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Alterations in the Nutrient Status of Soil and Enzymatic Activity of Finger Millet Cultivated Soil Accompanying to Nano Urea Application

Praveen Udapudi, Pushpa K., Sukanya T. S., Krishnamurthy R.

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ABSTRACT

An experiment was conducted at the Zonal Agricultural Research Station, Gandhi Krishi Vigyan Kendra, University of Agricultural Sciences, Bangalore, with the aim of assessing the impact of nano nitrogen on growth, yield, nutrient uptake, nitrogen use efficiency and enzymatic activity in finger millet cultivation. Among different treatments, application of 75% RDN + seed treatment with nano urea + foliar spray of nano urea at 30 and 50 DAS showed significant improvements in various growth and yield parameters of finger millet. At 90 DAS, it resulted in a remarkable increase in the number of leaves hill^{-1} (36.73), leaf area (982.90 cm^2 hill^{-1}) and leaf area index (3.28). The treatment also led to enhanced growth indices viz., absolute growth rate of 0.74 g day^{-1}, a relative growth rate of 0.029 g g^{-1} day^{-1} and a crop growth rate of 24.80 g m^2 day^{-1} during 60-90 DAS period. Significantly, it boosted the grain yield of 3,397 kg ha^{-1} for finger millet over control. Notably, this treatment exhibited higher NPK (86.56, 25.93 and 55.36 kg ha^{-1} respectively) uptake at harvest. It also demonstrated superior agronomic efficiency, internal utilization efficiency and nutrient increment efficiency of nitrogen (52.57, 39.24 and 1.40 kg kg^{-1} respectively). These findings underscore the potential of nano nitrogen in enhancing finger millet growth, increasing yield, optimizing nutrient uptake and improving nitrogen use efficiency in finger millet cultivation.

Keywords Productivity, Growth indices, Nutrient uptake, Urease activity, Nitrogen use efficiency.

Praveen Udapudi[1]*, Pushpa K.[2], Sukanya T. S.[3] , Krishnamurthy R.[4]

[2]Assistant Professor
[1,2] Department of Agronomy,
UAS, GKVK, Bengaluru 560065, India

[3]Professor
AICRP on Small Millets
ZARS, UAS, GKVK, Bengaluru 560065, India

[4]Professor & Scheme Head
AICRP on STCR
UAS, GKVK, Bengaluru 560065, India

Email: praveenvudapudi0143@gmail.com
*Corresponding author

INTRODUCTION

Finger millet (*Eleusine coracana* L. Gaertn.), commonly known as ragi, holds a paramount position among small millets due to its remarkable adaptability and productive potential particularly under limited resources and rainfed agriculture (Singh *et al.* 2022). In India, finger millet cultivation spans 1.19 million hectares, yielding approximately 1.98 million tonnes of this crucial crop with an average productivity of

1661 kg ha^{-1} (Anon 2022). Realizing its full potential for production entails the strategic supply of essential nutrients from reliable sources. Nutrient availability is essential in nurturing crop growth and ensuring sustained yields. Nitrogen (N) emerges as a cornerstone nutrient for plant growth, notably due to its pivotal role in chlorophyll synthesis, a process critical for photosynthesis. Moreover, nitrogen is a constituent of various enzyme proteins, regulating and facilitating numerous aspects of plant development (Mahantesh *et al.* 2023). Efficient nutrient management becomes imperative to maximize productivity. In cases where nutrient application lacks synchronization with crop requirements, substantial losses occur within the soil-plant system, leading to diminished fertilizer use efficiency.

To address these challenges comprehensively, modern agricultural techniques like 'Nanotechnology' come into play. Nano-fertilizers, a novel class of synthetic fertilizers containing easily accessible nutrients on a nano scale have shown promise in elevating crop yields, enhancing nutrient content in edible parts optimizing nutrient use efficiency and impacting soil nutrient status after the harvest of finger millet crop. These nano-fertilizers excel in precision agriculture by aligning nutrient supply with the dynamic demands of various crop growth stages throughout the entire growth period (Al-Juthery *et al*. 2018). Traditional soil application methods of fertilizers though widespread encounter limitations primarily concerning nutrient accessibility to plants. Inorganic nutrients often accumulate in the soil as insoluble forms, rendering them susceptible to leaching due to rainfall or irrigation. These limitations can be effectively circumvented through seed treatment and foliar application using nano urea. Notably, nitrogen supplementation through seed treatment and foliar spray has demonstrated significant efficacy (Ramya *et al.* 2020). The judicious utilization of nano-fertilizers, tailored nutrient management and innovative application techniques hold the potential to revolutionize finger millet cultivation. This not only leads to improved crop growth and yield but also positively impacts nutrient uptake, soil nutrient status post-harvest, nitrogen use efficiency and soil enzymatic activity, thereby ensuring sustainable and productive finger millet farming.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Zonal Agricultural Research Station (ZARS), Gandhi Krishi Vigyan Kendra (GKVK), University of Agricultural Sciences (UAS), Bangalore. The center is situated in the V^{th} agro-climatic zone under Eastern Dry Zone of Karnataka at 13º 05' N latitude and 77º 34' E longitude and at an altitude of 924 m above mean sea level. The soil of the experimental site was red sandy loam in texture, classified under the order Alfisols. The composite soil samples from 0 to 20 cm depth were collected randomly in experimental area before sowing from each replication. The moisture content at field capacity was 18.63% with a bulk density of 1.43 g cc^{-1}. The soil of the experimental site is slightly acidic in reaction (6.22) with lower electrical conductivity (0.24 dS m^{-1}) and organic carbon content (0.38%). It has low available nitrogen (266.80 kg ha^{-1}), medium phosphorus (28.50 kg ha^{-1}) and potassium (278.60 kg ha^{-1}) status.

Treatment details and cultivation practices

The experiment consists of eight treatments laid out in Randomized Complete Block Design with three replications. Treatments composed of application of varied levels of recommended dose of nitrogen (RDN) and nano urea as seed treatment (ST: Seed treatment with 80 ml nano nutrient kg^{-1} seed), foliar spray (FS: Foliar spray at 0.4% solution at 30 and 50 DAS) and both. T_1: Absolute control, T_2: 100% RDF, T_3: 50% RDN + ST, T_4: 50% RDN + FS, T_5: 50% RDN + ST + FS, T_6: 75% RDN + ST, T_7: 75% RDN + FS, T_8: 75% RDN + ST + FS. The finger millet variety GPU-66 seeds were sown in lines (Drill sowing) at the rate of 12.5 kg ha^{-1} at a depth of 2-3 cm, maintaining 30 cm row to row and 10 cm plant to plant spacing. The crop was fertilized with 50 kg N, 40 kg P_2O_5 and 37.5 kg K_2O through urea, single super phosphate and muriate of potash respectively. According to the treatments, seeds were treated with nano urea before 2 hrs of sowing and foliar application of nano urea at 30 and 50 days after sowing. Individual gross plot size was 3.9 m × 3.0 m (11.7 m^2). All sorts of plant protection measures along with water and weed management practices were followed in all the treatments as and when needed.

Observations recorded

Growth and yield

From the experimental plot, five plants from each net plot were tagged to record observation on growth parameters and yield. At 90 DAS, number of leaves were counted and recorded from the randomly selected five hills and expressed as number of leaves hill^{-1}. Likewise, green leaves from the selected plants from border rows were separated and used for leaf area measurement by using leaf area meter (Inc/ LI- COR Ltd., Nebraska USA) and expressed as cm^2 hill^{-1}. The grain yield obtained from each net plot area was sun dried for 4-6 days in the threshing yard. When the moisture per cent brings down to 10-12%, threshing was carried out, grains were separated, cleaned and weighed. Later the grain yield per net plot was computed on hectare basis and expressed in kilogram per hectare.

Growth indices

Leaf area index: It was worked out by dividing the leaf area hill^{-1} from land area covered by the plants as per the formula given by Watson (1952).

$$\text{LAI} = \frac{\text{Leaf area hill}^{-1}\ (\text{cm}^2\ \text{hill}^{-1})}{\text{Spacing for each hill}\ (\text{cm}^2\ \text{hill}^{-1})}$$

Leaf area duration: It was calculated between 90 DAS – at harvest by using the formula given by Power *et al.* (1967).

$$\text{LAD} = \frac{\text{LAI}_1 + \text{LAI}_2}{\ } \times (t_2 - t_1)$$

Where, LAD = Leaf area duration, expressed in days

LAI_1 = Leaf area index of hill at time t_1
LAI_2 = Leaf area index of hill at time t_2

Absolute growth rate: It represents the increasing the mass of plant per unit of time and it is expressed as g day^{-1} (Watson 1952).

$$\text{AGR} = (W_2 - W_1) / (t_2 - t_1)$$

Where, AGR = Absolute growth rate expressed in gram day^{-1}

W_1 = Dry weight of hill at time t_1
W_2 = Dry weight of hill at time t_2

Relative growth rate: It is the measurement of productivity of plant, defined as the increase in dry mass per unit of plant mass over a specified period of time and it is expressed as g g^{-1} day^{-1} (Watson 1952).

$$\text{RGR} = \text{In}(W_2) - \text{In}(W_1) / (t_2 - t_1)$$

Where, In = Natural logarithm

W_1 = Dry weight of hill at time t_1
W_2 = Dry weight of hill at time t_2

Crop growth rate: It is measured as mass increase in crop biomass per unit ground area per unit time and it is expressed as g cm^{-2} day^{-1} (Watson 1952).

$$\text{CGR} = 1/P \times (W_2 - W_1) / (t_2 - t_1)$$

Where, CGR = Crop growth rate, expressed in gram cm^{-2} day^{-1}

W_1 = Dry weight of hill at time t_1
W_2 = Dry weight of hill at time t_2
P = Land area in cm^2

Available nutrient status of soil

The available nitrogen was determined by macro Kjeldhal distillation of soil sample following alkaline permanganate method (Subbaiah and Asija 1956). The available phosphorus was determined by Bray's No.1 extractant (0.03 N NH_4F + 0.025 N HCl) method (Bray and Kurtz 1945). Similarly, the available potassium was determined by neutral normal ammonium acetate method (Jackson 1973).

Soil enzymatic activity

Determination of dehydrogenase enzyme was carried out by adopting the methodology as given by Casida *et al.* (1964). Similarly, determination of urease enzyme was carried out by adopting the methodology as given by Eivazi and Tabatabai (1977).

Nutrient uptake:

$$\text{Nutrient uptake} = \frac{\text{Nutrient concentration (\%)} \times \text{Dry matter (kg ha}^{-1}\text{)}}{100}$$

Nitrogen use efficiency (NUE)

Agronomic efficiency (AE_N) is defined as the economic production obtained per unit of nutrient applied. It can be calculated with the help of following equation and expressed as kg kg^{-1}.

$$AE_N \text{ (kg kg}^{-1}\text{)} = \frac{\text{Grain yield of fertilized plot (kg)} - \text{Grain yield of control plot (kg)}}{\text{Quantity of nutrient applied (kg)}}$$

Apparent recovery efficiency (REN) is the quantity of nutrient taken up by the crop to the per unit of nutrient applied (Fagaria *et al*. 2011) and expressed as percentage.

$$RE_N \text{ (\%)} = \frac{\text{Nutrient uptake of the fertilized plot} - \text{Nutrient uptake of the control plot}}{\text{Quantity of nutrient applied}} \times 100$$

Internal utilization efficiency (IUE_N) is defined as the yield obtained per unit of nutrient uptake. It can be calculated with the help of following equation and expressed as kg kg^{-1}.

$$IUE_N \text{ (kg kg}^{-1}\text{)} = \frac{\text{Yield obtained (kg)}}{\text{Quantity of nutrient uptake (kg)}}$$

Nutrient increment efficiency (NIE_N) is the additional grain or economic yield over the control obtained per unit of economic yield from control. It can be calculated with the help of following equation and expressed as kg kg^{-1}.

$$NIE_N \text{ (kg kg}^{-1}\text{)} = \frac{\text{Grain yield of fertilized plot} - \text{Grain yield of control plot}}{\text{Grain yield of control plot}}$$

Economic nutrient use efficiency (EE_N) is defined as the economic yield obtained per unit of rupee invested on nutrient applied. It can be calculated with the help of following equation and expressed as kg grain per ₹ invested.

$$EE_N = \frac{\text{Grain or economic yield}}{\text{Amount invested on nutrient}}$$

Statistical analysis

The experimental data pertaining to each character were analyzed statistically by using the technique of Analysis of Variance (Gomez and Gomez 1984) for Randomized Complete Block Design. The significance was tested by "Variance ratio" (F), standard error of mean (SEm ±) and critical difference (CD) were worked out for each character studied to evaluate differences between the treatments and interaction effect at 5% level.

RESULTS AND DISCUSSION

Crop growth and yield

Among the different treatments, application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS recorded significantly higher number of leaves $hill^{-1}$ (36.73), leaf area (982.90 cm^2 $hill^{-1}$), leaf area index (3.28) at 90 DAS, leaf area duration (87.38) during 90 DAS to at harvest and grain yield (3,397 kg ha^{-1}) (Table 1).

Nitrogen plays a crucial role as a constituent of chlorophyll and numerous essential amino acids, thereby promoting the production of a higher number of leaves. Nano nitrogen which facilitated swift absorption and enhanced nitrogen availability to the plants. This in turn contributed to the production of a greater number of leaves (Al-Saray and Faiz 2019).

The augmented leaf area observed at 90 DAS is likely a consequence of enhanced light interception and an elevated photosynthetic rate, ultimately resulting in improved dry matter production. The application of nitrogen in nano form to the foliage appears to offer an ample supply of nitrogen molecules and increased surface area, thereby facilitating greater nitrogen absorption. Nitrogen being a vital component of chlorophyll, plays a pivotal role in promoting the expansion of leaf area, which in turn maximizes the assimilation of photosynthates. Higher

Table 1. Effect of nano urea on number of leaves $hill^{-1}$, leaf area, leaf area index at 90 DAS, leaf area duration (during 90 DAS to at harvest) and grain yield in finger millet cultivated soil.

Treatments		Number of leaves $hill^{-1}$	Leaf area (cm^2 $hill^{-1}$)	Leaf area index	Leaf area duration (Days) (90 DAS to at harvest)	Grain yield (kg ha^{-1})
T_1	Absolute control	27.18	706.56	2.36	63.41	1415
T_2	100% RDF	30.97	896.44	2.99	78.79	2924
T_3	50% RDN + ST	28.31	802.23	2.67	69.93	2650
T_4	50% RDN + FS	29.41	836.71	2.79	72.18	2498
T_5	50% RDN + ST + FS	31.25	886.97	2.96	77.07	2678
T_6	75% RDN + ST	30.56	872.69	2.91	75.23	2608
T_7	75% RDN + FS	33.85	904.69	3.02	80.57	3058
T_8	75% RDN + ST + FS	36.73	982.90	3.28	87.38	3397
	F-test	*	*	*	*	*
	SEm ±	0.84	23.18	0.08	2.03	68.83
	CD (p=0.05)	2.55	70.31	0.23	6.17	208.76

leaf area requires a greater number of leaves (Mallikarjuna 2021). These results are in conformity with the findings of Patil *et al*. (2003) in sweet sorghum.

The notable expansion in leaf area led to a significant increase in the Leaf Area Index (LAI). LAI holds substantial importance as an agronomic parameter that serves as a valuable indicator of crop growth and provides predictive insights into crop yield. A well-suited LAI is a prominent indicator of the potential for high crop yields as it effectively manages the interplay between the crop's sink and source, ensuring a balanced development of each organ within the crop. This is in line with study of Shinggu and Gani (2012).

Leaf area duration expanded as the crop matured, representing the extent and persistence of leafiness throughout the crop's growth period. This duration effectively captures the cumulative impact of light interception and is closely linked to crop yield. The relationship is straightforward: Increased duration directly correlates with higher yield potential. With an extended duration, there is a greater window of opportunity for photosynthesis to occur, leading to increased production of dry matter and its distribution to economically valuable parts of the crop. This prolonged leaf area duration played a pivotal role in enhancing crop growth parameters and ultimately contributed to higher yields. The results were in conformity with the findings of Hunkova *et al.* (2016).

Nano urea enhances nutrient absorption by plants, facilitating the optimal development of various plant components and critical metabolic processes like photosynthesis. As a result, there is an increase in the maximum accumulation and movement of photosynthates to the economically valuable parts of the plant, ultimately ensuring a higher yield. This improvement can be attributed to the heightened strength of both the source (leaves) and the sink (economic parts) of the plant. Similar results were reported by Morsy *et al*. (2021).

Growth indices

Among the different treatments, application of 75% RDN + seed treatment with nano urea + two sprays

Table 2. Effect of nano nitrogen on growth indices during 60-90 DAS in finger millet cultivated soil.

Treatments		Absolute growth rate (g day^{-1})	Relative growth rate (g g^{-1} day^{-1})	Crop growth rate (g m^2 day^{-1})
T_1	Absolute control	0.59	0.017	19.71
T_2	100% RDF	0.70	0.026	23.44
T_3	50% RDN + ST	0.61	0.027	20.31
T_4	50% RDN + FS	0.62	0.025	20.58
T_5	50% RDN + ST + FS	0.62	0.024	20.79
T_6	75% RDN + ST	0.61	0.024	20.48
T_7	75% RDN + FS	0.70	0.026	23.26
T_8	75% RDN + ST + FS	0.74	0.029	24.80
F-test		*	*	*
SEm ±		0.018	0.0007	0.59
CD (p=0.05)		0.055	0.0022	1.79

of nano urea at 30 and 50 DAS recorded significantly higher absolute growth rate (0.74 g day^{-1}), relative growth rate (0.029 g g^{-1} day^{-1}) and crop growth rate (24.80 g m^2 day^{-1}) (Table 2).

Absolute growth rate (AGR) reached maximum at 90 DAS and thereafter it declined towards maturity. Greater AGR was mainly due to increased leaf number, leaf area and leaf area duration of plant leading to higher photosynthesis by higher nutrient availability. These results validate the findings of Sankar *et al*. (2020) who also indicated the positive effects of nitrogen on AGR of wheat crop.

Foliar application of nano nitrogen fertilizer improved the relative growth rate (RGR) due to the timely availability and efficient utilization of nutrient mainly nitrogen via nano form by the finger millet crop resulted in a greater number of leaves per hill and leaf area per hill. The results are also in conformity with the findings of Ravichandran and Srinivasan (2017).

The crop growth rate showed the curvilinear trend of increase up to 90 DAS of crop and later declined marginally due to leaf senescence. Prolonged leaf area duration has resulted in higher growth rate of crop. Further, this has been resulted in increased leaf area and leaf area index (LAI) which is a reference tool for measurement of crop growth rate where it is an indicative of higher mobilizable protein pools available at the beginning of the reproductive phase. Similar findings were also reported by Sharma and Mishra (1997).

Nutrient uptake at harvest

At harvest, significantly higher NPK uptake was recorded under application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS (86.56, 25.93 and 55.36 kg ha^{-1} respectively) and that of least NPK uptake was noticed in absolute control (41.29, 9.66 and 26.57 kg ha^{-1} respectively) (Fig. 1).

Better uptake of nitrogen might be due the fact that, foliar application of nano nitrogen that caused rapid absorption due to larger surface area and particle

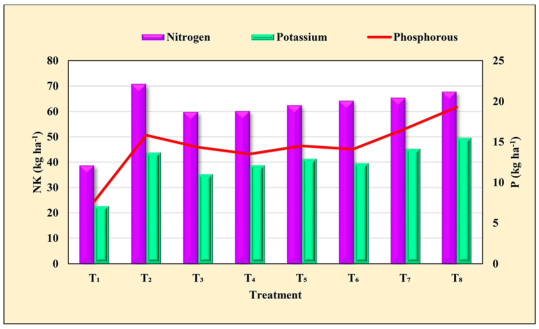

Fig. 1. Effect of nano nitrogen on total nutrient uptake (NPK) at harvest in finger millet cultivated soil.

size less than the pore size (5 to 50 nm) of leaves of the plant which can enhance penetration of nutrient into the plant tissues from applied surface and augment content and uptake of the nutrient. These results are in accordance with the findings of Chandana *et al.* (2021). As nanoparticles present in nano nitrogen triggers metabolic activities in plants resulting in increased root exudation and acidity. Subsequently, desorption of PO_4^{3-} may occurs as a result of a ligand exchange reaction triggered by plant root exudation, potentially disrupting the adsorption-desorption equilibrium and releasing phosphorus into the soil solution where it is easily available for uptake (Sahu *et al.* 2022). These results are in accordance with the findings of Lahari *et al.* 2021. Improved uptake of potassium might be due to the foliar application of nano nitrogen that have reduced particle size resulting in increased specific surface area and number of particles per unit area of a fertilizer that provide more opportunity to contact of nano-fertilizer with plants which leads to more penetration and uptake of the nutrient. These results are in accordance with the findings of Sharma *et al.* (2022).

Available nutrient status after harvest

Significantly, higher value for the available nitrogen was recorded in 100% RDF treatment (233.80 kg ha^{-1}) as compared to all other treatments. It was mainly because of higher application of nitrogen fertilizer to the soil (Table 3).

Available phosphorus and potassium did not differ significantly among the treatments. However, nu-

Table 3. Effect of nano nitrogen on available nitrogen, phosphorus and potassium after harvest in finger millet cultivated soil.

Treatmenst		Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
T_1	Absolute control	205.86	48.44	260.51
T_2	100% RDF	233.80	42.46	241.87
T_3	50% RDN + ST	211.54	43.57	249.43
T_4	50% RDN + FS	216.04	44.19	246.29
T_5	50% RDN + ST + FS	207.88	43.46	244.05
T_6	75% RDN + ST	223.24	43.74	245.54
T_7	75% RDN + FS	221.36	41.90	240.60
T_8	75% RDN + ST + FS	217.95	39.74	236.70
	F-test	*	NS	NS
	SEm±	3.15	1.53	5.97
CD (p=0.05)		9.79	-	-

merically higher values for the available phosphorus and potassium were recorded under absolute control (48.44 and 260.51 kg ha^{-1} respectively). It might be due to the lower dry matter accumulation, grain and straw yield under absolute control treatment leads to least uptake of nutrients. Hence, higher amount of phosphorus and potassium remained in the soil and the results are in conformity with the findings of Pruthviraj and Chandrashekara (2021).

The nutrient retained in the soil after harvest of the crop mainly depends on both supply of nutrients through sources and uptake by the crop. In general, higher the uptake of nutrients by crop lower will be the residual available nutrients in the soil. Further, higher the nutrients quantity supplied higher is the residual soil nutrients. However, several factors influence the uptake as well as available nutrients.

Nitrogen use efficiency

To achieve sufficient nutrient delivery and attain optimal results, fertilizer application is essential. Plants that excel in nutrient absorption and utilization significantly enhance the effectiveness of applied fertilizers. This not only reduces input costs but also helps mitigate nutrient losses into ecosystems. Employing best management techniques stands as the most effective external strategy for enhancing nitrogen use efficiency. Improved grain yields can be attributed to the enhanced nutrient utilization efficiency, stemming from the efficient utilization of provided fertilizers under favorable growth conditions (Table 4).

Higher agronomic efficiency of nitrogen (AE_N) was recorded with application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS (52.57 kg kg^{-1}). It was mainly due to the fact that, seed treatment with nano urea during sowing and lower application of conventional urea to soil and also efficient use of nano nitrogen which applied as foliar spray during 30 and 50 DAS results in greater yield with lesser nutrient applied. These results are in conformity with the findings of Hokmalipour *et al.* (2010).

Higher internal utilization efficiency of nitrogen

Table 4. Effect of nano nitrogen on nitrogen use efficiencies in finger millet cultivated soil.

Treatments		Agronomic efficiency (kg kg^{-1})	Internal utilization efficiency (kg kg^{-1})	Apparent recovery efficiency (%)	Nutrient increment efficiency (kg kg^{-1})	Economic nutrient use efficiency (kg per rupee invested)
T_1	Absolute control	-	34.27	-	-	-
T_2	100% RDF	30.18	36.05	79.73	1.07	4.79
T_3	50% RDN + ST	48.62	39.01	106.51	0.87	3.51
T_4	50% RDN + FS	43.04	38.18	96.52	0.77	2.07
T_5	50% RDN + ST + FS	50.12	38.07	115.8	0.89	1.63
T_6	75% RDN + ST	31.78	38.75	69.31	0.84	2.87
T_7	75% RDN + FS	43.63	38.65	100.52	1.16	2.25
T_8	75% RDN + ST + FS	52.57	39.24	120.10	1.40	1.88
Ftest		*	*	*	*	*
SEm ±		3.33	0.61	6.97	0.08	0.42
CD (p=0.05)		9.98	1.83	20.92	0.25	1.27

(IUEN) was recorded with application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS (39.24 kg kg^{-1}). It was mainly due to higher yields were obtained with lower amount of nitrogen applied to soil along with nano nitrogen foliar spray and seed treatment that results in efficient nitrogen utilization and reduces the risks of nitrogen losses i.e., leaching, denitrification and volatilization. These results were in conformity with the findings of Hegab *et al.* (2018).

Higher apparent recovery efficiency of nitrogen (ARE_N) was recorded with application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS (120.10%). It was mainly due to the lower application of conventional fertilizer to the soil and efficient utilization of nano nitrogen which is applied as foliar spray results in loftier yield. These results were in conformity with the findings of Hillary *et al*. (2018) and Hulmani *et al*. (2021).

Higher nutrient increment efficiency (NIE) was recorded with application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS (1.40 kg kg^{-1}). It might be due to additional yield obtained over absolute control.

Higher economic nutrient use efficiency of nitrogen (EE_N) was noticed under 100% RDF (4.79 kg grain per rupee invested). It was mainly due to the fact that higher yields were obtained per rupee invested on nitrogen fertilizer.

Table 5. Impact of nano nitrogen on dehydrogenase and urease activity in finger millet cultivated soil.

	Treatments	Dehydrogenase (µg TPF g $soil^{-1}$ 24 hr^{-1})	Urease (µg NH_4-N g $soil^{-1}$ hr^{-1})
T_1	Absolute control	73.25	14.28
T_2	100% RDF	83.95	26.59
T_3	50% RDN + ST	79.35	15.83
T_4	50% RDN + FS	84.32	16.32
T_5	50% RDN + ST + FS	85.88	17.86
T_6	75% RDN + ST	86.37	22.35
T_7	75% RDN + FS	86.81	23.11
T_8	75% RDN + ST + FS	87.69	25.83
F-test		NS	*
SEm ±		2.94	0.53
CD (p=0.05)		-	1.62

Soil enzymatic activities

Soil enzyme activities are 'sensors' of soil degradation since, they integrate information about microbial status and physico-chemical conditions of soil in relation to nutrients availability (Aon and Colaneri 2001). As a consequence, microbiological properties such as soil enzyme activities have been suggested as potential indicators of soil quality because of their rapid response to changes in soil management. The data pertained to dehydrogenase and urease activity was furnished in Table 5.

There was no significant difference in dehydrogenase activity of soil after harvest of finger millet between the treatments. But numerically higher value was recorded with application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS (87.69 µg TPF g $soil^{-1}$ 24 hr^{-1}) than other treatments. It might be due to efficient nitrogen availability and utilization which could be attributed to a higher concentration of root exudates secreted by the finger millet root system. According to Rout *et al.* (2017), root exudates are an excellent source of nutrients for microbes, especially those in the rhizosphere. Similar findings were recorded with Adhikari *et al.* (2016) in maize crop.

Significantly, higher urease activity was recorded under 100% RDF treatment (26.59 µg NH_4-N g $soil^{-1}$ hr^{-1}) and which was on par with 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS (25.83 µg NH_4-N g $soil^{-1}$ hr^{-1}). It was mainly due to the fact that application of urea fertilizer as a source of nitrogen. Urea fertilizer is easily hydrolyzed by the urease enzyme to produce carbon dioxide and ammonical nitrogen which increases urease activity (Sawicka *et al.* 2020). In contrast, application of nano nitrogen increased the plant root secretion which can induce the activity of urease in soil which increased soil nutrient availability and providing a suitable environment for soil microorganisms resulting in improved urease activity. Above findings are supported by Nibin *et al*. (2019) in wheat crop.

CONCLUSION

Based on the comprehensive analysis, the application of 75% RDN + seed treatment with nano urea + two sprays of nano urea at 30 and 50 DAS proved to be highly effective in promoting higher growth, yield, nutrient uptake, nitrogen use efficiency and soil enzymatic activity in finger millet cultivated soil. Based on the results of this experiment, it can be concluded that the use of nano nitrogen did not have a significant impact on enzymatic activity. Furthermore, the application of this nano nitrogen concentration (4 ml l^{-1}) is unlikely to be detrimental to microorganisms. Therefore, the most suitable approach for maintaining soil health appears to be a foliar spray of nano urea at a rate of 4 ml l^{-1} at 30 and 50 DAS in conjunction with 75% RDN along with full dose of P and K. Additionally, treating seeds with nano urea is recommended as part of this soil health management strategy.

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