by the United States National Academies being as one of the most nutritious among all the cereals. In India, 1.70 million tonnes of finger millet was produced from a total area of 1.21 million hectares with an average productivity of 1396 kg ha$^{-1}$ (Anonymous, 2022). In Karnataka, it occupied an area of 0.85 million hectares with a production of 1.13 million tonnes and average productivity of 1332 kg ha$^{-1}$ (Anonymous, 2022) indicating the lion share in finger millet production.

Finger millet is mostly raised under resource-poor conditions with minimum agronomic management in turn resulting in lower productivity (Harika *et al.*, 2019). With the global upsurge in population and rapid urbanization, farmers across the globe are left with the daunting task of feeding more mouths every year which has prompted the large-scale use of fertilizers. To achieve higher productivity, adequate supply of nutrients through the right source could be an important approach. Nutrients are vital for maintaining and improving crop growth and yield. When nutrient application is not synchronized with crop demand, losses from the soil-plant system are large leading to lower fertilizer use efficiency. To address these problems, there is a need to explore one of the frontier technologies such as 'Nanotechnology. Nano-fertilizers are new generation synthetic fertilizers which contain readily available nutrients in nano-scale range. So nano fertilizers may increase the efficiency of nutrient uptake, enhance yield and nutrient content in the edible parts and also minimize its accumulation in the soil (Pruthviraj *et al.*, 2022).

Among the various nutrients, the physiological role of nitrogen and zinc attributes to enhanced crop productivity (Ramya *et al.*, 2020). Apart from soil applications, foliar spray of nutrients has been shown to be a practical means of replenishing the reservoir of nutrients in the leaves. Indeed supplementation of nutrients, through foliar spray could be the most efficient and appropriate strategy (Liu and Lal, 2015). So far, several researchers have found the beneficial effect of nano fertilizers on different crops, but studies on the prospects of nano fertilizers in finger millet is scarce. Hence, the present investigation was undertaken.

## Material and Methods

The field experiment was carried out for two consecutive years in 2021 and 2022 at AICRPDA, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bengaluru. The soil of experimental site was red sandy clay loam in texture. The soil of experimental site was strongly acidic in reaction (4.68), the soil was low in organic carbon content (0.40 %) and available nitrogen (256.08 kg ha$^{-1}$), high in available phosphorus (51.31 kg ha$^{-1}$) and medium in potassium (146.34 kg ha$^{-1}$). The textural class of the soil was characterized by International pipette method as outlined by Piper, 1966. The soil pH was determined by potentiometric method (Piper, 1966), electrical conductivity using conductivity bridge (Jackson, 1973) and organic carbon was estimated using Walkley and Black wet-oxidation method (Jackson, 1973). Available nitrogen was assessed by following Alkaline permanganate method as outlined by Subbaiah and Asija (1956), available phosphorus and potassium content of the soil was quantified following Bray's colorimetry and Flame photometer method respectively outlined by Jackson (1973).

The experiment consisted of 18 treatments with four levels of nitrogen ($A_1$: No nitrogen, $A_2$: 50% of RDN, $A_3$: 75% RDN and $A_4$: 100% RDN) and four methods of fertilizer application ($B_1$: Soil application of zinc, $B_2$: Foliar application of nano nitrogen @ 2ml l$^{-1}$ at 35 and 55 DAS, $B_3$: Foliar application of nano zinc @ 2ml l$^{-1}$ at 35 and 55 DAS and $B_4$: Foliar application of nano nitrogen and nano zinc @ 2ml l$^{-1}$ at 35 and 55 DAS) along with two controls (control-1: PK, control-2: NPK). For all the treatments, recommended phosphorus and potassium were applied as per standard recommendation. Growth parameters like number of tillers per hill, number of leaves per hill, dry matter production per hill and SPAD meter readings of five randomly selected plants were recorded at 30, 60, 90 DAS and at harvest. The grain and straw yield obtained from each net plot area was converted to kg ha$^{-1}$. Nutrient use efficiency (NUE) is a critically important concept in the evaluation of crop production systems. Nitrogen use efficiency was calculated using the formula given by Paul *et al.* (2015).

## Results and Discussion

### Effect of Nitrogen Levels and Method of Fertilizer Application on Growth Parameters

### Number of Tillers Per Hill

The number of tillers per hill at different stages of growth as influenced by levels of nitrogen and

TABLE 1

Number of tillers per hill at different growth stages of finger millet as influenced by levels of nitrogen and methods of fertilizer application

| Treatment | 30 DAS | 60 DAS | 90 DAS | At harvest |
|---|---|---|---|---|
| Factor A (Nitrogen levels) | | | | |
| $A_1$ - $N_0$ | 2.10 | 6.14 | 9.56 | 8.89 |
| $A_2$ - $N_{50}$ | 2.23 | 6.97 | 10.40 | 10.08 |
| $A_3$ - $N_{75}$ | 2.44 | 8.74 | 12.12 | 12.46 |
| $A_4$- $N_{100}$ | 2.52 | 9.07 | 12.54 | 12.88 |
| F test | NS | * | * | * |
| S.Em± | 0.09 | 0.15 | 0.12 | 0.15 |
| CD at 5 % | - | 0.42 | 0.34 | 0.43 |
| Factor B (Method of fertilizer application) | | | | |
| $B_1$ - Soil application of Zn | 2.17 | 6.99 | 10.38 | 10.20 |
| $B_2$ - Nano-N | 2.40 | 7.94 | 11.42 | 11.35 |
| $B_3$ - Nano-Zn | 2.22 | 7.34 | 10.85 | 10.68 |
| $B_4$ - Nano-N + Nano-Zn | 2.50 | 8.65 | 11.97 | 12.08 |
| F test | NS | * | * | * |
| S.Em± | 0.09 | 0.15 | 0.12 | 0.15 |
| CD at 5 % | - | 0.42 | 0.34 | 0.43 |
| Interactions (A×B) | | | | |
| $A_1B_1$ | 1.95 | 5.60 | 8.99 | 8.38 |
| $A_1B_2$ | 2.15 | 6.30 | 9.74 | 9.16 |
| $A_1B_3$ | 2.13 | 6.11 | 9.61 | 8.76 |
| $A_1B_4$ | 2.16 | 6.55 | 9.91 | 9.24 |
| $A_2B_1$ | 2.14 | 6.76 | 10.03 | 9.50 |
| $A_2B_2$ | 2.31 | 7.03 | 10.58 | 10.23 |
| $A_2B_3$ | 2.14 | 6.94 | 10.35 | 10.16 |
| $A_2B_4$ | 2.33 | 7.15 | 10.63 | 10.45 |
| $A_3B_1$ | 2.28 | 7.52 | 10.88 | 11.30 |
| $A_3B_2$ | 2.55 | 9.20 | 12.66 | 12.92 |
| $A_3B_3$ | 2.28 | 7.81 | 11.32 | 11.42 |
| $A_3B_4$ | 2.65 | 10.41 | 13.62 | 14.22 |
| $A_4B_1$ | 2.32 | 8.09 | 11.61 | 11.64 |
| $A_4B_2$ | 2.59 | 9.22 | 12.70 | 13.10 |
| $A_4B_3$ | 2.32 | 8.49 | 12.14 | 12.37 |
| $A_4B_4$ | 2.86 | 10.50 | 13.72 | 14.39 |
| F test | NS | * | * | * |
| S.Em± | 0.19 | 0.29 | 0.23 | 0.30 |
| CD at 5 % | - | 0.84 | 0.68 | 0.86 |
| PK (Control-1) | 1.82 | 5.49 | 8.72 | 8.23 |

Continued....

Table 1 Continued....

| Treatment | 30 DAS | 60 DAS | 90 DAS | At harvest |
|---|---|---|---|---|
| NPK (Control-2) | 2.36 | 8.07 | 11.56 | 11.49 |
| F test | NS | * | * | * |
| S.Em± | 0.19 | 0.30 | 0.25 | 0.30 |
| CD at 5 % | - | 0.87 | 0.71 | 0.86 |

methods of fertilizer application was found to vary significantly in both the years of study and presented in Table 1.

At 30 DAS, there were no significant differences for number of tillers per hill. While, at 60 DAS, 90 DAS and harvest significantly maximum number of tillers per hill was recorded with application of 100 per cent RDN (9.07, 12.54 and 12.88, respectively) and was on par with application of 75 per cent RDN (8.74, 12.12 and 12.46, respectively). Among methods of fertilizer application, foliar spray of nano-N and nano-Zn (8.65, 11.97 and 12.08) recorded greater number of tillers per hill at 60 DAS, 90 DAS and harvest, respectively followed by foliar spray of nano-N (7.94, 11.42 and 11.45, respectively). Among various interactions, application of 100 per cent RDN along with foliar application of nano-N and nano-Zn (10.50, 13.72 and 14.39) recorded maximum number of tillers and was on par with application of 75 per cent RDN along with foliar application of nano-N and nano-Zn (10.41, 13.62 and 14.22) 60 DAS, 90 DAS and at harvest, respectively.

Tillering is caused by the mother culm nutrient content in the early stage of crop growth, which provides carbohydrates and other essential nutrients for tiller production (Ishizuka and Tanaka, 1954). The number of tillers per hill increased significantly with increased nitrogen levels. Nitrogen application promotes cytokinin biosynthesis, and inhibits its degradation, thereby inducing tiller bud development (Liu *et al*., 2011), and also affect auxin transport and strigolactone synthesis to regulate axillary bud activation (Jong *et al*., 2014). Application of nano-N and nano-Zn enhanced tillering by improving nutrient solubility, facilitating root uptake and enabling more efficient translocation within the plant. Additionally, nano-nutrients may act as signaling molecules, triggering pathways associated with tiller initiation and development. Nano fertilizers are readily taken up by the epidermis of leaves and translocated to stems, facilitating active molecule uptake and enhancing growth (Abdel-Aziz *et al*., 2018).

**Number of Leaves Per Hill**

Number of leaves per hill of finger millet was significantly influenced by the levels of nitrogen and methods of fertilizer application. The data pooled over two years are presented in Table 2.

At 30 DAS, there were no significant differences in number of leaves per hill. However, the number of leaves per hill increased significantly at 60 DAS, 90 DAS and at harvest with increasing nitrogen levels where A4 (100 % RDN) (75.75, 83.64 and 44.13, respectively) had the supremacy over all other levels of nitrogen and the lower number of leaves per hill was recorded with no application of nitrogen at all the growth stages. Among methods of fertilizer application, foliar application of nano-N and nano-Zn resulted in significantly higher number of green leaves per hill at 60 DAS (73.80), 90 DAS (82.16) and harvest (41.41) followed by foliar application of nano-N (66.40, 75.66, 37.75, respectively). Among various interactions, combined application of 100 per cent RDN along with foliar application of nano-N and nano-Zn has (91.60, 97.53 and 51.17) recorded significantly higher number of leaves at 60 DAS, 90 DAS and harvest which was on par with application of 75 per cent RDN along with foliar application of nano-N and nano-Zn (90.06, 95.55 and 50.67, respectively).

Yuvakkumar *et al*. (2011) reported that the number of green leaves increased up to 60 DAS, then decreased from 90 DAS to harvest due to

TABLE 2

Number of leaves per hill at different growth stages of finger millet as influenced by levels of nitrogen and methods of fertilizer application

| Treatment | 30 DAS | 60 DAS | 90 DAS | At harvest |
|---|---|---|---|---|
| Factor A (Nitrogen levels) | | | | |
| $A_1$ - $N_0$ | 17.63 | 52.13 | 64.43 | 27.83 |
| $A_2$ - $N_{50}$ | 18.51 | 57.54 | 68.64 | 33.19 |
| $A_3$ - $N_{75}$ | 19.66 | 72.29 | 80.37 | 41.86 |
| $A_4$- $N_{100}$ | 20.18 | 75.75 | 83.64 | 44.13 |
| F test | NS | * | * | * |
| S.Em± | 0.67 | 1.80 | 1.66 | 0.80 |
| CD at 5 % | - | 5.20 | 4.80 | 2.31 |
| Factor B (Method of fertilizer application) | | | | |
| $B_1$ - Soil application of Zn | 18.31 | 57.37 | 68.92 | 33.08 |
| $B_2$ – Nano-N | 19.10 | 66.40 | 75.66 | 37.75 |
| $B_3$ – Nano-Zn | 18.53 | 60.15 | 70.33 | 34.76 |
| $B_4$ – Nano-N + Nano-Zn | 20.05 | 73.80 | 82.16 | 41.41 |
| F test | NS | * | * | * |
| S.Em± | 0.67 | 1.80 | 1.66 | 0.80 |
| CD at 5 % | - | 5.20 | 4.80 | 2.31 |
| Interactions (A×B) | | | | |
| $A_1B_1$ | 17.06 | 48.41 | 62.28 | 25.19 |
| $A_1B_2$ | 17.87 | 53.72 | 65.50 | 28.93 |
| $A_1B_3$ | 17.46 | 51.74 | 63.67 | 27.42 |
| $A_1B_4$ | 18.13 | 54.66 | 66.26 | 29.80 |
| $A_2B_1$ | 18.38 | 55.83 | 67.65 | 31.76 |
| $A_2B_2$ | 18.56 | 58.06 | 68.91 | 33.76 |
| $A_2B_3$ | 18.44 | 57.43 | 68.70 | 33.21 |
| $A_2B_4$ | 18.66 | 58.86 | 69.29 | 34.02 |
| $A_3B_1$ | 18.63 | 60.20 | 70.65 | 36.10 |
| $A_3B_2$ | 19.63 | 75.94 | 83.44 | 43.76 |
| $A_3B_3$ | 18.76 | 62.71 | 71.83 | 36.90 |
| $A_3B_4$ | 21.63 | 90.06 | 95.55 | 50.67 |
| $A_4B_1$ | 19.15 | 65.04 | 75.11 | 39.28 |
| $A_4B_2$ | 20.33 | 77.87 | 84.80 | 44.55 |
| $A_4B_3$ | 19.45 | 68.48 | 77.11 | 41.51 |
| $A_4B_4$ | 21.78 | 91.60 | 97.53 | 51.17 |
| F test | NS | * | * | * |
| S.Em± | 1.35 | 3.61 | 3.33 | 1.60 |
| CD at 5 % | - | 10.42 | 9.61 | 4.63 |
| PK (Control-1) | 15.20 | 47.01 | 57.49 | 23.84 |

Continued....

Table 2 Continued....

| Treatment | 30 DAS | 60 DAS | 90 DAS | At harvest |
|---|---|---|---|---|
| NPK (Control-2) | 18.97 | 64.20 | 74.54 | 39.27 |
| F test | NS | * | * | * |
| S.Em± | 1.34 | 3.71 | 3.66 | 1.63 |
| CD at 5 % | - | 10.65 | 10.51 | 4.70 |

photosynthates transfer to reproductive regions, which resulted in senescence of older leaves. Increased nitrogen levels helped in better formation of photosynthetic apparatus and potassium caused better partitioning of photosynthates to various plants parts, this better supply of plant growth factors is positively correlated with number of leaves per hill. The significant increment in number of leaves per hill with the foliar application of nano fertilizers might be due to the fact that nano fertilizers instigated the activity of nitrate reductase, chloroplast (Hong *et al.* 2005) and antioxidant enzyme system (Nekrasova *et al.* 2011) which enhanced the growth and resulted in higher number of leaves. These findings were in accordance with those of Rathnayaka *et al.* (2018) who observed more number of leaves in rice with the application of nano fertilizers.

**Total Dry Matter Production (g hill$^{-1}$)**

The data on total dry matter production (TDMP) at various growth stages revealed that TDMP was significantly influenced by levels of nitrogen and methods of fertilizer application (Table 3).

The TDMP per hill increased continuously from emergence to harvest. The rate of increase of dry matter was faster between 30 DAS to 60 DAS and thereafter the increase was slow up to harvest. The maximum TDMP at 60 DAS, 90 DAS and at harvest were observed with the application of 100 per cent RDN (21.28, 41.09 and 56.51 g hill$^{-1}$, respectively) and was on par with application of 75 per cent RDN (20.27, 40.30 and 55.05 g hill$^{-1}$, respectively) which was superior over 50 per cent RDN. Among methods of fertilizer application, foliar application of nano-N and nano-Zn recorded higher TDMP at 60 DAS (20.76 g hill$^{-1}$), 90 DAS (40.70 g hill$^{-1}$) and at harvest (53.46 g hill$^{-1}$) followed by foliar application of nano-N (19.20, 38.90 and 50.81 g hill$^{-1}$, respectively). There was significant interaction between nitrogen levels and methods of fertilizer application, among different combinations 100 per cent RDN with foliar spray of nano-N and nano-Zn recorded significantly higher dry matter production per hill at 60 DAS (24.87 g hill$^{-1}$), 90 DAS (44.88 g hill$^{-1}$) and at harvest (61.05 g hill$^{-1}$) which was on par with application of 75 per cent RDN + foliar application of nano-N and nano-Zn (24.23, 44.84 and 61.64 g hill$^{-1}$, respectively). Significantly lower dry matter production per hill was recorded with application of PK alone (control-1).

The amount of total dry matter produced is determined by the plant's photosynthetic capability, which is determined by the amount of total dry matter accumulated in the leaves. Higher plant height, larger number of leaves hill$^{-1}$ and increased leaf area hill$^{-1}$ resulted in the maximum dry matter production. These findings are in consistent with those of Rani *et al.* (2019). Better plant growth led to more dry matter accumulation in leaves and stem at early growth stages and better transfer to grain at later stages, resulting in higher total dry matter production. Similar findings were observed by Miller and Sayre (1948). Application of nano-N and nano- Zn had a significant effect on dry matter production. Treatment receiving 100 per cent RDN + foliar spray of nano-N and nano-Zn resulted in higher dry matter production at all stages of observations. Application of nano-N and nano-Zn enhanced chlorophyll and increased light interception, absorption and utilization of solar radiation thus enhanced photosynthesis which was reflected in LAI and dry matter production. Due to the higher uptake of nutrients, better source to sink

TABLE 3

Total dry matter production (g hill-1) at different growth stages of finger millet as influenced by levels of nitrogen and methods of fertilizer application

| Treatment | 30 DAS | 60 DAS | 90 DAS | At harvest |
|---|---|---|---|---|
| Factor A (Nitrogen levels) | | | | |
| $A_1$ - $N_0$ | 2.52 | 15.88 | 35.46 | 40.95 |
| $A_2$ - $N_{50}$ | 2.62 | 17.53 | 37.15 | 46.51 |
| $A_3$ - $N_{75}$ | 2.75 | 20.27 | 40.30 | 55.05 |
| $A_4$ - $N_{100}$ | 2.80 | 21.28 | 41.09 | 56.51 |
| F test | NS | * | * | * |
| S.Em± | 0.06 | 0.51 | 0.55 | 0.51 |
| CD at 5 % | - | 1.46 | 1.59 | 1.48 |
| Factor B (Method of fertilizer application) | | | | |
| $B_1$ - Soil application of Zn | 2.63 | 17.41 | 37.18 | 46.44 |
| $B_2$ – Nano-N | 2.68 | 19.20 | 38.90 | 50.81 |
| $B_3$ – Nano-Zn | 2.65 | 17.60 | 37.21 | 48.31 |
| $B_4$ – Nano-N + Nano-Zn | 2.74 | 20.76 | 40.70 | 53.46 |
| F test | NS | * | * | * |
| S.Em± | 0.06 | 0.51 | 0.55 | 0.51 |
| CD at 5 % | - | 1.46 | 1.59 | 1.48 |
| Interactions (A×B) | | | | |
| $A_1B_1$ | 2.49 | 15.58 | 35.15 | 37.10 |
| $A_1B_2$ | 2.54 | 15.94 | 35.57 | 42.94 |
| $A_1B_3$ | 2.51 | 15.75 | 35.33 | 39.83 |
| $A_1B_4$ | 2.55 | 16.27 | 35.78 | 43.95 |
| $A_2B_1$ | 2.59 | 17.44 | 37.05 | 45.36 |
| $A_2B_2$ | 2.63 | 17.50 | 37.18 | 46.60 |
| $A_2B_3$ | 2.61 | 17.54 | 37.10 | 46.88 |
| $A_2B_4$ | 2.66 | 17.66 | 37.30 | 47.18 |
| $A_3B_1$ | 2.68 | 17.69 | 37.56 | 50.83 |
| $A_3B_2$ | 2.74 | 21.41 | 41.17 | 56.17 |
| $A_3B_3$ | 2.72 | 17.77 | 37.60 | 51.55 |
| $A_3B_4$ | 2.88 | 24.23 | 44.84 | 61.64 |
| $A_4B_1$ | 2.75 | 18.94 | 38.95 | 52.47 |
| $A_4B_2$ | 2.80 | 21.95 | 41.70 | 57.52 |
| $A_4B_3$ | 2.77 | 19.35 | 38.83 | 54.99 |
| $A_4B_4$ | 2.88 | 24.87 | 44.88 | 61.05 |
| F test | NS | * | * | * |
| S.Em± | 0.13 | 1.01 | 1.10 | 1.03 |
| CD at 5 % | - | 2.93 | 3.18 | 2.96 |
| PK (Control-1) | 2.44 | 15.55 | 35.00 | 36.84 |

Continued....

Table 3 Continued....

| Treatment | 30 DAS | 60 DAS | 90 DAS | At harvest |
|---|---|---|---|---|
| NPK (Control-2) | 2.72 | 18.04 | 38.95 | 52.70 |
| F test | NS | * | * | * |
| S.Em± | 0.13 | 1.20 | 1.08 | 1.02 |
| CD at 5 % | - | 3.44 | 3.10 | 2.95 |

relation and higher translocation of starch, dry matter production was greater with application of nano fertilizers. This finding was in conformity with Lenka and Das (2019).

**SPAD Meter Readings**

The data pertaining to SPAD chlorophyll meter readings of finger millet at different growth stages was significantly influenced by nitrogen levels and methods of fertilizer application (Fig. 1). The SPAD values increased from 30 DAS, reached peak at 60 DAS and thereafter decreased towards harvest.

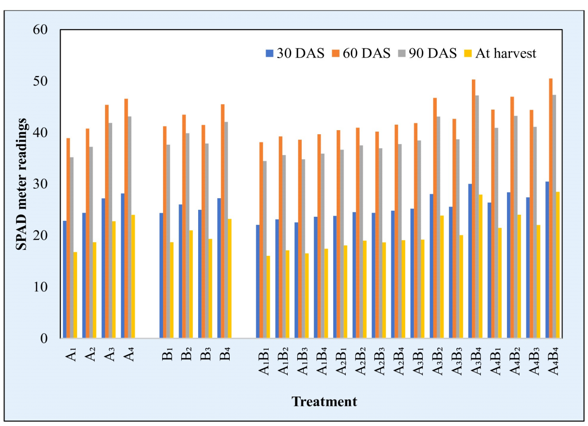


Fig. 1 : Influence of nitrogen levels and method of fertilizer application on SPAD meter readings of finger millet

Nitrogen levels significantly influenced the relative chlorophyll readings (SPAD) at all the growth stages except at 30 DAS. The crop fertilized with 100 per cent RDN (46.57, 43.14 and 24.00) recorded significantly greater chlorophyll readings at 60 DAS, 90 DAS and at harvest, respectively and was superior over 50 per cent RDN (40.78, 37.22 and 18.69, respectively) but on par with the application of 75 per cent RDN (45.38, 41.86 and 22.76, respectively). The relative chlorophyll meter readings at different stages of crop growth were significantly influenced by mode of fertilizer application. At 30 DAS, 60 DAS, 90 DAS and at harvest, foliar application of nano-N and nano-Zn (45.50, 42.05 and 23.22) produced higher relative chlorophyll readings as compared to other treatments. There was significant interaction between nitrogen levels and method of fertilizer application at 60, 90 DAS and harvest of finger millet. At 60, 90 DAS and at harvest 100 per cent RDN with foliar application of nano-N and nano-Zn (50.51, 47.33 and 28.48, respectively) has recorded significantly higher SPAD value and was on par with 75 per cent RDN with foliar application of nano-N and nano-Zn (50.31, 47.20 and 27.93, respectively). Lower values were observed with application of PK only (37.27, 32.88 and 15.11, respectively).

Chlorophyll is associated with nitrogen levels and determines the final yield of crops. The higher SPAD readings obtained under higher levels of nitrogen would probably be evident from LAD values and relatively higher plant N content due to higher leaf photosynthetic area coupled with persistence of the leaf area for relatively longer period. These results are in similar line with those of Pavani *et al.* (2012). The maximum SPAD readings were recorded with the foliar application of nano nitrogen and nano zinc @ 35 and 55 DAS. The nano fertilizers help in capture of sunlight, facilitates manufacture of pigments, and stimulates rubisco activity which aids to improve chlorophyll Janmohammadi *et al.* (2016). The positive effects of zinc NPs on chlorophyll content may be due to the essential role that Zn plays in chlorophyll biosynthesis by protecting the sulfhydryl group of chlorophyll molecules (Cakmak and Horst, 1991). Thus the combination of conventional fertilizers along with foliar application of nano fertilizers led to

TABLE 4

Grain yield, straw yield and harvest index as influenced by nitrogen levels and methods of fertilizer application in finger millet

| Treatment | Grain yield (kg ha$^{-1}$) | | | Straw yield (kg ha$^{-1}$) | | | Harvest index | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | Pooled | 2021 | 2022 | Pooled | 2021 | 2022 | Pooled |
| Factor A | | | | | | | | | |
| $A_1$ - $N_0$ | 1523 | 1879 | 1701 | 2128 | 2844 | 2486 | 0.42 | 0.40 | 0.41 |
| $A_2$ - $N_{50}$ | 2041 | 2334 | 2188 | 2834 | 3620 | 3227 | 0.42 | 0.40 | 0.41 |
| $A_3$ - $N_{75}$ | 2822 | 3152 | 2987 | 4222 | 4464 | 4343 | 0.40 | 0.41 | 0.41 |
| $A_4$- $N_{100}$ | 2925 | 3213 | 3069 | 4428 | 4548 | 4488 | 0.40 | 0.41 | 0.40 |
| F test | * | * | * | * | * | * | NS | NS | NS |
| S.Em± | 54 | 31 | 32 | 83 | 54 | 51 | 0.01 | 0.005 | 0.004 |
| CD at 5 % | 157 | 89 | 93 | 241 | 156 | 146 | - | - | - |
| Factor B | | | | | | | | | |
| $B_1$ - Soil application of Zn | 2025 | 2428 | 2226 | 2999 | 3530 | 3265 | 0.41 | 0.41 | 0.41 |
| $B_2$ - Nano N | 2439 | 2707 | 2573 | 3509 | 3919 | 3714 | 0.41 | 0.41 | 0.41 |
| $B_3$ - Nano Zn | 2185 | 2525 | 2355 | 3266 | 3735 | 3500 | 0.40 | 0.40 | 0.40 |
| $B_4$ - Nano N + Nano Zn | 2662 | 2919 | 2791 | 3838 | 4292 | 4065 | 0.41 | 0.40 | 0.41 |
| F test | * | * | * | * | * | * | NS | NS | NS |
| S.Em± | 54 | 31 | 32 | 83 | 54 | 51 | 0.01 | 0.005 | 0.004 |
| CD at 5 % | 157 | 89 | 93 | 241 | 156 | 146 | - | - | - |
| Interactions (A×B) | | | | | | | | | |
| $A_1B_1$ | 1362 | 1652 | 1507 | 1977 | 2673 | 2325 | 0.41 | 0.38 | 0.40 |
| $A_1B_2$ | 1535 | 1906 | 1720 | 2143 | 2812 | 2478 | 0.42 | 0.41 | 0.41 |
| $A_1B_3$ | 1512 | 1851 | 1681 | 2133 | 2809 | 2471 | 0.41 | 0.40 | 0.41 |
| $A_1B_4$ | 1684 | 2109 | 1897 | 2257 | 3081 | 2669 | 0.43 | 0.41 | 0.42 |
| $A_2B_1$ | 1728 | 2230 | 1979 | 2378 | 3107 | 2743 | 0.42 | 0.42 | 0.42 |
| $A_2B_2$ | 2151 | 2329 | 2240 | 2995 | 3834 | 3414 | 0.42 | 0.38 | 0.40 |
| $A_2B_3$ | 2061 | 2273 | 2167 | 2890 | 3594 | 3242 | 0.42 | 0.39 | 0.40 |
| $A_2B_4$ | 2226 | 2504 | 2365 | 3072 | 3943 | 3508 | 0.42 | 0.39 | 0.41 |
| $A_3B_1$ | 2415 | 2876 | 2645 | 3651 | 4051 | 3851 | 0.40 | 0.41 | 0.41 |
| $A_3B_2$ | 3033 | 3295 | 3164 | 4448 | 4513 | 4480 | 0.41 | 0.42 | 0.41 |
| $A_3B_3$ | 2471 | 2908 | 2689 | 3784 | 4230 | 4007 | 0.39 | 0.41 | 0.40 |
| $A_3B_4$ | 3368 | 3531 | 3449 | 5007 | 5063 | 5035 | 0.40 | 0.41 | 0.41 |
| $A_4B_1$ | 2595 | 2954 | 2775 | 3991 | 4288 | 4139 | 0.39 | 0.41 | 0.40 |
| $A_4B_2$ | 3036 | 3296 | 3166 | 4450 | 4514 | 4482 | 0.41 | 0.42 | 0.41 |
| $A_4B_3$ | 2699 | 3069 | 2884 | 4256 | 4308 | 4282 | 0.39 | 0.41 | 0.40 |
| $A_4B_4$ | 3371 | 3535 | 3453 | 5015 | 5081 | 5048 | 0.40 | 0.41 | 0.41 |
| F test | * | * | * | * | * | * | - | - | - |

Continued....

Table 4 Continued....

| Treatment | Grain yield (kg ha$^{-1}$) | | | Straw yield (kg ha$^{-1}$) | | | Harvest index | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | Pooled | 2021 | 2022 | Pooled | 2021 | 2022 | Pooled |
| S.Em± | 109 | 62 | 64 | 167 | 108 | 101 | 0.02 | 0.01 | 0.01 |
| CD at 5 % | 314 | 178 | 186 | 481 | 312 | 293 | NS | NS | NS |
| Control 1 | 1223 | 1632 | 1427 | 1901 | 2438 | 2169 | 0.39 | 0.40 | 0.39 |
| Control 2 | 2499 | 2932 | 2715 | 3957 | 4246 | 4101 | 0.39 | 0.41 | 0.40 |
| F test | * | * | * | * | * | * | NS | NS | NS |
| S.Em± | 109 | 65 | 63 | 159 | 107 | 100 | 0.02 | 0.01 | 0.01 |
| CD at 5 % | 313 | 186 | 182 | 458 | 309 | 287 | - | - | - |

increase the chlorophyll readings due to the interaction among them.

**Effect of Nitrogen Levels and Method of Fertilizer Application on Grain Yield, Straw Yield and Harvest Index**

The data on grain and straw yield of finger millet influenced by the application of levels of nitrogen and method of fertilizer application were pooled and are presented in Table 4.

Regarding grain and straw yield, a substantial difference was observed among the treatments. The present study revealed that among different nitrogen levels, application of 100 per cent RDN resulted in significantly higher finger millet grain (3069 kg ha$^{-1}$) and straw yield (4488 kg ha$^{-1}$) but was on par with application of 75 per cent nitrogen and recommended PK (2987 and 4343 kg ha$^{-1}$, respectively). Among different methods of fertilizer application, foliar application of nano nitrogen and nano zinc @ 35 and 55 DAS resulted in significantly higher finger millet grain (2791 kg ha$^{-1}$) and straw yield (4065 kg ha$^{-1}$) compared to foliar application of nano nitrogen or nano zinc individually. The interaction effect of 100 per cent nitrogen with foliar spray of nano-N and nano-Zn recorded significantly higher grain yield (3453 kg ha$^{-1}$) and straw yield (5048 kg ha$^{-1}$) and was on par with the application of 75 per cent N and recommended PK + foliar spray of nano-N and nano-Zn (3449 and 5035 kg ha$^{-1}$, respectively) and other treatments in comparison. The lowest grain (1427 kg ha$^{-1}$) and straw yield (2169 kg ha$^{-1}$) were found with application of only P and K (control-1). Harvest index failed to vary significantly in response to levels of nitrogen and methods of fertilizers application.

Increased nitrogen rates from 0 to 100 per cent RDN significantly enhanced the grain and straw yield. This was mainly due to higher dry matter, leading to higher production and transportation of assimilates to fill the seeds thereby resulting in higher yield McDonald, (2002). The enhanced grain yield was mainly due to nitrogen application increasing the dry matter production, improving growth rate, promoting elongation of internodes and activity of growth hormones like gibberellins. These results are in accordance with Singh *et al*. (2000). The lowest grain and straw yield were recorded with application of only P and K (control-1) due to the imbalanced fertilization. The finger millet grain and straw yields were significantly higher with the foliar application of nano nitrogen and nano zinc and it was attributed to the improvement in growth parameters and test weight, ultimately leading to an increase in grain yield (Du *et al*., 2011).

This unique characteristic of nano fertilizers allows to regulate the release of nutrients, ensuring that crops receive correct quantity of nutrients in suitable proportion and promotes productivity of finger millet grain and straw yield. Foliar application of nano urea was ascribed to quick absorption of nutrients by the plant and easy translocation, which helps in better rates of photosynthesis and greater accumulation of dry matter, resulting in higher straw yield. A similar trend was observed by Khalil *et al.* (2019). Conventional fertilizer along with nano fertilizer application increased the yield because nano fertilizers have a synergistic impact with conventional fertilizer to improve nutrient absorption by plant cells, resulting in optimal growth and finally yield (Jyothi and Hebsur, 2017). Similar results were reported by Benzon *et al*. (2015) and Rathnayaka *et al*. (2018).

**Effect of Nitrogen Levels and Method of Fertilizer Application on Nitrogen Uptake and Nitrogen use Efficiency**

Nitrogen uptake by the grain and straw of finger millet (Fig. 2) was significantly influenced by the nitrogen levels. Nitrogen uptake by finger millet under different levels of nitrogen application showed that N uptake increased with increase in levels of N application. Higher nitrogen uptake in grain (34.00 kg $ha^{-1}$) and straw (28.05 kg $ha^{-1}$) was recorded in 100 per cent RDN and was on par with 75 per cent RDN (30.62 and 26.55 kg $ha^{-1}$, respectively). Similar trend was followed in total uptake. Among method of fertilizer application, foliar application of nano-N and nano-Zn has recorded higher uptake in grain (30.25 kg $ha^{-1}$) and straw (25.30 kg $ha^{-1}$) followed by the only application of nano-N (27.98 and 23.15 kg $ha^{-1}$, respectively). There was significant interaction between nitrogen levels and method of fertilizer application on nitrogen uptake of finger millet at harvest. Application of 100 per cent RDN with foliar application

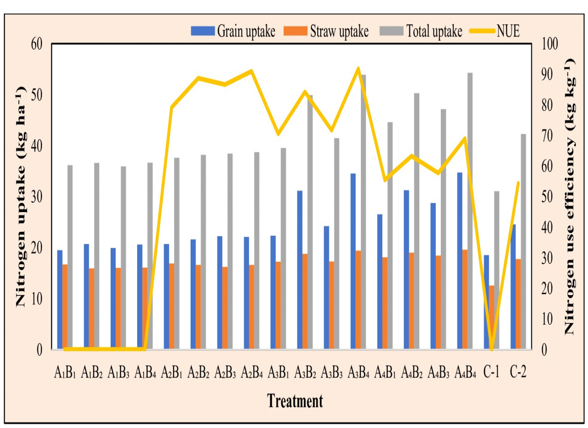


Fig. 2 : Influence of nitrogen levels and methods of fertilizer application on nitrogen uptake and nitrogen use efficiency of finger millet

of nano-N and nano-Zn has recorded significantly higher nitrogen uptake in grain (38.10 kg $ha^{-1}$) and straw 31.55 kg $ha^{-1}$) and was on par with 75 per cent RDN with foliar application of nano-N and nano-Zn (35.36 and 30.72 kg $ha^{-1}$, respectively). Lower values were observed with application of PK only (15.27 and 13.67 kg $ha^{-1}$, respectively). In all the method of fertilizers application, application of 75 per cent RDN recorded higher nitrogen use efficiency compared to application of 100 per cent RDN. Combined application of 75 per cent N and recommended PK along with foliar spray of nano-N and nano-Zn recorded higher nitrogen use efficiency (91.78 kg $kg^{-1}$).

The higher nitrogen uptake in 100 per cent and 75 per cent RDN was attributed to better availability of nutrients that increased uptake of nutrients. These results were in conformity with the findings of Duryodhana *et al*. (2004), Nigade and More (2013), Saraswathi *et al*. (2015) and Rani *et al*. (2017). The higher nitrogen uptake was due to increased availability of nutrients in the crop root zone that resulted in increased absorption of the elements by the plants as well as higher dry matter production. Similar results were also reported by Vajantha *et al*. (2017) and Prakasha *et al*. (2018). Foliar application of nano nitrogen and nano zinc might have caused rapid absorption of nutrients due to larger surface area and particle size less than the pore size (5 to 50 nm) of leaves of the plant which enhanced penetration into the plant tissues from applied surface and augmented uptake of the nutrients. Further, fertilizer particles coated with nano membranes might have also facilitated slow and steady release of nutrients. The present increase in the N uptake with foliar application of nano nitrogen and nano zinc could be attributed to the synergistic effect between the nitrogen and zinc which might have aided in more enzymatic activity. The present findings were also supported by the reports of Ashoka *et al*. (2008), Apoorva *et al.* (2016).

Combined application of 75 per cent N and recommended PK along with foliar spray of nano-N and nano-Zn recorded higher nitrogen use efficiency than application of conventional fertilizers. Due to the significantly smaller size of the nanoparticles, nano-fertilizers exhibit an increased surface area, offering more sites to enhance various metabolic process within the plant system. This results in the production of more photosynthates with less consumption of nutrients and thus direct contact of nanoparticles by foliar application improved the NUE (Manikanta *et al*., 2023). Full dose of RDN recorded lower nitrogen use efficiency possibly due to the loss of nitrogen through denitrification, volatilization, leaching and fixation in the soil especially NO3-N and NH4-N. Higher AEN was mainly due to more capacity of the plant to increase yield per unit nutrient uptake leading to better accumulation and conversion of N from source to sink. These results are in conformity with the findings of Hulmani *et al*. (2021).

**Simple Linear Regression Analysis**

Although correlation gives information about the nature of relationship that exists between different variables, the significance of the relation and extent is not well defined (Sanam *et al*. 2021). Hence, to quantify the extent of the contribution of different variables to dependent factor like grain yield, linear regression between an explanatory variable and an explained variable was employed. The linear regression between nitrogen uptake and yield is shown in Fig. 3. It shows that nitrogen uptake has the greatest impact on grain yield when employing different levels of nitrogen and method of fertilizer application. According to the prediction power, nitrogen accounted for 90.3 per cent of grain yield.

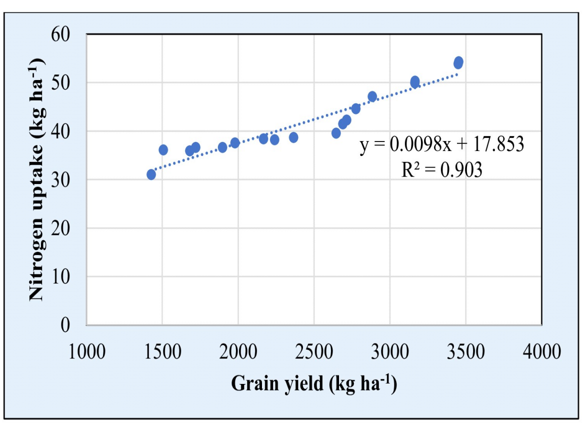


Fig. 3 : Simple Linear Regression relationship between yield and nitrogen uptake

Foliar spray of nano nitrogen and nano zinc proved extremely efficient in increasing growth and yield of finger millet. Application of 100 per cent RDN along with spraying of nano-N and nano-Zn increased growth parameters and was on par with application of 75 per cent RDN with spraying of nano-N and nano-Zn. The results of the study revealed that, application of 75per cent RDN along with foliar application of nano nitrogen and nano zinc at 35 DAS and 55 DAS recorded 24 per cent higher finger millet grain yield compared to RDF. Application of nutrients matching the crop growth need has increased productivity and also helped to reduce the use of conventional fertilizers. Thus, application of 75 per cent RDN with spraying of nano-N and nano-Zn @ 2ml $l^{-1}$ was found to be more productive.

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