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Effect of Nano Fertilizers on Growth, Yield, Nutrient Uptake and Soil Microbiology of *Kharif* Sorghum

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Foliar nutrition is aimed to eliminate the problems of fixation and immobilization of nutrients. Hence, foliar nutrition is being recognized as a significant way of fertilizing modern agriculture, especially under rainfed conditions. Nano fertilizers because of smaller size and higher surface

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area are efficient as compared to conventional and produce better results when used in combined form.
Study Design: The experiment was laid out in Randomized complete block design with three replications.
Place and Duration of Study: A field experiment was conducted in medium black soils at Agricultural Research Station, Hagari, during *Kharif* 2022.
Methodology: There were ten treatment combinations, consisting of different doses of RDF (50 % RNP, 75 % RNP and 100 % RDF and absolute control) with different doses of nano urea and Dap sprayed at 30 and 45 DAS for CSH-16 hybrid of sorghum.
Results: Application of 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS recorded significantly higher number of leaves, leaf area and leaf area index. It also produced higher earhead length (35.9 cm), number of grains $earhead^{-1}$ (2207), grain weight (57 g $plant^{-1}$) and test weight (29.3 g 1000 $grains^{-1}$). Nutrient content and uptake also showed higher values for the same treatment along with the nutrient use efficiency indices. Whereas, significant reduction in soil microbes was noticed by the application of treatment.
Conclusion: Combined application of conventional and nano fertilizers helped to increase growth, growth attributes like number of leaves, leaf area, leaf area index, yield attributes, nutrient content, nutrient uptake and nutrient use efficiency of sorghum.

Keywords: Sorghum; foliar nutrition; nano urea; nano DAP; IFFCO.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is an important crop for resource poor, small and marginal farmers in semi-arid regions. The rainy season (*Kharif*) sorghum grain is used both for human consumption and livestock feed and post-rainy season (*rabi*) produce is used primarily for human consumption in our country. Thus, it is the key for the sustenance of human and livestock populations. In India the area and production of sorghum during 2022-23 was 4.5 m ha and 4.4 m t, respectively with a productivity of 978 kg ha^{-1} [1]. In Karnataka the area and production of sorghum during 2022-23 was 0.75 m ha and 0.903 m t, respectively with a productivity of 1205 kg ha^{-1} [2].

In order to get higher yield farmers are applying higher dose of fertilizers which is causing a huge impact on environment. The NUE (Nutrient use efficiency) of basic nutrients like nitrogen (N) is 30-35 per cent and that of phosphorus (P) and potassium (K) is 18-20 per cent and 35-40 per cent, respectively. This has resulted into decrease in crop response to application of plant nutrients from 15 kg food grain kg^{-1} NPK during 1974-79 to less than 6 kg food grain kg^{-1} NPK in 2007-12 [3]. The diminished NUE threatens the future production and food security. Alternatively, fertilizer use efficiency (FUE), which is dependent on several factors including nutrient uptake and soil health, determines agricultural and environmental stability. As Sorghum being a nutritive exhaustive crop, it demands relatively higher amount of fertilizers but unscientific fertilizer management has affected the soil health and resulted in avert yield responses to applied fertilizer.

In order to complement the nutritional needs of crops, foliar spraying of nutrients coupled with basal applicational of conventional fertilizers provides a number of benefits. India's dry land tracts experience moisture deficits, which reduce production since fewer nutrients are available there. With this approach, nutrients are used more effectively and shortages are quickly corrected. New generation special fertilizers that are just intended for foliar feeding and fertilization have recently been launched.

We need to use new generation special fertilizers like nano fertilizers which have emerged as 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 [4] 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 a relatively longer time so as to facilitate the nutrient absorption that corresponds to the crop requirement without any shortcomings associated with specialized fertilizer inputs [5].

Nano urea and DAP fertilizers have been developed indigenously, for the first time in the world at IFFCO Nano Biotechnology Research Centre (NBRC), Kalol, Gujarat through a proprietary patented technology. Farmers are using urea and DAP fertilizers for soil as well as foliar application to crops. However, the efficacy is lower. Thus, the goal of the current study is to determine the effect of nano fertilizers on growth, yield, nutrient uptake and soil microbiology of *kharif* sorghum.

2. MATERIALS AND METHODS

A field experiment was conducted during *kharif*, 2022 at Agricultural Research Station, Hagari, on *Vertisol* having pH 7.95 and EC 0.79 dS m^{-1}. The soil was medium in organic carbon content (5.4 g kg^{-1}) and available P_2O_5 (42.70 kg ha^{-1}), and low in available N (236.50 kg ha^{-1}) with high available K_2O content (348.60 kg ha^{-1}). The experimental site was located at a latitude of 15˚ 13´ North, longitude of 7˚ 05´ East and an altitude of 414 meters above mean sea level in North Eastern Dry Zone of Karnataka (Zone 2).

During the cropping period of 2022-23, a total rainfall of 602.1 mm was received from July 2022 to October 2022 as against the normal rain of 390 mm. The average maximum air temperature was recorded in the month of June (34.4 ºC) during the experimental period. The mean minimum temperature was more than normal during July, August and October, and less than the normal in the months of June and September. The mean monthly relative humidity ranged from 77.9 per cent in October to 93.3 per cent in September during the crop growth period and it was more than the normal during the months of June, July, August and September and less than the normal in October as given in Fig. 1.

The research was arranged in Randomized complete block design, there were ten treatments consisting of different doses of RDF (four treatments with 50% RNP, four with 75% RNP, one with 100% RDF and one absolute control) with different doses of nano urea and DAP sprayed at 30 and45 days after sowing (DAS). After the previous crop was harvested, the ground was ploughed once again, followed by two harrowing. The field was prepped to a

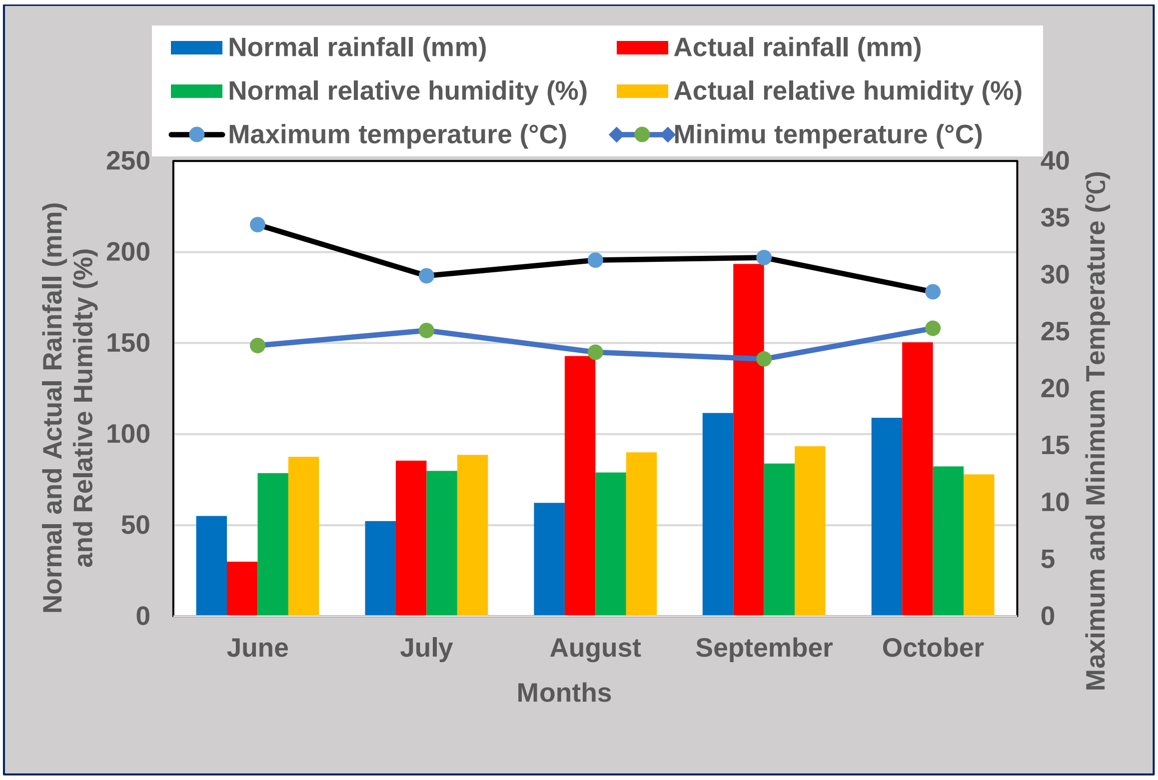

Fig. 1. Monthly meteorological data for experimental year (2022) against normal for 25 years at ARS, Hagari (Karnataka)

good seedbed and the fields were set out in preparation for sowing. The hybrid CSH-16 was used. The basal application of fertilizers in the form of urea, DAP, MOP and $ZnSo_4$ were applied as per treatments with recommended dose of 100:75:37.5:15 kg $N:P_2O_5:K_2O:ZnSo_4$ ha^{-1}. The crop was sown on 04^{th} July 2022 with a spacing of 45 × 15 cm. The crop was irrigated next day for uniform germination. Intercultivation was done to remove all weeds from the field in order to check crop weed competition. Growth parameters such as number of leaves and leaf area were recorded at interval of 30 days. Harvesting was done at physiological maturity of the crop. The earheads were harvested from the standing crop in the net plot area and were sun dried. The sun dried earheads were threshed, cleaned and yield parameters were recorded. The samples were collected harvest and dried at 65 ^{0}C in a hot air oven, powdered using a grinder, fitted with stainless steel bladders and preserved in polythene bags for further analysis of uptake of N, P and K as suggested by Jackson (1973) [6]. During the field experiment, a composite soil sample was collected from experimental plot before sowing. After harvest of the crop, soils from each treated plot were taken separately. The collected soil samples were dried under shade, powdered using pestle and mortar and passed through 2 mm sieve and preserved for analysis. For organic carbon analysis, the 2 mm sieved soil samples were subjected for further grinding and passed through 0.2 mm sieve. Samples were analyzed for organic carbon, available nitrogen, phosphorus, potassium and soil microbiology parameters.

2.1 Statistical Analysis

The data collected from the experiment at different growth stages and at harvest were subjected to statistical analysis as described by Panse and Sukhatme (1967) [7]. The level of significance used for 'F' test was P=0.05. Critical Difference (CD) values were calculated at 5 per cent probability level if the F test will find to be significant.

3. RESULTS AND DISCUSSION

3.1 Growth Attributes

significantly higher number of leaves per plant were noticed in the treatment receiving 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS (11.8, 12.1 and 8.9 at 60, 90 DAS and at harvest, respectively) (Table 1). Similar results were reported by Rajput et al. [8] and Maheta et al. [9]. Combined application of chemical and nano fertilizers increased the availability of nitrogen and phosphorous 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 nodes and internodes increased which resulted in higher number of leaves.

Higher leaf area and leaf area index of sorghum were recorded by application of 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS (30.0, 35.2 and 30 dm^2 $plant^{-1}$ and 4.44, 5.21 and 4.45, at 60, 90 DAS and at harvest, respectively). Adequate supply of nitrogen and phosphorous through conventional and nano fertilizers at right concentration would help in production of more number of leaves due to reduced competition among the plants for nutrients which yielded in higher leaf area. The increased leaf area resulted in increased leaf area index. These findings were in accordance with Mallikarjuna [10].

3.2 Yield Attributes

Significantly higher length of earhead (35.9 cm), number of grains $earhead^{-1}$ (2207), grain weight (57.0 g $plant^{-1}$) and test weight (29.0 g 1000 $grains^{-1}$) was recorded by application of 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS (Table 2). Similar results were reported by Sharma et al. [11] and Chavan et al. [12] Combined application of conventional and nano fertilizers (nano urea and DAP) ensured optimum and balanced nutrient availability throughout the crop period especially during the critical stages of crop. This is due to smaller size and larger effective surface area of nano particles which can easily penetrate into the plant and lead to better uptake of nitrogen and phosphorous. The higher uptake results in 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 results in increased biomass, yield attributing characters and finally yield by amplifying the translocation of assimilates to grains.

3.3 Nutrient Uptake and Available Nutrients in Soil at Harvest

The uptake of major nutrients *viz.,* nitrogen (133.9 kg ha^{-1}), phosphorous (53.8 kg ha^{-1}) and potassium (109 kg ha^{-1}) was significantly higher in treatments receiving the foliar application of 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS (Fig. 2). The increase in nutrient uptake was due to nano fertilizers which have higher surface area and smaller particle size, less than the pore size of root and leaves of the plant which can increase their penetration into the plant from applied surface and improve nutrient uptake. The results are in accordance with the findings of Gupta et al. [13].

Significantly higher available nitrogen, phosphorous and potassium was recorded in recommended dose of fertilizers (RDF) (209.3, 43.3 and 301.2 kg ha^{-1}). Higher available soil nitrogen, phosphorus and potassium were noticed in recommended dose of fertilizers as higher amount of fertilizers (100 %) were applied in this treatment as compared to others. Similarly, least was noticed in absolute control as no fertilizers (0 %) were applied. The results are in accordance with the findings of Sahu et al. [14].

Table 1. Number of leaves per plant, leaf area and leaf area index of sorghum as influenced by different levels of chemical and nano fertilizers

Treatments	Number of leaves			Leaf area (dm 2 plant -1) and leaf area index		
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
T_1 : 50% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	9.3	10.0	7.7	22.8(3.38)	27.9(4.13)	25.5(3.78)
T_2 : 50% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	8.9	9.9	7.5	22.4(3.32)	26.6(3.94)	24.7(3.66)
T_3 : 50% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	9.8	10.6	8.0	24.2(3.59)	30.0(4.45)	26.7(3.95)
T_4 : 50% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	9.5	10.3	7.8	23.3(3.45)	29.0(4.30)	25.8(3.83)
T_5 : 75% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	10.7	10.9	8.3	26.8(3.97)	31.4(4.65)	28.0(4.15)
T_6 : 75% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	10.1	10.7	8.1	25.0(3.70)	31.1(4.60)	27.0(4.0)
T_7 : 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	11.8	12.1	8.9	30.0(4.44)	35.2(5.21)	30.0(4.45)
T_8 : 75% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	11.6	11.9	8.7	28.9(4.28)	34.1(5.05)	29.2(4.33)
T_9 : Recommended dose of fertilizers (RDF)	11.1	11.6	8.4	27.4(4.06)	32.7(4.85)	28.5(4.23)
T_{10} : Absolute control (No NPKZn)	8.1	8.8	6.8	19.4(2.87)	22.2(3.28)	21.8(3.22)
S.Em±	0.2	0.3	0.2	1.0(0.14)	1.1(0.16)	0.6(0.09)
C.D. (P=0.05)	0.7	1	0.5	2.8(0.42)	3.2(0.47)	1.7(0.26)

( ) – values in bracket indicate leaf area index

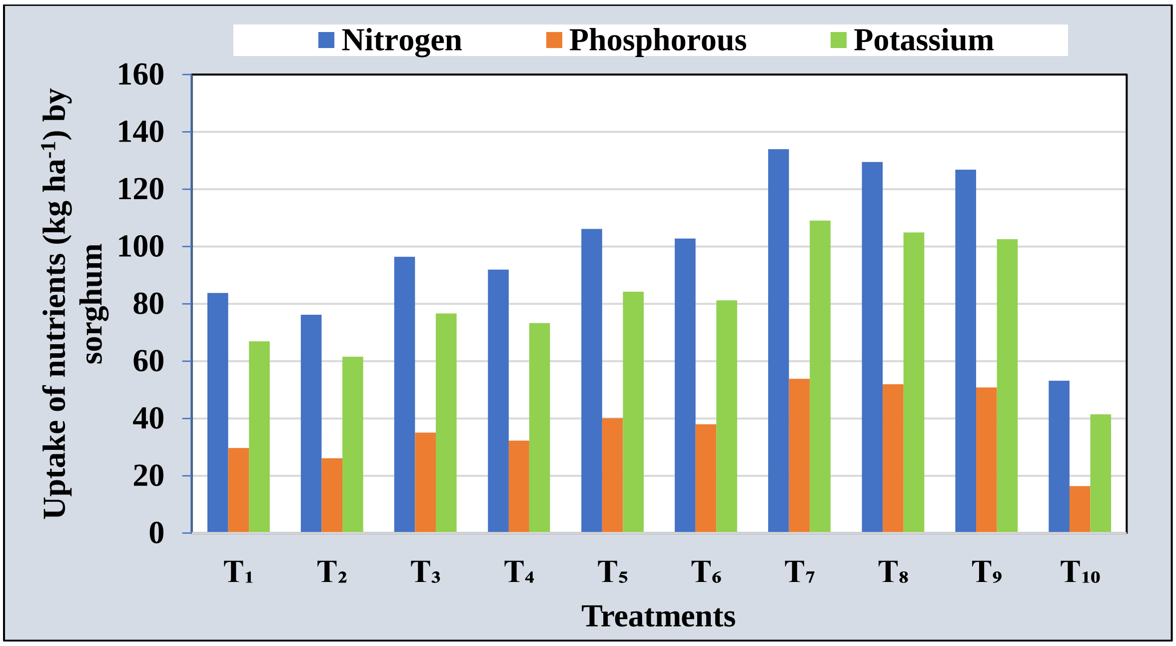

Fig. 2. Nutrient uptake (kg ha^{-1}) by *kharif* sorghum at harvest as influenced by different levels of chemical and nano fertilizers

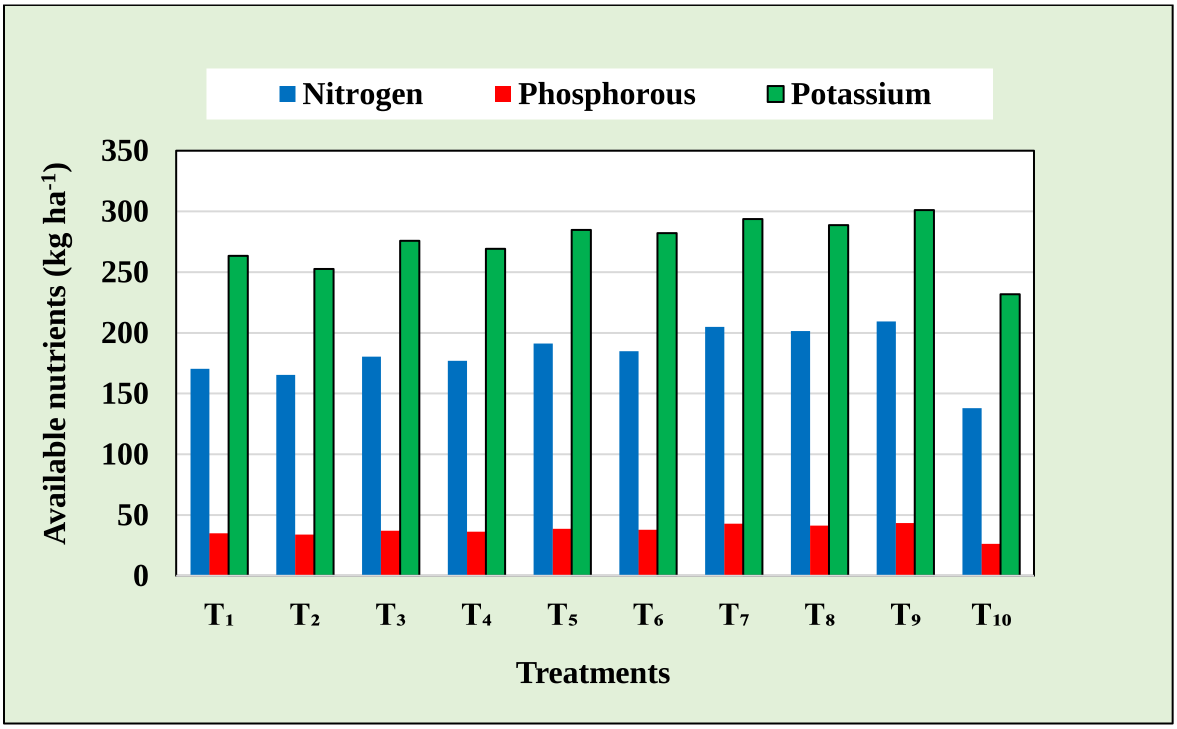

Fig. 3. Available nutrients in soil (kg ha^{-1}) at harvest as influenced by different levels of chemical and nano fertilizers in *kharif* sorghum

T_1 : 50% RNP as basal + Nano-urea & DAP spray @ 1.0 ml/l each at 30 and 45 DAS
T_2 : 50% RNP as basal + Nano-urea & DAP spray @ 2.ml/l each at 30 DAS
T_3 : 50% RNP as basal + Nano-urea & DAP spray @ 1.5 ml/l each at 30 and 45 DAS
T_4 : 50% RNP as basal + Nano-urea & DAP spray @ 3.0 ml/l each at 30 DA
T_5 : 75% RNP as basal + Nano-urea & DAP spray @ 1.0 ml/l each at 30 and 45 DAS
T_6 : 75% RNP as basal + Nano-urea & DAP spray @ 2.0 ml/l each at 30 DA
T_7 : 75% RNP as basal + Nano-urea & DAP spray @ 1.5 ml/l each at 30 and 45 DAS
T_8 : 75% RNP as basal + Nano-urea & DAP spray @ 3.0 ml/l each at 30 DA
T_9 : Recommended dose of fertilizers (RDF)
T_{10} : Absolute control (No NPKZn)

Table 2. Length of earhead, number of grains earhead^{-1}, grain weight and test weight of *kharif* sorghum as influenced by different levels of chemical and nano fertilizers

Treatments	Length of earhead (cm)	Number of grains earhead^{-1}	Grain weight (g plant^{-1})	Test weight (g 1000 grains^{-1})
T_1 : 50% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	26.8	1919	46.0	26.3
T_2 : 50% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	24.6	1910	44.2	26.3
T_3 : 50% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	28.1	1973	48.7	26.7
T_4 : 50% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	27.4	1948	46.5	26.7
T_5 : 75% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	30.3	2070	51.7	27.7
T_6 : 75% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	28.3	2015	49.9	27.7
T_7 : 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	35.9	2207	57.0	29.3
T_8 : 75% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	34.9	2162	54.8	29.0
T_9 : Recommended dose of fertilizers (RDF)	33.5	2139	53.3	28.7
T_{10} : Absolute control (No NPKZn)	20.5	1754	35.5	24.3
S.Em±	1.0	44.3	1.4	0.5
C.D. (P=0.05)	3.0	132	4.3	1.5

3.4 Nutrient use Efficiency

Application of 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS recorded significantly higher agronomic efficiency with respect to nitrogen and phosphorous (17.5 kg seed yield kg^{-1} N applied and 26.4 kg seed yield kg^{-1} P applied, respectively) (Table 3). Higher agronomic efficiency was noticed in 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS due to the higher nutrient uptake which increased the yield and biomass of the sorghum. Higher agronomic efficiency of nitrogen and phosphorus was mainly due to increased availability and uptake of nutrients leading to higher growth and yield, thereby producing higher yield kg^{-1} nutrient applied resulting in higher agronomic efficiency. Similar results were also obtained by Lingaraj [15].

Significantly higher recovery efficiency with respect to nitrogen and phosphorous (0.79 kg N uptake kg^{-1} N applied and 0.55 kg P uptake kg^{-1} P applied respectively) was noticed in treatment receiving 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS (Table 3). Basal application of FYM, conventional fertilizers followed by foliar spray of nano fertilizers increased physiological characters, dry matter production and its partitioning. Reduced particle size increases the specific surface area and quantity of particles per unit area of a fertilizer, which increases the chance for contact with nano fertilizer and increases nutrient penetration and uptake. Thereby increasing the uptake of nutrients per kg of fertilizer applied resulting in higher recovery efficiency. Similar results were also obtained by Amrutha [16].

3.5 Soil Microbiology

Significantly higher results with respect to bioassay studies (bacterial, fungal, actinomycetes population and dehydrogenase activity) were found in recommended dose of fertilizers (RDF) as compared to all other treatments and this was found on par with absolute control (Table 4). Whereas, significantly lower results with respect to bioassay studies were observed in nano fertilizers treated treatments. This was due to smaller size and higher surface area of nano particles which can enter the cell of microbes and affect the growth and development of micro-organisms. Moreover, beneficial soil microorganisms that degrade organic matter, which maintain long-term soil fertility, may be sensitive to this broad-spectrum antimicrobial product. These nano-formulation applicaions might have undesirable consequences for soil fertility and plant yields over the long term, especially as a result of repeated exposures This work is confirmatory with the work of Rajput et al. [17] and Xu et al. [18].

Table 3. Agronomic and recovery efficiency of *kharif* sorghum as influenced by different levels of chemical and nano fertilizers

	Agronomic efficiency		Recovery efficiency	
Treatments	Nitrogen	Phosphorous	Nitrogen	Phosphorous
T_1 : 50% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	10.3	16.3	0.40	0.27
T_2 : 50% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	9.4	14.8	0.30	0.20
T_3 : 50% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	13.6	21.5	0.56	0.38
T_4 : 50% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	13.1	20.6	0.50	0.32
T_5 : 75% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	11.7	17.6	0.52	0.35
T_6 : 75% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	10.8	16.3	0.48	0.32
T_7 : 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	17.5	26.4	0.79	0.55
T_8 : 75% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	16.6	25.0	0.74	0.52
T_9 : Recommended dose of fertilizers (RDF)	13.1	19.4	0.58	0.40
T_{10} : Absolute control (No NPKZn)	0.0	0.0	0.00	0.00
S.Em±	0.5	0.8	0.03	0.02
C.D. (P=0.05)	1.5	2.4	0.08	0.06

Table 4. Soil microbiology of *kharif* sorghum as influenced by different levels of chemical and nano fertiizers

Treatments	Total bacterial population (× 10^6 cfu g^{-1})	Total fungi population (× 10^4 cfu g^{-1})	Total actinomycetes population (× 10^4 cfu g^{-1})	Dehydrogenase activity (µg TPF g^{-1} soil day^{-1})
T_1 : 50% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	54.1	27.0	22.6	25.9
T_2 : 50% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	52.1	25.9	21.7	24.9
T_3 : 50% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	53.8	26.2	22.1	25.2
T_4 : 50% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	51.9	25.3	20.9	24.1
T_5 : 75% RNP as basal + nano urea & DAP spray @ 1.0 ml l^{-1} each at 30 and 45 DAS	57.9	29.5	25.1	28.1
T_6 : 75% RNP as basal + nano urea & DAP spray @ 2.0 ml l^{-1} each at 30 DAS	55.2	28.1	23.9	27.1
T_7 : 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS	56.6	29.0	24.9	27.8
T_8 : 75% RNP as basal + nano urea & DAP spray @ 3.0 ml l^{-1} each at 30 DAS	54.9	27.9	23.1	26.8
T_9 : Recommended dose of fertilizers (RDF)	61.2	32.5	27.6	30.3
T_{10} : Absolute control (No NPKZn)	59.4	31.2	26.9	29.3
S.Em±	1.0	0.6	0.8	0.6
C.D. (P=0.05)	3.0	1.9	2.4	1.8

Note: data at 60 DAS

4. CONCLUSION

Combined application of conventional and nano fertilizers i.e., 75% RNP as basal + nano urea & DAP spray @ 1.5 ml l^{-1} each at 30 and 45 DAS helped to increase growth attributes, yield parameters and nutrient uptake by the plants.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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