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EFFECT OF NANO UREA ON GROWTH, YIELD AND ECONOMICS OF PEARL MILLET

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ABSTRACT

A field experiment was conducted at College of Agriculture, Bheemarayanagudi during *kharif*, 2023 to study the effect of nano urea on growth and yield of pearl millet. The experiment was laid out in RCBD with eight treatments and replicated thrice. The treatments consist of different doses of RDF with different doses of nano urea sprayed at 30 and 45 DAS. The results revealed that application of 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS recorded significantly higher growth parameters *viz*., plant height (174.78 cm), number of tillers (4.71), number of leaves (18.20), leaf area (1416.55 cm^2 $plant^{-1}$), leaf area index (3.16), dry matter production and its accumulation in different plant parts, yield parameters *viz*., length of ear head (27.33 cm), ear head weight (46.18 g $plant^{-1}$), grain weight (34.53 g $plant^{-1}$) and thousand seed weight (15.38 g), grain yield (3838 kg ha^{-1}) and stover yield (8856 kg ha^{-1}). Further, it was found to record significantly higher uptake of nitrogen, phosphorus and potassium (12.7, 43.4 and 56.1 kg ha^{-1}, respectively). Significantly higher gross returns (` 94621 $ha^{-1}$), net returns (` 59251 ha^{-1}) and BC ratio (2.68) were also recorded with 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS. It was found on par with recommended dose of fertilizers and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS. The absolute control was recorded with lower growth parameters, yield parameters, yield as well as economic returns.

Key words : Pearl millet, Nano urea, Growth, Yield, Economics.

Introduction

Pearl millet (*Pennisetum glaucum* L.) is an annual tillering diploid (2n=14) crop which belongs to family *gramineae* and subfamily *panicoideae*. Pearl millet is widely grown in the world. It has been grown in Africa and Indian subcontinent since pre-historic time. Pearl millet is commonly known as candle millet, horse millet, bulrush millet and bajra. It is a major crop of arid and semi-arid regions of India and mostly grown as rainfed crop during *kharif* season.

In India, pearl millet is a primary source of dietary energy (360 kcal kg^{-1}) for rural population and fourth most important cereal after rice, wheat and sorghum. It is rich source of protein, calcium, phosphorous and iron. Pearl millet contain fairly high amount of thiamine, riboflavin and niacin. Pearl millet is also used as poultry feed, cattle feed and alcohol extraction. Pearl millet provide grain for human consumption and for livestock in the arid and semi-arid tropics.

Pearl millet is a drought resistant crop extensively grown in arid and semi-arid regions of the world so that it is called as tropical cereal. Among major cereals, pearl millet is highly tolerant to heat, drought, saline and acid soils and it is easy to grow in arid regions where rainfall is insufficient for maize or even sorghum (FAO, 2004). Pearl millet requires a minimum temperature of around 25°C for germination and thrives well in hot climates, displaying resilience to high temperatures. The crop has ability to withstand low and erratic rainfall. Pearl millet performs well with an ideal rainfall range of 400 to 600 mm during the growing season optimizes its growth and yield. The crop prefers red, medium deep black and sandy soils with good drainage and a pH range of 6.0 to 8.5. Due to its warm-season nature and sensitivity to frost, it is typically cultivated in low to medium altitude areas.

Pearl millet is world's sixth most valuable cereal crop after wheat, rice, maize, barley and sorghum. In India, it is grown on an area of 6.8 million ha with production of 9.8 million tonnes and productivity of 1441 kg ha^{-1}, during the year 2021-22 (Anonymous, 2024). In the year 2022-2023, total production was 11.4 million tonnes and expected to produce 10.3 million tonnes in the year 2023-24. The productivity was 904 kg ha^{-1}. Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana are the major pearl millet growing states. Among them, Karnataka stands sixth in the country that produced 1.71 lakh tonnes of grains from 1.48 lakh ha area (Anon., 2024 a). The average productivity of the state is 1158 kg ha^{-1} which is much below than its production potential that vary greatly with rainfall intensity and its distribution.

Plant nutrition for cultivation of pearl millet is critical for increased productivity. Nitrogen is one of the most important macronutrients which is essential for their growth, development and yield (Tremblay *et al.*, 2011). Nitrogen is acknowledged as a vital and fundamental nutrient for enhancing crop growth rates, development and achieving optimal grain yields. Various ecological factors including temperature which influences greatly on crop growth and plant development. Augmentation of nitrogenous fertilizer levels to pearl millet are found to be a very effective for enhancing crop growth and development due to increased rate of photosynthesis (Fayyaz-ul-Hassan *et al.*, 2005).

Loss of nutrients from fields by way of leaching and gaseous emissions have been contributing to the environmental pollution and climate change, this can be reduced by the application of nano urea which has no residual effect. Urea forms 82 per cent of the total nitrogenous fertilizers consumed in India and it has recorded exponential increase in consumption over the years. It is expected that urea consumption will touch 35 million tonnes during 2020-21. Around 30-50 per cent of nitrogen from urea is utilized by plants and the rest gets wasted due to quick chemical transformation as a result of leaching, volatilization and run off losses thereby low use efficiency. The excess application of urea contributes to the greenhouse gas in form of nitrous oxide leads to global warming.

The conventional nitrogenous fertilizer industries generally produce synthetic ammonia, nitric acid, ammonium nitrate, urea and urea-ammonium nitrate (UAN). These fertilizers may also contain sulphur, chlorine, potassium, calcium, carbon besides the major nutrient nitrogen. However, the percentage of nitrogen taken up by the plants is far less than the quantity of fertilizer applied. Thereby the farmers are forced to apply more fertilizers to satisfy the plant needs. The present drawbacks forced the agricultural scientists to develop new fertilizer formulation with higher efficiency and having lesser soil, water and air pollution.

Nanotechnology is a rising field of science capable of resolving issues and problems that are impossible to tackle in engineering and biological sciences. Among the advancement in sciences, nanotechnology is being visualized as a rapidly evolving field that has potential to revolutionize agriculture and food systems as well as to improve the condition of the poor. Nanotechnology has emerged as an innovative solution with the production of nano agri-inputs for addressing the issue of low or declining nutrient use efficiency (NUE) with minimal environmental footprint. Therefore, nanotechnology is gradually moving from the experimental stage to the operational and application stage. This will lead to more tangible presence of the technology in the agricultural sector (Baruah and Dutta, 2009). In this regard, using nano fertilizer to control release of nutrients can be an effective step towards achieving sustainable agriculture and environment (Cui *et al.*, 2010).

Nano fertilizers have an effective alternative solution for addressing crop nutritional deficiencies through enhanced bioavailability of nutrients and limited losses to the environment. Nano scale materials can enhance the fertilizer use efficiency while foliar application can meet the crop nutrient requirement effectively as per its need. Whereas, the nano fertilizers are called as nutrient vectors that are developed by using nano scale raw material substrates that are ranging from 1-100 nm (Lal, 2008; Sharma, 2008) which have the ability to manipulate the materials to atom level, molecular and macromolecular scale. Nano particles have a large surface area and have the ability to retain an abundant amount of nutrients and release them slowly and stably for relatively longer time so as to facilitate the nutrient absorption that corresponds to the crop requirement without any shortcomings associated with specialized fertilizer inputs (Komarneni, 2009; Kothari *et al.*, 2019).

Nano urea is a source of nitrogen which is an essential nutrient for crop growth and development. The size of one nano urea particle is about 30 nano metre (1 nm is one billionth of a meter) compared to the granular urea which has about 10,000 times more surface area to volume size. Further, due to ultra-small size and surface properties of nano urea, it gets absorbed by the plants when sprayed on the leaves.

Thus, nano fertilizers are emerging as an alternative to conventional fertilizers becoming important tools in agriculture for improving crop growth, yield and quality parameters and reduce wastage of fertilizers. Nanotechnology can reduce the rate of fertilizer nutrients loss through leaching and increase their availability to plants which ultimately leads to reduced water and soil pollution. The use of nitrogen nano fertilizer is essential for reducing higher requirement of fertilizer, cost and environment issues.

Materials and Methods

The experimental site was geographically situated in North Eastern Dry Zone (Zone - II) of Karnataka at a Latitude of 16º15′ North, Longitude of 77º21′ East with an Altitude of 389 meters above mean sea level. The soil of the experimental site was medium black to deep black with clay loam texture. The College of Agriculture, Bheemarayanagudi (UAS Raichur) comes under UKP command where rice-rice, chilli, cotton and redgram are predominant crops.

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications and eight treatments comprising of different doses of RDF with different doses of nano urea sprayed at 30 and 45 DAS. The treatments consisting of T_1: 50% RDN as basal + nano urea spray @ 2.0 ml l^{-1} at 30 and 45 DAS, T_2: 50% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS, T_3: 50% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS, T_4: 75% RDN as basal + nano urea spray @ 2.0 ml l^{-1} at 30 and 45 DAS, T_5: 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS, T_6: 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS, T_7: RDF (100:50:25 kg N: P_2O_5: K_2O ha^{-1}: FYM @ 6.0 t ha^{-1}) and T_8: Absolute control (No NPK).

Results and Discussion

Growth parameters

Plant height : It is evident from the data that the plant height progressively increased with the advancement in the age of crop up to harvest. Foliar application of nano urea had significant influence on plant height at all the stages of crop growth and development except at 30 DAS. However, at 30 DAS, the maximum plant height was obtained with the application of recommended dose of fertilizers (32.09 cm) and minimum with absolute control (24.26 cm) at tillering stage. At 60 DAS and at harvest, significantly higher plant height was obtained with application of 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS (161.42 and 174.78 cm, respectively). Application of recommended dose of fertilizers was found as next best treatment which recorded plant height of 158.14 and 168.81 cm, respectively and it was closely followed by application of 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (152.98 and 168.48 cm, respectively) and all these treatments were statistically on par with each other. Significantly lower plant height of 110.44 and 126.84 cm was recorded with absolute control at 60 DAS and at harvest, respectively (Table 1 and Fig. 1).

Significant increase in plant height might be due to the fact that basal application of conventional fertilizers along with foliar spray of nano urea increased the availability of nutrients to the growing plant. Nano urea helped in quick absorption of nutrients through stomata of leaves resulted in increased chlorophyll formation, photosynthetic rate, dry matter production, activity of enzymes and auxin metabolism in the plant, which in turn enlarge the cell and cell elongation might have resulted in taller plants. These results are in conformity with the findings of Yasser *et al.* (2020) and Mallikarjuna (2021) in maize, Sharma *et al.* (2021) in pearl millet, Midde *et al.* (2022) in rice and Balachandar *et al.* (2023) in sorghum.

Number of leaves plant^{-1} : Non-significant variations were observed with number of leaves per plant of pearl millet at 30 DAS due to foliar spray of nano urea at different doses. However, the maximum number of leaves per plant were obtained with the application of recommended dose of fertilizers (12.57) and minimum number of leaves per plant were recorded with absolute control (9.09). At 60 DAS and at harvest, application of 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS recorded significantly higher number of leaves plant^{-1} (26.35 and 18.20, respectively) and it was found at par with T_7: Recommended dose of fertilizers (24.90 and 17.11, respectively) and T_5: 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (25.31 and 16.71, respectively). However, absolute control recorded lower number of leaves plant^{-1} at 60 DAS and at harvest (13.91 and 7.91, respectively) (Table 1).

Combined application of nitrogenous fertilizer and nano urea increased the availability of nitrogen which accelerated the enzymatic activity of photosynthesis, carbohydrate metabolism, synthesis of protein and cell division which in turn enhanced the plant height. As a consequence of increased plant height, the number of

Table 1 : Plant height and number of leaves plant^{-1} at different growth stages of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

Treatment	Plant height (cm)			Number of leaves per plant^{-1}		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1	28.52	122.06	132.25	11.05	17.21	12.33
T_2	28.69	131.63	140.89	11.31	19.24	12.61
T_3	29.35	127.21	143.52	11.32	20.33	13.27
T_4	30.09	138.47	159.56	11.88	22.20	14.21
T_5	30.78	152.98	168.48	11.89	25.31	16.71
T_6	31.79	161.42	174.78	11.93	26.35	18.20
T_7	32.09	158.14	168.81	12.57	24.90	17.11
T_8	24.26	110.44	126.84	9.09	13.91	7.91
S.Em. ±	**1.82**	**2.22**	**3.06**	**0.72**	**0.60**	**0.61**
C.D. at 5%	**NS**	**6.74**	**9.29**	**NS**	**1.83**	**1.86**

Note:

NS - Non significant

RDF - 100:50:25 kg N:P_2O_5:K_2O ha^{-1}; FYM @ 6 t ha^{-1}

RDN - Recommended Dose of Nitrogen (100 kg ha^{-1})

DAS - Days After Sowing

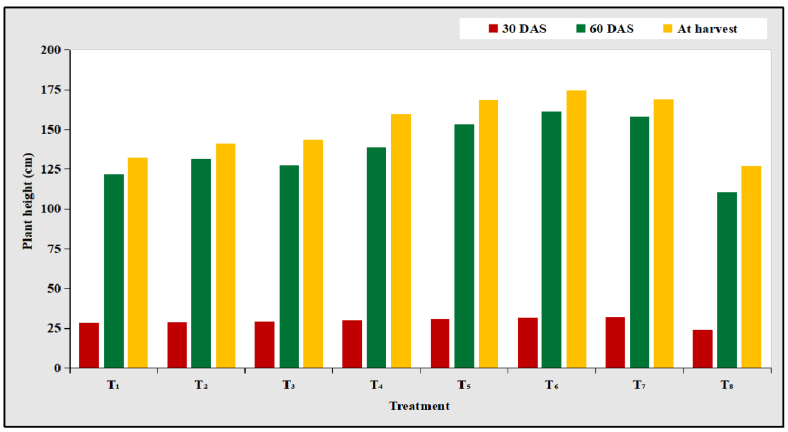

Fig. 1 : Plant height (cm) at different growth stages of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

nodes and internodes increased and thus resulted in higher number of leaves. Similar results were also obtained by Babubhai *et al.* (2019) in *rabi* maize, Yasser *et al*. (2020) in maize, Bhavani *et al.* (2020) in aerobic rice and Rajput *et al.* (2022) in little millet.

Leaf area (cm^2 plant^{-1}) : At 30 DAS, there was no significant difference in leaf area among different treatments. However, the treatment T_7: Recommended dose of fertilizers recorded numerically higher leaf area (635.64 cm^2 plant^{-1}) than absolute control which recorded lower leaf area (545.63 cm^2 plant^{-1}). At 60 DAS and at harvest, the treatment receiving 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS recorded significantly higher leaf area per plant (1894.25 and 1416.55 cm^2 plant^{-1}, respectively) over other treatments. Further, this treatment was found on par with recommended dose of fertilizers (1859.59 and 1398.86 cm^2 plant^{-1}, respectively) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (1827.62 and 1356.45 cm^2 plant^{-1}, respectively). Significantly lower leaf area per plant was recorded with absolute control (1387.12 and 1119.33 cm^2 plant^{-1}, respectively) (Table 2).

Increase in number of leaves per plant ultimately increased leaf area with application of 75% RDN as basal + nano urea spray @ 4 ml l^{-1} at 30 and 45 DAS followed by recommended dose of fertilizers 75% RDN as basal + nano urea spray @ 3 ml l^{-1} at 30 and 45 DAS as compared to all other treatments. Adequate supply of nitrogen through conventional fertilizers and nano urea at right concentration might be helped in production of higher number of leaves due to reduced competition among the plants for nutrients which yielded higher leaf area. Further, it might also be due to increased number of leaves. These results are in conformity with the findings of Rajesh *et al*. (2021) in sweet corn, Samanta *et al*. (2022) in finger millet, Sharma *et al.* (2021) in pearl millet and Bhargavi and Sundari (2023) in rice.

Leaf area index : The leaf area index at 30 DAS did not differ significantly due to application of different levels of nitrogenous fertilizer and foliar spray of nano urea. However, numerically higher leaf area index was recorded with application of recommended dose of fertilizers (1.41) and lower with the absolute control (1.21) at tillering stage. At 60 DAS and at harvest, significantly higher leaf area index was registered with the treatment which received 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS (4.32 and 3.16, respectively). However, it was statistically on par with application of recommended dose of fertilizers (4.13 and 3.11, respectively) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (4.06 and 3.02, respectively). Significantly lower leaf area index was recorded with absolute control (3.08 and 2.49, respectively) (Table 2).

The increase in leaf area index was due to increase in number of leaves and leaf area plant^{-1} of pearl millet. As a result of foliar spray of nano urea along with basal dose of conventional fertilizers, the availability of nitrogen increased. The increased availability of nitrogen resulted in increased plant height, number of leaves, leaf area and in turn increased leaf area index. Mallikarjuna (2021) in maize, Rajput *et al.* (2022) in little millet, Samanta *et al.* (2022) in finger millet and Bhargavi and Sundari (2023) in rice were also obtained similar results in their investigation.

Number of tillers plant^{-1} : Professed tillering per plant is an important factor determining the growth and it contributes towards yield. The number of tillers plant^{-1} increased continuously up to 60 DAS and there after it remains constant till harvest. At 30 DAS, number of tillers plant^{-1} did not differ significantly among different treatments. However, application of recommended dose of fertilizers recorded higher number of tillers plant^{-1} (2.75) followed by 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS (2.41). Lower number of tillers plant^{-1} were recorded with absolute control (1.15). At 60 DAS, the lower number of tillers plant^{-1} was observed with absolute control (2.27). The treatment T_6: 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS recorded significantly higher number of tillers plant^{-1} (4.81) over rest of the treatments. This treatment was statistically on par with that of recommended dose of fertilizers (4.51) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (4.41). At harvest, number of tillers per plant followed same trend as that of 60 DAS. But observed slight decrease in their number in all the treatments (Table 3).

The increase in number of tillers per plant might be due to nitrogen application through soil as well as foliar spray of nano urea. The nitrogen plays important role in increasing cell number and cell size resulted in higher number of tillers. The similar results were also reported by Benzon *et al.* (2015) and Rathnayaka *et al.* (2018) in rice, Mehta and Bharat (2019) and Singh *et al.* (2022) in wheat, Arya *et al.* (2022) in pearl millet.

Total dry matter production (g plant^{-1}) : The data revealed that non-significant difference among the treatments were observed due to different levels of nitrogenous fertilizers and foliar spray of nano urea at 30 DAS. However, higher and lower total dry matter production was found with recommended dose of fertilizers (13.49 g plant^{-1}) and absolute control (11.22 g plant^{-1}), respectively. At 60 DAS and at harvest, among different treatments, the treatment receiving 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS recorded significantly higher total dry matter production (72.95 and 246.45 g plant^{-1}, respectively) and it was found on par with recommended dose of fertilizers (69.58 and 237.62 g plant^{-1}, respectively) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (68.88 and 234.34 g plant^{-1}, respectively). Significantly lower total dry matter production in pearl millet was recorded with absolute control (46.39 and 161.18 g plant^{-1}, respectively) (Table 3 and Fig. 2).

Dry matter accumulation increased with the crop age and reached maximum at harvest. Nitrogen application both as basal soil application and foliar spray in later stages improved the overall crop growth and development due to improved dry matter accumulation. The higher total dry matter production could be attributed to luxuriant growth, taller plants, more green leaves and leaf area. The plants made better use of available resources, resulted in increased dry matter accumulation. Tiny size of nano fertilizers resulted in better absorption of nutrients which might have been helped plant growth mechanisms. Plant metabolic activities such as chlorophyll synthesis and photosynthetic activity enhanced vegetative growth which might be due to proper supply of nutrients in time and accumulation of dry matter in leaves helped the photosynthetic area to remain active for longer period and was responsible for overall growth of plant in terms of dry matter production. Nano urea has higher nutrient use efficiency resulted in higher growth and dry matter production. Similar observations were observed by Yasser *et al.* (2020) and Mallikarjuna (2021) in maize, Singh *et al.* (2022) in wheat, Balachandar *et al.* (2023) and Chinnappa *et al.* (2023) in sorghum.

Yield parameters

Length of ear head (cm) : Length of ear head varied significantly due to different levels of nitrogenous fertilizer and foliar spray of nano urea. Significantly higher ear head length was recorded in 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS (27.33 cm) and found on par with recommended dose of fertilizers (26.28 cm) and 75% RDN as basal + nano urea spray @

Table 2 : Leaf area and leaf area index at different growth stages of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

Treatment	Leaf area (cm^2 $plant^{-1}$)			Leaf area index		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1	618.26	1645.65	1249.85	1.36	3.66	2.78
T_2	618.35	1690.02	1265.56	1.36	3.76	2.81
T_3	620.45	1739.57	1298.25	1.37	3.87	2.89
T_4	628.55	1784.45	1320.56	1.39	3.97	2.93
T_5	628.90	1827.62	1356.45	1.40	4.06	3.02
T_6	630.98	1894.25	1416.55	1.40	4.32	3.16
T_7	635.64	1859.59	1398.86	1.41	4.13	3.11
T_8	545.63	1387.12	1119.33	1.21	3.08	2.49
S.Em. ±	**30.33**	**37.36**	**22.05**	**0.18**	**0.10**	**0.05**
C.D. at 5%	**NS**	**113.31**	**66.87**	**NS**	**0.32**	**0.15**

Note:
NS - Non significant, **RDN -** Recommended Dose of Nitrogen (100 kg ha^{-1})
RDF -100:50:25 kg N:P_2O_5:K_2O ha^{-1}; FYM @ 6 t ha^{-1}, **DAS -** Days After Sowing.

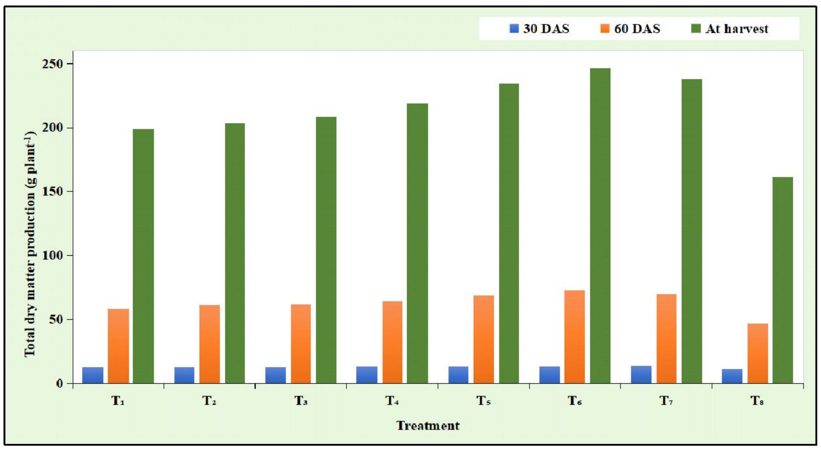

Fig. 2 : Total dry matter production (g $plant^{-1}$) at different growth stages of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

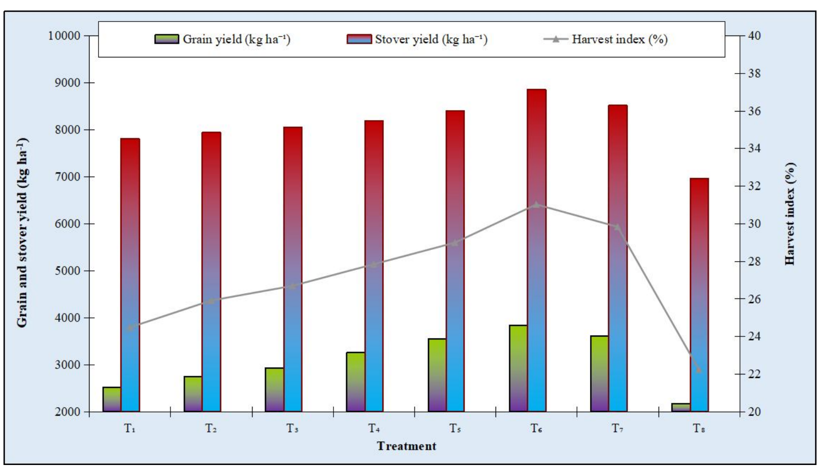

Fig. 3 : Grain yield, stover yield and harvest index of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

3.0 ml l^{-1} at 30 and 45 DAS (25.39 cm). Significantly lower ear head length (17.59 cm) was recorded with absolute control (Table 4).

Ear head weight (g $plant^{-1}$) : The ear head weight differed significantly among the treatments as influenced by different levels of nitrogenous fertilizers and foliar spray of nano urea and data is presented in Table 4. Significantly higher ear head weight was found with the treatment which received 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS (128.93 g $plant^{-1}$). It was found on par with the treatment which received recommended dose of fertilizers (126.23 g $plant^{-1}$) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (125.23 g $plant^{-1}$). Significantly lower ear head weight was observed with absolute control (82.27 g $plant^{-1}$) (Table 4).

Grain weight (g $plant^{-1}$) : The variation in the grain weight of pearl millet was due to different levels of nitrogenous fertilizer and foliar spray of nano urea. Among different treatments, application of 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS produced significantly higher grain weight (34.53 g $plant^{-1}$) and it was found on par with recommended dose of fertilizers (32.34 g $plant^{-1}$) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (31.70 g $plant^{-1}$). Significantly lower

Table 3 : Number of tillers plant^{-1} and total dry matter production at different growth stages of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

Treatment	Number of tillers plant^{-1}			Total dry matter production (g plant^{-1})		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1	2.14	3.34	3.14	12.62	58.19	199.08
T_2	2.14	3.48	3.38	12.63	60.88	203.2
T_3	2.15	3.62	3.52	12.69	61.64	208.35
T_4	2.39	4.08	4.08	13.06	64.43	218.7
T_5	2.40	4.41	4.51	13.24	68.88	234.34
T_6	2.41	4.81	4.71	13.33	72.95	246.45
T_7	2.75	4.51	4.53	13.49	69.58	237.62
T_8	1.15	2.27	2.17	11.22	46.39	161.18
S.Em. ±	**0.33**	**0.15**	**0.14**	**1.29**	**1.62**	**4.03**
C.D. at 5%	**NS**	**0.46**	**0.42**	**NS**	**4.91**	**12.24**

Note:
NS - Non significant, **DAS -** Days After Sowing
RDN - Recommended Dose of Nitrogen (100 kg ha^{-1})
RDF -100:50:25 kg N:P_2O_5:K_2O ha^{-1}; FYM @ 6 t ha^{-1}

Table 4 : Yield parameters of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

Treatment	Length of ear head (cm)	Ear head weight (g plant^{-1})	Grain weight (g plant^{-1})	Thousand seed weight (g)
T_1	19.75	106.28	26.91	12.26
T_2	21.35	107.20	27.89	12.31
T_3	21.77	108.98	29.43	13.26
T_4	23.53	116.16	30.50	13.66
T_5	25.39	125.23	31.70	13.94
T_6	27.33	128.93	34.53	15.38
T_7	26.28	126.23	32.34	14.14
T_8	17.59	82.27	20.81	10.59
S.Em. ±	**1.26**	**1.89**	**1.09**	**0.73**
C.D. at 5%	**3.81**	**5.73**	**3.30**	**2.23**

Note:
NS - Non significant
RDN - Recommended Dose of Nitrogen (100 kg ha^{-1})
RDF -100:50:25 kg N:P_2O_5:K_2O ha^{-1}; FYM @ 6 t ha^{-1}
DAS - Days After Sowing

grain weight was noticed with absolute control (20.81 g plant^{-1}) (Table 4).

Thousand seed weight (g) : The data related to influence of different levels of nitrogenous fertilizer and foliar spray of nano urea on thousand seed weight of pearl millet varied significantly among different treatments. Significantly lower thousand seed weight was recorded with absolute control (10.59 g). Application of 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS produced significantly higher thousand seed weight (15.38 g). Further, this treatment was found statistically on par with recommended dose of fertilizers (14.14 g) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (13.94 g) (Table 4).

Yield

Grain yield : Application of different levels of nitrogenous fertilizer and foliar spray of nano urea showed a significant effect on the grain yield of pearl millet. Among all treatments, 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS recorded significantly higher grain yield (3838 kg ha^{-1}) over rest of the treatments and was found on par with recommended dose of fertilizers (3617 kg ha^{-1}) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (3551 kg ha^{-1}). Significantly lower grain yield was recorded with absolute control (2179 kg ha^{-1}) (Table 5 and Fig. 3).

Higher grain yield was recorded with application of 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30

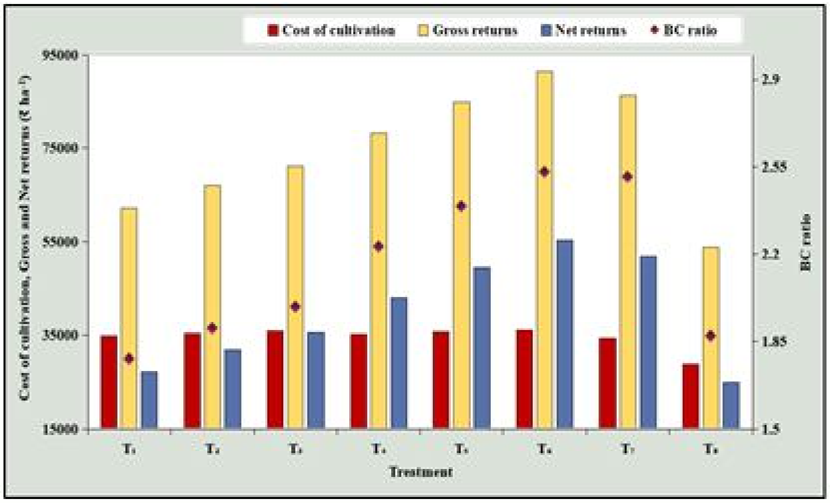

Fig. 4 : Economics of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

Table 5 : Grain yield, stover yield and harvest index of pearl millet as influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea.

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1	2522	7809	24.47
T_2	2751	7943	25.90
T_3	2936	8053	26.68
T_4	3258	8185	28.26
T_5	3551	8400	30.02
T_6	3838	8856	30.23
T_7	3617	8515	29.82
T_8	2179	6961	22.23
S.Em. ±	**95**	**203**	**2.60**
C.D. at 5%	**288**	**615**	**NS**

Note: NS - Non significant, **RDN -** Recommended Dose of Nitrogen (100 kg ha^{-1})
RDF -100:50:25 kg N:P_2O_5:K_2O ha^{-1}; FYM @ 6 t ha^{-1}, **DAS -** Days After Sowing.

and 45 DAS might be attributed due to higher yield components *viz.*, ear head length, ear head weight, grain weight and thousand seed weight. In addition to this, combined application of nitrogenous fertilizer and foliar spray of nano urea ensured optimum and balanced nutrient availability throughout the crop period especially during the critical stages of crop needs the smaller size particle lead to larger effective surface area of nano particles could be helped to easily penetrate into the plant and lead to better uptake of nitrogen. The higher uptake resulted optimal growth of plant parts and metabolic processes like photosynthesis that increase photosynthates accumulation and translocation to the economically productive parts of the plant which resulted increased biomass, yield attributing characters and finally yield by amplifying the translocation of assimilates to seeds. Similar results were reported by Sharma *et al.* (2021) in rice, Arya *et al.* (2022), Khan *et al.* (2023) and Karanjikar *et al.* (2024) in pearl millet, Bhargavi and Sundari (2023) in rice and Chinnappa *et al.* (2023) in sorghum.

Stover yield : Stover yield of pearl millet was significantly influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea. Application of 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS recorded significantly higher stover yield (8856 kg ha^{-1}) as compared to other treatments and it was found on par with recommended dose of fertilizers (8515 kg ha^{-1}) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (8400 kg ha^{-1}). Significantly lower stover yield was produced with absolute control (6961 kg ha^{-1}) (Table 5 and Fig. 3).

Higher stover yield indicated more dry matter retained at harvest. Stover yield of pearl millet have positive relationship with plant growth parameters such as plant height, number of leaves per plant, leaf area per plant, LAI, number of tillers per plant and dry matter accumulation in different parts of the plant (leaves, stem and ear head). Likewise, the increase in stover production might be credited due to foliar spray of nano urea which enhanced rapid uptake by the plant and ease of translocation which assisted in a quicker rate of photosynthesis and more dry matter accumulation resulted in higher stover yield. It was also noticed that the addition of nitrogenous fertilizer as well as foliar spray of nano urea increased the absorption area which contributed to increase the accumulation of dry matter and improving plant growth in general. The results were in conformity with the findings of Yasser *et al.* (2020) and Mallikarjuna (2021) in maize, Samui *et al.* (2022) in *rabi* maize, Khan *et al.* (2023) and Karanjikar *et al.* (2024) in pearl millet.

Harvest index : Harvest index of pearl millet was not influenced by different levels of nitrogenous fertilizer and foliar spray of nano urea. However, higher and lower harvest index was recorded in 75% RDN as basal + nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS (30.23%) and absolute control (22.23%), respectively (Table 5 and Fig. 3).

Economics

Significantly higher gross returns, net returns and BC ratio were noticed with application of 75% RDN as basal

+ nano urea spray @ 4.0 ml l^{-1} at 30 and 45 DAS (` 91,373 $ha^{-1}$, ` 55,316 ha^{-1} and 2.53, respectively) and it was found on par with recommended dose of fertilizers (` 86,287 $ha^{-1}$, ` 51,895 ha^{-1} and 2.51, respectively) and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS (` 85,026 $ha^{-1}$, ` 49,459 ha^{-1} and 2.39, respectively). Lower gross returns, net returns and BC ratio were noticed with absolute control (` 53,802 $ha^{-1}$, ` 25,002 ha^{-1} and 1.87, respectively) (Fig. 4).

Conclusion

Application of 75 per cent RDN along with nano urea spray @ 4 ml l^{-1} at 30 and 45 DAS was found beneficial for effective management of nitrogen requirement of pearl millet and recorded higher growth parameters, yield parameters and yield of pearl millet. With the application of both conventional and nano nitrogen fertilizer, yield and yield parameters of pearl millet can be boosted. Higher economic returns were also found with the treatment 75 per cent RDN along with nano urea spray @ 4 ml l^{-1} at 30 and 45 DAS and this was found on par with recommended dose of fertilizers and 75% RDN as basal + nano urea spray @ 3.0 ml l^{-1} at 30 and 45 DAS.

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