International Journal *of* Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(8): 367-376
Received: 15-06-2024
Accepted: 18-07-2024

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Influence of nano urea on growth, yield and quality of pigeon pea

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i8Se.1270

Abstract
The field experiment was conducted at ZARS, GKVK, Bangalore, Karnataka, India during *Kharif* 2021 on influence of nano urea on growth, yield and quality of pigeonpea. Results indicated that application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5% + $ZnSO_4$ @ 0.5% resulted significantly higher number of pods plant^{-1} (116.2), pod yield (52.3 g plant^{-1}), pod bearing length plant^{-1} (64.7 cm) seed yield (1179 kg ha^{-1}) and stalk yield (4568 kg ha^{-1}) and higher uptake of nutrients (kg ha^{-1}) i.e., nitrogen (111.5), phosphorus (16.9) and potassium (82.3) hence higher nutrient use efficiency (kg grains kg^{-1} nutrient applied) i.e., nitrogen (93.0), phosphorus (23.58) and potassium use efficiency (47.16) and across the different phenophases of crop, from 120 DAS till harvest higher values of absolute growth rate (1.97 g plant^{-1} day^{-1}), crop growth rate (14.57 g m^{-2} day^{-1}) and relative growth rate (0.012 g g^{-1} day^{-1}) were observed.

Keywords: Nano urea, growth, yield, pigeon pea

Introduction
Pigeonpea [*Cajanus cajan* (L.) Millsp.] is a protein-rich pulse crop native to the Indian sub-continent, belongs to the family Fabaceae, and is popularly known as arhar, tur and redgram. It is the sixth most important grain legume grown in the semi-arid tropics of Asia under wide cropping systems and the second most important grain legume in India after chickpea. Pigeonpea contains 20-22 percent protein, 1.2 percent fat and 65 percent carbohydrate. It is widely consumed as dhal as an affordable source of protein. Pulses are the major source of protein the in Indian diet. To meet the pulse requirement for ever growing population, an annual growth rate of the pulse should be 4.2 percent (IIPR, 2011) [1]. India is the largest producer of pigeonpea. In India, pigeonpea is cultivated on an area of 4.7 mha, with 4.31 mt annual production and 914 kg ha^{-1} productivity. India is the largest producer, importer and consumer of pulses in the world. Major problems with pulses production include low yield potential, unstable production levels due to biotic and abiotic stresses, climate change, loss of soil fertility and limited land resources. Pigeonpea is climate resilient crop and has potential to increase the income of small and marginal farmers. Also, it is a low nitrogen requirement crop as it fixes atmospheric nitrogen (40-50 kg N ha^{-1}). It has deep-root system and slow initial growth due to which it is best as intercrop. Apart from grains, its immature stems and leaves can be used as green manure. With these many benefits, there is a lot of scope for increasing pigeonpea production by proper management practices to overcome national and global food security challenges.
During the green revolution, many modern agricultural technologies were introduced and one among them was the use of chemical fertilizers. Now we are becoming too much dependent on chemical fertilizers for our overall food production. In the present situation, fertilizers are responsible for the world's 40 - 60 percent of food production.
Fertilizers supply essential plant nutrients and have now become an integral part of our Indian agricultural system. In India, per hectare consumption of fertilizer is 144.9 kg ha^{-1} (2019-20). Among the fertilizers urea is most widely used due to its low cost.

But due to excessive and imbalanced application of fertilizers, many problems have been aroused. The ideal NPK usage ratio of India should be 4: 2: 1, but the practical usage of NPK in India is 7: 2.8: 1. This imbalanced application of fertilizer is the main reason for the deterioration of soil health. Some of the important problems aroused include low fertilizers response ratio and low nutrient use efficiency. During the 1970s, the fertilizer response ratio was 13.4, but now it is reduced to only 2.7. It means over the years though our fertilizer consumption is increasing but our yield is stagnant. Similarly, in order to increase the yield, farmers apply more and more fertilizers but these fertilizers undergo various losses. Thus, nutrient use efficiency reduces due to various losses and fertilizers like urea enter the environment causing various pollutions like water pollution, soil pollution, greenhouse gas emission and eutrophication. Ultimately, when they enter the food chain, causes human health hazards like methemoglobinemia. To overcome these problems caused by conventional chemical fertilizers, one of the sustainable and promising approaches is the use of nano technology in agriculture.

Nano fertilizers are defined as materials in a nanometer scale (1-100 nm), containing macro and micronutrients that are delivered to crops in a controlled mode. In general, 1nm scale means one billionth of a meter (10^{-9}). The main features of nano fertilizers are their small size due to which their surface area and reactivity increases and facilitates easy penetration of nutrients in plants and improves nutrient use efficiency by avoiding losses.

Nano-fertilizers are advantageous over conventional fertilizers by having large surface area and particle size which is less than the pore size of root and leaves of the plant which can increase penetration into the plant from the applied surface and improve uptake and nutrient use efficiency (Liu and Lal, 2015) [13]. The usage of nano fertilizers in small quantities makes the soil not get loaded with salts that usually are prone to over-application using conventional fertilizers on a short- or long-term basis (Leon Silva, 2019) [11]. Fertilizers in the nano form, improves the productivity of crops and efficiently regulate the delivery of nutrients to plants and targeted sites, guaranteeing the minimal usage of agrochemicals. Nano-fertilizers are synthesized to regulate the release of nutrients depending on the requirements of the crops and are more efficient than ordinary fertilizers (Liu and Lal, 2015) [13]. Rameshaiah *et al*. (2015) [19] reported that nano-fertilizers increase nutrient use efficiency (NUE) by 3 times. These nano fertilizers have many other advantages, suppress crop diseases by acting directly on phytopathogens, improve stress tolerance and improve soil health. These nanomaterials also enhance crop production indirectly by improving crop nutrition and boosting plant defence pathways.

Among the nutrients, nitrogen is the most essential nutrient for crop growth and development. As Indian soils are deficient in nitrogen, it is mainly supplied through fertilizers. Indian farmers greatly depend on urea. The annual consumption of urea was 33.6 m t in 2019-20 which made India the second largest consumer of urea in world. A urea granule contains 46 percent of nitrogen and has nutrient use efficiency of around 30 to 40 percent. This indicates that upto 70 percent nitrogen is lost and it is a major threat for environment and human health. To reduce urea consumption nano urea can be used. The nano-nitrogen fertilizer (nano urea) of IFFCO is a nitrogen-based formulation where urea is coated with polymers to make nano-size particles. The nano urea fertilizer is recommended to apply as a foliar spray and is said to contain 4 percent nitrogen. Spraying of nano nitrogen at the rate of 2-4 ml $litre^{-1}$ of water at critical crop growth stages triggers crop response, fulfils its nutritional requirement and improves nutrient availability in the rhizosphere. When sprayed on leaves, nano N fertilizer easily gets absorbed and enters through stomata due to its nano size.

Pigeonpea is mainly cultivated in marginal lands which are low in fertility. A mineral nutrient deficiency limits nitrogen fixation and ultimately reduces the yield. Both major and micronutrients are important for nodulation. In pigeonpea, fertilizers are applied as basal dose. It is a long-duration crop and over the period the nutrients are lost and during its critical growth stages, nutrient deficiency is observed. Excess application of nitrogen fertilizers will not only lead to losses but also reduces nodulation in pulses. To avoid this, foliar application of nano urea at critical stages can be a sustainable alternative practice.

These efficient fertilizers are expected to enhance crop growth, yield and quality while reducing environmental footprint. Also, the deficiency of micronutrients has been emerging in India. Around 50 percent of soil is deficient in zinc. Thus, the application of micronutrients along with major nutrients can increase plant physiological functions, protein quality and yield levels by providing balanced nutrition, based on the crop requirement. The present study entitled “Influence of nano urea on growth, yield and quality of pigeonpea” has been undertaken to evaluate the response of pigeonpea crop to foliar application of nano urea with comparison to normal urea, so that a viable and economically feasible option can be given to the farmers for maintaining sustainable crop production with improved quality and enhanced nutrient use efficiency in the pigeonpea.

Materials and Methods

A field experiment entitled “Influence of nano urea on growth, yield, and Nutrient use efficiency of pigeonpea” was conducted during *Kharif* 2021 at K Block, ZARS, University of Agricultural Sciences, GKVK, Bengaluru. The experimental site belongs to Eastern Dry Zone (Agro-climatic Zone-V) of Karnataka and Located between 12º 51' N Latitude and 77º 35' E Longitude at an altitude of 930 m above mean sea level (MSL). The experiment was laid out in Randomised Complete Block Design with 3 replications and 15 treatments. Treatment details given in following table.1.

The soil of the experimental site was red sandy loam in texture, classified under the order *Alfisols*. The composite soil samples from 0 to 30 cm depth were collected randomly in experimental area before treatment imposition from each replication. Analysis was done for various physical and chemical properties of the soil. The values obtained along with methods followed for estimation are presented in Table 1. The textural class of the soil was red sandy loam consisting of 53.40 percent coarse sand, 14.8 percent fine sand, 16.6 percent silt and 15.2 percent of clay. The soil was acidic (5.3) in reaction with an electrical conductivity of 0.17 dSm^{-1}. The organic carbon content was 0.36 percent. The soil was medium in available nitrogen (318.5 kg ha^{-1}), available phosphorous (48.5 kg ha^{-1}) and available potassium (280.5 kg ha^{-1}). The data on growth parameters of pigeonpea was recorded at 60, 90, 120 days after sowing (DAS) and at harvest. The experimental data recorded on the growth, yield and soil parameters were subjected to Fisher’s method of “Analysis of Variance” (ANOVA). For comparison between the treatment means, an appropriate value of critical difference (CD) was worked out wherever F- test was significant. All the data were analyzed and the results are presented and discussed at a probability level of 5 percent.

Table 1: Treatment details

T_1 =	RDF (NU)
T_2 =	RDF (NU)
T_3=	RDF (NU) + Soil application of $ZnSO_4$ @ 25 kg ha^{-1}
T_4 =	RDF (NU) + Soil application of $ZnSO_4$ @ 5 kg ha^{-1}
T_5 =	RDF (NU) + Soil application of $ZnSO_4$ @ 25 kg ha^{-1} + Soil application of $ZnSO_4$ @ 5 kg ha^{-1}
T_6 =	RDF (NU) + Foliar application of $ZnSO_4$ @ 0.5 percent
T_7 =	RDF (NU) + Foliar application of $ZnSO_4$ @ 0.5 percent
T_8=	RDF (NU) + Foliar application of $ZnSO_4$ @ 0.5 percent + Foliar application of $ZnSO_4$ @ 0.5 percent
T_9=	RDF (NU) + Soil application of $ZnSO_4$ @ 25 kg ha^{-1}
T_{10}=	RDF (NU) + Soil application of $ZnSO_4$ @ 5 kg ha^{-1}
T_{11}=	RDF (NU) + Soil application of $ZnSO_4$ @ 25 kg ha^{-1} + Soil application of $ZnSO_4$ @ 5 kg ha^{-1}
T_{12}=	RDF (NU) + Foliar application of $ZnSO_4$ @ 0.5 percent
T_{13}=	RDF (NU) + Foliar application of $ZnSO_4$ @ 0.5 percent
T_{14} =	RDF (NU) + Foliar application of $ZnSO_4$ @ 0.5 percent + Foliar application of $ZnSO_4$ @ 0.5 percent
T_{15} =	Water spray

In the experiment, treatments with RDF (Normal Urea) and water spray, 100 percent of RDF (N, P and K) was applied as basal dose at the time of sowing. In the treatments with RDF (Nano Urea), 100 percent of RDPK and 50 percent of RDN through normal urea as basal dose at the time of sowing and foliar application of nano nitrogen (3 ml l^{-1}) in three sprays at 60, 90 and 120 DAS were given. In the water spray treatment, foliar application with only water during 60, 90 and 120 DAS was done. In the treatments with soil application of 25 kg zinc and 5 kg ferrous sulphate ha^{-1} were applied as basal dose during the time of sowing along with RDF (Normal Urea) or RDF (Nano Urea). In the treatments with foliar application of water-soluble zinc and iron fertilizers, these fertilizers @ 0.5% each were sprayed at flowering and pod development stages of pigeonpea along with RDF (Normal Urea) and RDF (Nano Urea).

Climatic conditions

The normal as well as actual weather data on total rainfall, maximum and minimum temperature, relative humidity, sunshine hours, wind speed and pan evaporation prevailed during the crop period is represented in the Fig. 1

Table 2: Initial soil physical and chemical properties of the experimental site

Particulars	Values	Status	Method followed
I. Physical properties			
1. Coarse sand (%)	53.4	Red sandy loam	International pipette method (Piper, 1966)
2. Fine sand (%)	14.8		
3. Silt (%)	16.6		
4. Clay (%)	15.2		
II. Chemical properties			
1. pH (1:2.5)	5.4	Acidic	Potentiometric method (Jackson, 1973)
2. EC (1:2.5) (dS m^{-1})	0.16	Normal	Conductometric method (Jackson, 1973)
3. Organic carbon (%)	0.43	Medium	Wet oxidation method (Walkley and Black, 1934)
4. Available N (kg ha^{-1})	287	Medium	Alkaline potassium permanganate Method (Subbaiah and Asija, 1956)
5. Available P_2O_5 (kg ha-1)	36.5	Medium	Bray's method (Jackson, I973)
6. Available K_2O (kg ha-1)	255.5	Medium	Flame photometry (Jackson, 1973)
7. Available Zinc (mg kg^{-1})	2.9	Medium	Diethylenetriamine pentaacetate (DTPA) method (Lindsay and Norvell, 1978) Atomic absorption spectrophotometry
8. Available Iron (mg kg^{-1})	7.6	Medium	

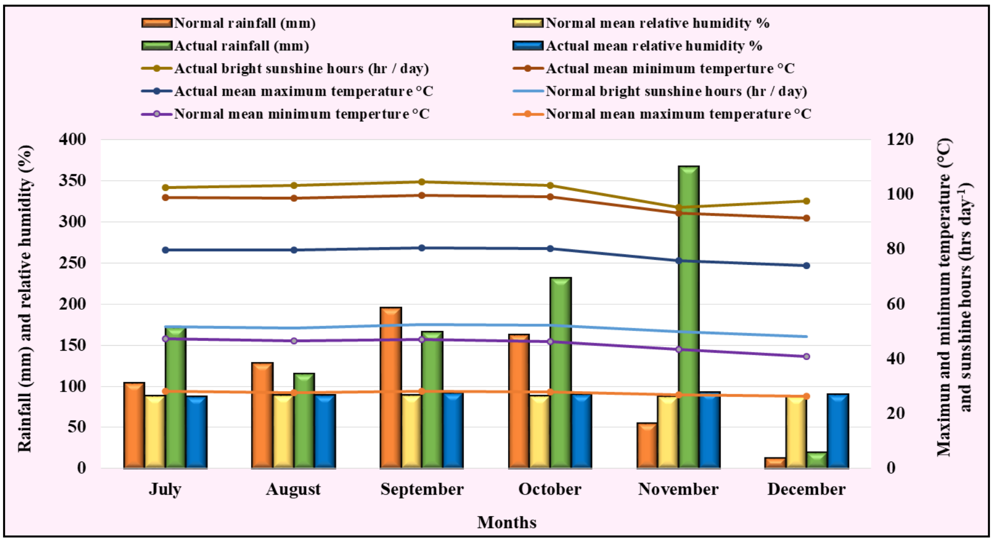

Fig 1: Meteorological data of the experimental site during crop growth period at GKVK, UAS, Bangalore

Results and Discussion

At harvest, significantly higher plant height (242 cm), number of branches plant-1 (23.7) and dry matter accumulation (254 g plant-1) were recorded with application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent and lower plant height (172 cm), number of branches plant-1 (17.2) and dry matter accumulation (165 g plant^{-1}) were observed with application of RDF (Normal Urea). Initial growth rate of pigeonpea was slow, which was reflected in plant height at 60 DAS which did not show any significant difference in the treatments. After that there was a significant increase in plant height was observed. This difference in increase in plant height of pigeonpea was recorded might be due to the application of nitrogen as basal dose with normal urea and by foliar spray with nano urea increased the availability of nutrients to the growing plant. Also, this nano fertilizer helped in quick absorption of nutrients through stomata of leaves viz. foliar application of nano urea and might have increased chlorophyll formation, photosynthetic rate, dry matter production and thus, enhanced the growth of the plant. The similar findings were reported by Rani *et al*. (2019) [20]. Nitrogen plays a vital role in plant growth and development. Application of nitrogen in nano form increases its availability at critical stages. Nitrogen enhances cell metabolism and cell divisional activities in shoot apical meristem which increases plant height (Kaur *et al*., 2015) [8]. Benzon *et al*. (2015) [3] opined that plant height was increased when nano-fertilizer was applied in combination with conventional fertilizer because nano-fertilizer can either provide nutrients for the plant or help in the transport or absorption of available nutrients resulting in better crop growth. Also, the foliar application of $ZnSO_4$ and $ZnSO_4$ at flowering and pod filling stage along with RDF increased the growth attributes due to balanced availability of micronutrients throughout growing period (Saakshi *et al*., 2020) [22].

In yield attributes, significantly higher number of pods plant-1 (116.2), pod yield (52.3 g plant^{-1}), pod bearing length plant^{-1} (64.7 cm) seed yield (1179 kg ha^{-1}) and stalk yield (4568 kg ha^{-1}) were recorded with application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent in pigeonpea. Significantly lower seed yield (874 kg $^{ha-1}$) and stalk yield (3688 kg ha^{-1}) were recorded with the application of RDF (Normal Urea).

The increase in seed yield might be due to the combined application of normal and nano urea along with micronutrients which ensured optimum and balanced nutrient availability throughout the crop period. Many research studies have showed the increase in yield due to application of fertilizers in nano form. Benzon *et al*. (2015) [3] reported positive effect of the nano-fertilizers on the efficacy of conventional fertilizer for better nutrient absorption by plant cells resulting to optimal growth of plant parts and metabolic process such as photosynthesis leads to higher photosynthates accumulation and translocation to the economic parts of the plant, thus resulting higher yield. In this experiment, combined application of normal urea and nano urea ensured nutrient availability thought out the crop period specially during the critical stages which resulted in increased biomass, lower flower drop and increased the yield attributing characters and finally, amplified translocation of assimilates to seeds which increased over all pigeonpea yield compared to only RDF. Similar results were reported by Kumar *et al*. (2020) [9]. Foliar application of micronutrients ensured quick absorption of essential nutrients, at the time of reproductive stage where the nutrient demand is at the peak due to indeterminate growth habit of the crop. Hence, it reduced the flower drop and ultimately enhanced the pod setting and resulted in higher seed yield (Elumle Priyanka, 2019) [4]. Also, zinc and ferrous sulphate includes sulphur which is a secondary nutrient which might be advantageous in increasing the crop yields (Kailas *et al*., 2017) [7]. Foliar application of nutrients at flowering and pod development stage might have been easily absorbed and better trans located in the plant and maintained constant requirement of nutrients at the reproductive stage of the crop.

Application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent recorded higher nutrient use efficiency (kg grains kg^{-1} nutrient applied) i.e., nitrogen use efficiency (93.0 kg grains kg^{-1} N applied), phosphorus use efficiency (23.58 kg grains kg^{-1} P applied) and potassium use efficiency (47.16 kg grains kg^{-1} K applied) in pigeonpea.

Higher nutrient use efficiency was recorded with foliar application of nano urea mainly due to the higher nutrient uptake which increased the yield and biomass of the pigeonpea. Below 100 nm nano-fertilizers makes plant use fertilizers more efficiently, reduces pollution, environmentally friendly, dissolve in water more effectively thus increase its metabolic activities (Joseph and Morrison, 2006) [6]. Higher nutrient use efficiency of nitrogen, phosphorus and potassium was mainly due to increased availability and uptake of nutrients leading to higher growth and yield attributes in turn increased yield kg-1 nutrient applied.

Significantly higher uptake of nutrients i.e., nitrogen uptake (111.5 kg ha^{-1}), phosphorus uptake (16.9 kg ha^{-1}) and potassium uptake (82.3 kg ha^{-1}) was recorded with the application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent.The increase in nutrient uptake was due to the foliar application of nano urea with zinc and ferrous sulphate which increased physiological characters, dry matter production and its partitioning. Reduction of particle size results in increased specific surface area and number of particles per unit area of a fertilizer that provide more opportunity to contact of nano-fertilizer which leads to more penetration and uptake of the nutrient and thus results in high nutrient use efficiency (Liscano *et al*., 2018) [12]. Marschner (1986) [15] opined that generally the levels of nutrients in xylem sap and their flux into the shoot decline during the reproductive phase in monocarphic plants. The foliar application of nutrients might reduce the nutrient depletion in the foliage. This might help in increasing the photosynthesis while reduce flower, pod abscission, and improve nutrient concentration in pigeonpea.

Significantly higher plant height (242 cm), number of branches plant^{-1} (23.7) and dry matter accumulation (254 g plant^{-1}) were recorded with application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent and lower plant height (172 cm), number of branches plant^{-1} (17.2) and dry matter accumulation (165 g plant^{-1}) were observed with application of RDF (Normal Urea). Initial growth rate of pigeonpea was slow, which was reflected in plant height at 60 DAS which did not show any significant difference in the treatments. After that there was a significant increase in plant height was observed. This difference in increase in plant height of pigeonpea was recorded might be due to the application of nitrogen as basal dose with normal urea and by foliar spray with nano urea increased the availability of nutrients to the growing plant. Also, this nano fertilizer helped in quick absorption of nutrients through stomata of leaves *viz*. foliar application of nano urea and might have increased chlorophyll formation, photosynthetic rate, and dry matter production and thus, enhanced the growth of the plant. The similar findings were reported by Rani *et al*. (2019) [20]. Nitrogen plays a vital role in plant growth and development. Application of nitrogen in nano form increases its availability at critical stages. Nitrogen enhances cell metabolism and cell divisional activities in shoot apical meristem which increases plant height (Kaur *et al*., 2015) [8]. Benzon *et al*. (2015) [3] opined that plant height was increased when nano-fertilizer was applied in combination with conventional fertilizer because nano-fertilizer can either provide nutrients for the plant or help in the transport or absorption of available nutrients resulting in better crop growth. Also, the foliar application of $ZnSO_4$ and $ZnSO_4$ at flowering and pod filling stage along with RDF increased the growth attributes due to balanced availability of micronutrients throughout growing period. There was a significant difference in chlorophyll content of pigeonpea at 90 and 120 DAS respectively. Significantly higher chlorophyll content (56.1and 69.6) was observed in the treatment with RDF (Nano Urea) + soil application of $ZnSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 5 kg ha^{-1} which was found on par with RDF (Normal Urea) + soil application of $ZnSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 5 kg ha^{-1} (50.3 and 66.5) and RDF (Nano Urea) + soil application of $ZnSO_4$ @ 25 kg ha^{-1} (49.9). Significantly lower chlorophyll content (41.1 and 56.2) was recorded with RDF (Normal Urea). Initially, there was no difference noticed in chlorophyll content of pigeonpea up to 60 DAS, after the application of nano urea, significant difference was observed. Increase in chlorophyll content in the leaves was due to supply of nitrogen in optimum quantity, which is necessary to form RNAs, DNA, several enzymes and energycompounds like ATP. It also plays an important role in various physiological processes and is an integral part of chlorophyll which gives green parts in plants. Along with the nitrogen, zinc and iron are also essential for increasing the chlorophyll content. Chlorophyll is responsible for photosynthesis and increases plant growth. Nano nitrogen due to its small size and high surface area easily gets absorbed by plants and increases nitrogen availability which increases the greenness of crop that is chlorophyll content in the leaves and is necessary for increasing photosynthetic rate and efficiency. Similar results were reported in wheat and maize, respectively.

During crop duration from 120 DAS till harvest, absolute growth rate (1.97 g $plant^{-1}$ day^{-1}), crop growth rate (14.57 g m^{-2} day^{-1}) and relative growth rate (0.012 g g^{-1} day^{-1}) were measured significantly higher with application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent. Significantly lower absolute growth rate of 1.07 g $plant^{-1}$ day^{-1} was recorded water spray while lower crop growth rate of 7.89 g m^{-2} day^{-1} and relative growth rate of 0.007 g g^{-1} day^{-1} were recorded with RDF (Normal Urea). RGR is the rate of accumulation of new dry matter per unit of existing dry matter. It is an indirect measurement of rate of resource acquisition (Lowry and Smith, 2018). In this experiment, RGR was increased may be due to increased photosynthetic efficiency by retaining more chlorophyll content and efficient translocation. These results are supported by the findings of in soybean. Nano fertilizers gets quickly absorbed and translocated by the plant tissues. Unutilized nutrients get stored in plant vacuoles and are released based on crop requirement. This might also have helped to increase assimilates in plants and improved the dry matter accumulation at periodic intervals. These results were in corroboration with the findings of Swati Mehta (2017) [24].

Yield attributes (Table and fig 2) significantly higher number of pods $plant^{-1}$ (116.2), pod yield (52.3 g $plant^{-1}$), pod bearing length $plant^{-1}$ (64.7 cm) seed yield (1179 kg ha^{-1}) stalk yield (4568 kg ha^{-1}) higher nutrient use efficiency (kg grains kg^{-1} nutrient applied) i.e., nitrogen use efficiency (93.0 kg grains kg^{-1} N applied), phosphorus use efficiency (23.58 kg grains kg^{-1} P applied) and potassium use efficiency (47.16 kg grains kg^{-1} K applied) in were recorded with application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent in pigeonpea. Significantly lower seed yield (874 kg ha^{-1}) and stalk yield (3688 kg ha^{-1}) were recorded with the application of RDF (Normal Urea). Significantly higher uptake of nutrients i.e., nitrogen uptake (111.5 kg ha^{-1}), phosphorus uptake (16.9 kg ha^{-1}) and potassium uptake (82.3 kg ha^{-1}) was recorded with the application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent. Foliar spray of nano urea ensured nitrogen supply at critical stages which increased the yield attributing characters. Studies revealed that nano-NPK is considered as the biological pump for the plants to absorb nutrients and water opined that the increased water uptake due to application of nano-materials which increased the N, P and K uptake and resulted in increased biomass production. Micronutrients also helped to increase the growth and yield parameters which reflected into better source-sink relationship as compared to RDF alone. These results were in accordance with Elumle Priyanka (2019) [4]. Higher pod bearing length of pigeonpea due to foliar application of nutrients which might be result in easy availability, absorption, and mobilization of nutrients by spending less energy which increased the distance between lowest to topmost pod on the branches of pigeonpea and increased number of pods $plant^{-1}$. Nano urea when sprayed on plant surface leads to storage of remaining nitrogen in plant cells that may release slowly and that can prevent the plant biotic and abiotic stress produces the high grain yield (Midde *et al*., 2022) [16]. The increase in yield can be attributed to the higher availability of assimilates with foliar spray of micronutrients (Kailas *et al*., 2017) [7]. Overall, there was effective translocation of assimilates to the seeds which increased the seed yield. The increase in seed yield might be due to the combined application of normal and nano urea along with micronutrients which ensured optimum and balanced nutrient availability throughout the crop period. Many research studies have showed the increase in yield due to application of fertilizers in nano form. Benzon *et al*. (2015) [3] reported positive effect of the nano-fertilizers on the efficacy of conventional fertilizer for better nutrient absorption by plant cells resulting to optimal growth of plant parts and metabolic process such as photosynthesis leads to higher photosynthates accumulation and translocation to the economic parts of the plant, thus resulting higher yield. In this experiment, combined application of normal urea and nano urea ensured nutrient availability thought out the crop period specially during the critical stages which resulted in increased biomass, lower flower drop and increased the yield attributing characters and finally, amplified translocation of assimilates to seeds which increased over all pigeonpea yield compared to only RDF. Similar results were reported by Kumar *et al.* (2020) [9] in chickpea and blackgram. Foliar application of micronutrients ensured quick absorption of essential nutrients, at the time of reproductive stage where the nutrient demand is at the peak due to indeterminate growth habit of the crop. Hence, it reduced the flower drop and ultimately enhanced the pod setting and resulted in higher seed yield (Elumle Priyanka, 2019) [4] (Kailas *et al*., 2017) [7] reported that foliar application of nutrients at flowering and pod development stage might have been easily absorbed and better translocated in the plant and maintained constant requirement of nutrients at the reproductive stage of the crop. The full potential of crop regarding to yield could be exhibited only when it will get an adequate agro-climatic conditions. Agro-climatic conditions largely influence the crop growth and yield. During the experiment in *Kharif* 2021, more rainfall was experienced specially during flowering and pod filling stages which were reflected in lower yield of pigeonpea compared to average yield over the years.

Protein yield (kg ha^{-1}) and higher seed nitrogen content (39.4 kg ha^{-1}), zinc content (37.53 g ha^{-1}) and iron content (78.14 g ha^{-1}) (Fig:3) of pigeonpea was significantly higher (233.4 kg ha^{-1}) with application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + foliar application of $ZnSO_4$ @ 0.5 percent. Protein content (%) did not differ significantly by the foliar application of nano urea in pigeonpea. The increase in protein yield was mainly due to increase in yield of pigeonpea. Nitrogen acts as building blocks of protein. Nano urea increased the N content in plant due to more utilization and less losses. The improvement in nitrogen and protein content was due to enhanced photosynthetic rates and chlorophyll content in leaves of plants. Increased protein yield of pigeonpea may also because of the fact that involvement of nitrogen, iron as well as zinc which takes part in nitrate conversion to ammonia in plants, zinc sulphate also activates indole acetic acid and which makes amino acid to protein.

Table 3: Growth attributes of pigeonpea as influenced by foliar application of nano urea

Treatments	Plant height (cm)	Number of branches plant^{-1}	Dry matter accumulation (g plant^{-1})	Chlorophyll content of pigeonpea	Absolute growth rate (m^{-2} day^{-1})	Crop growth rate (m^{-2} day^{-1})	Relative growth rate (m^{-2} day^{-1})
T_1 = RDF (NU)	172	17.2	165	56.2	1.10	7.89	0.007
T_2 = RDF (nU)	195	20.0	186	62.2	1.13	8.39	0.008
T_3 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	209	18.7	219	64.2	1.38	10.23	0.008
T_4 = RDF (NU) +SA $ZnSO_4$ @ 5kg ha^{-1}	206	18.0	208	63.8	1.30	9.62	0.008
T_5 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	212	20.6	225	66.5	1.42	10.48	0.008
T_6 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	217	21.7	221	62.1	1.77	13.07	0.011
T_7 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	211	19.8	218	61.5	1.85	13.70	0.011
T_8 = RDF (NU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	228	22.4	237	62.5	1.89	13.95	0.011
T_9 = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	226	22.6	229	66.1	1.30	9.61	0.009
T_{10} = RDF (nU) + SA $ZnSO_4$ @ 5kg ha^{-1}	219	19.7	227	64.5	1.37	10.11	0.008
T_{11} = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	231	23.3	248	69.6	1.55	11.47	0.008
T_{12} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	227	22.1	242	63.1	1.92	14.22	0.010
T_{13} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	222	20.7	236	63.0	1.74	12.85	0.010
T_{14} = RDF (nU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	242	23.7	254	63.8	1.97	14.57	0.012
T_{15} = Water spray	180	19.3	174	61.2	1.07	8.14	0.008
F test	*	*	*	*	*	*	*
S.Em. ±	8.1	1.03	8.99	1.91	0.08	0.57	0.0005
C.D @ 5%	28.8	3.00	26.04	5.52	1.10	1.66	0.0013

NU: Normal Urea	nU: Nano Urea
SA: Soil application	FA: Foliar application

Table 4: Yield and yield attributes of pigeonpea as influenced by foliar application of nano urea

Treatments	Number of pods plant^{-1}	Pod yield plant^{-1} (g)	Pod bearing length (cm)	Seed yield (kg ha^{-1})	Stalk yield (kg ha^{-1})
T_1 = RDF (NU)	89.6	42.9	54.4	874	3688
T_2 = RDF (nU)	95.2	44.7	56.0	958	4043
T_3 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	103.7	45.7	56.4	999	4289
T_4 = RDF (NU) +SA $ZnSO_4$ @ 5kg ha^{-1}	103.6	45.2	54.3	967	4294
T_5 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	112.2	48.3	64.0	1090	4462
T_6 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	98.2	49.3	57.8	1112	4219
T_7 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	106.5	46.3	55.4	1030	4388
T_8 = RDF (NU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	111.2	51.4	63.9	1163	4389
T_9 = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	102.8	49.7	58.2	1129	4397
T_{10} = RDF (nU) + SA $ZnSO_4$ @ 5kg ha^{-1}	109.8	46.6	56.4	1079	4183
T_{11} = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	113.2	51.8	63.6	1166	4466
T_{12} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	108.1	50.6	56.1	1138	4453
T_{13} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	104.5	47.4	54.7	1081	4151
T_{14} = RDF (nU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	116.2	52.3	64.7	1179	4568
T_{15} = Water spray	91.0	43.9	55.1	896	3934
F test	*	*	*	*	*
S.Em. ±	3.99	1.79	2.43	43	154
C.D @ 5%	11.57	5.19	7.04	123	446

NU: Normal Urea	nU: Nano Urea
SA: Soil application	FA: Foliar application

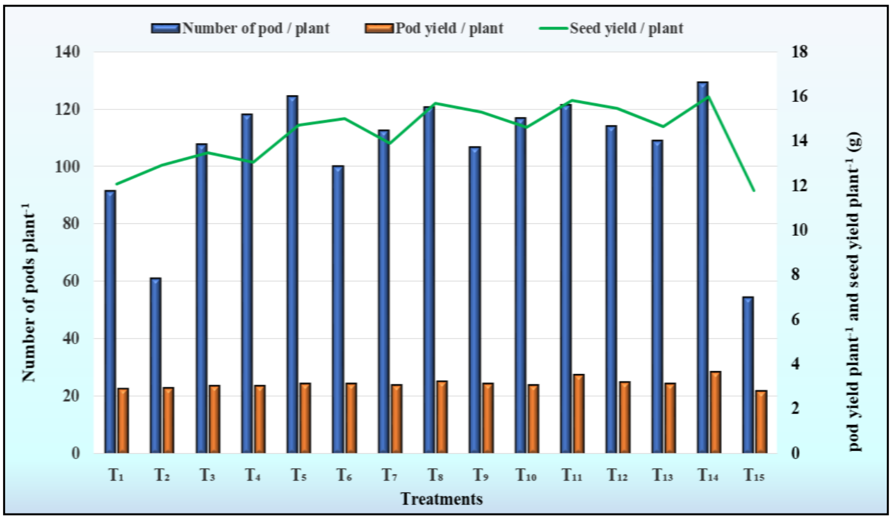

Fig 2: Number of pods plant^{-1}, pod yield plant^{-1} (g) and seed yield plant^{-1} (g) of pigeonpea as influenced by foliar application of nano urea

Table 5: Effect of foliar application of nano urea on nutrient use efficiency of pigeonpea

Treatments	NUE (kg grains kg^{-1} of N fertilizer applied)	PUE (kg grains kg^{-1} of P fertilizer applied)	KUE (kg grains kg^{-1} of K fertilizer applied)
T_1 = RDF (NU)	35.0	17.48	35.84
T_2 = RDF (nU)	75.6	19.16	38.32
T_3 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	40.0	19.98	39.96
T_4 = RDF (NU) +SA $ZnSO_4$ @ 5 kg ha^{-1}	38.7	19.34	38.68
T_5 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	43.6	21.8	43.6
T_6 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	44.5	22.24	44.48
T_7 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	41.2	20.6	41.2
T_8 = RDF (NU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	46.5	23.26	46.52
T_9 = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	89.0	22.58	45.16
T_{10}= RDF (nU) + SA $ZnSO_4$ @ 5 kg ha^{-1}	85.2	21.6	43.2
T_{11}= RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	92.0	23.32	46.64
T_{12} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	89.7	22.76	45.52
T_{13} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	85.3	21.62	43.24
T_{14}= RDF (nU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	93.0	23.58	47.16
T_{15} = Water spray	35.8	17.92	34.96

NUE: PUE: KUE

NU: Normal Urea	nU: Nano Urea
SA: Soil application	FA: Foliar application

Table 6: Yield and yield attributes of pigeonpea as influenced by foliar application of nano urea

Treatments	Number of pods plant^{-1}	Pod yield plant^{-1} (g)	Pod bearing length (cm)	Seed yield plant^{-1} (g)	Shelling percentage (%)	Test weight (g/100 seeds)
T_1 = RDF (NU)	89.6	42.9	54.4	16.8	55.98	13.9
T_2 = RDF (nU)	95.2	44.7	56.0	17.9	57.06	14.9
T_3 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	103.7	45.7	56.4	18.5	57.05	14.7
T_4 = RDF (NU) +SA $ZnSO_4$ @ 5kg ha^{-1}	103.6	45.2	54.3	18.1	55.97	14.9
T_5 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	112.2	48.3	64.0	19.7	60.52	14.9
T_6 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	98.2	49.3	57.8	20.0	61.65	15.3
T_7 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	106.5	46.3	55.4	18.9	58.74	15.9
T_8 = RDF (NU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	111.2	51.4	63.9	20.7	57.53	15.4
T_9 = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	102.8	49.7	58.2	20.3	62.05	15.2
T_{10} = RDF (nU) + SA $ZnSO_4$ @ 5kg ha^{-1}	109.8	46.6	56.4	19.7	61.06	15.0
T_{11} = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	113.2	51.8	63.6	20.8	60.56	15.5
T_{12} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	108.1	50.6	56.1	20.5	61.49	15.1
T_{13} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	104.5	47.4	54.7	19.7	59.95	15.4
T_{14} = RDF (nU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	116.2	52.3	64.7	21.0	62.40	15.9
T_{15} = Water spray	91.0	43.9	55.1	17.1	58.53	14.4
F test	*	*	*	*	NS	NS
S.Em. ±	3.99	1.79	2.43	0.85	3.22	0.54
C.D @ 5%	11.57	5.19	7.04	2.46	-	-

NU: Normal Urea	nU: Nano Urea
SA: Soil application	FA: Foliar application

Table 7: Protein content and protein yield of pigeonpea as influenced by foliar application of nano urea

Treatments	Protein (%)	Protein yield (kg ha^{-1})
T_1 = RDF (NU)	18.7	163.8
T_2 = RDF (nU)	19.0	182.4
T_3 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	19.2	191.5
T_4 = RDF (NU) +SA $ZnSO_4$ @ 5 kg ha^{-1}	19.1	184.5
T_5 = RDF (NU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	19.4	211.8
T_6 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	19.3	214.1
T_7 = RDF (NU) + FA $ZnSO_4$ @ 0.5%	19.1	197.0
T_8 = RDF (NU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	19.6	227.8
T_9 = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1}	19.5	220.4
T_{10} = RDF (nU) + SA $ZnSO_4$ @ 5 kg ha^{-1}	19.3	208.0
T_{11} = RDF (nU) + SA $ZnSO_4$ @ 25 kg ha^{-1} + SA $ZnSO_4$ @ 5 kg ha^{-1}	19.5	227.7
T_{12} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	19.2	218.6
T_{13} = RDF (nU) + FA $ZnSO_4$ @ 0.5%	19.5	210.4
T_{14} = RDF (nU) + FA $ZnSO_4$ @ 0.5% + FA $ZnSO_4$ @ 0.5%	19.8	233.4
T_{15} = Water spray	18.9	169.2
F test	NS	*
S.Em. ±	0.69	7.45
C.D. @ 5%	-	21.57

NU: Normal Urea	nU: Nano Urea
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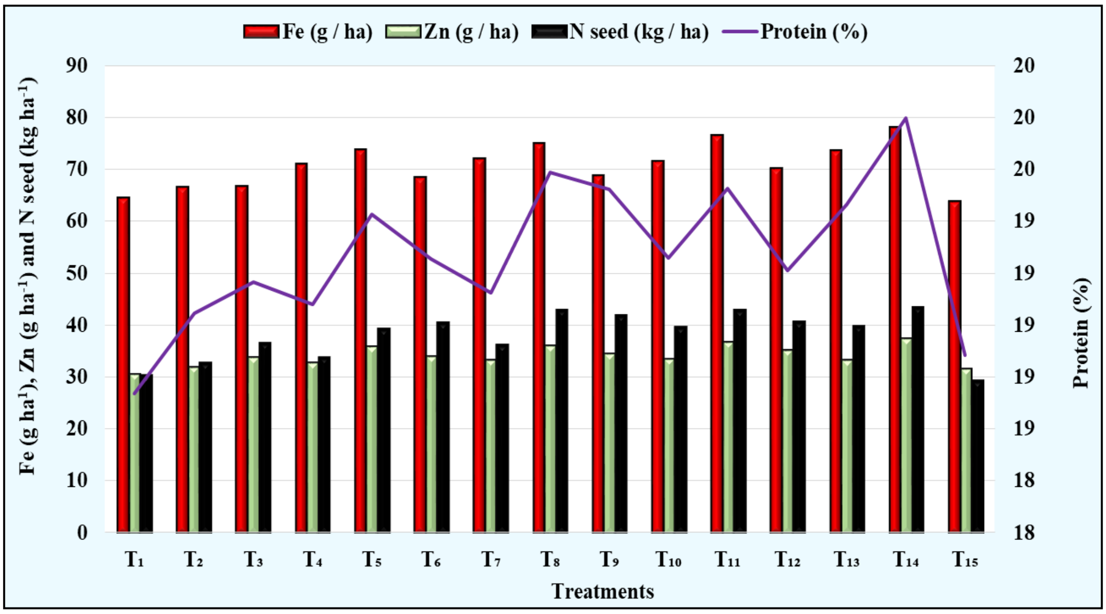

Fig 3: Protein (%), N (kg ha-1), Zn and Fe (g ha-1) content of pigeonpea seeds as influenced by foliar application of nano urea

These findings are like the reports obtained by Mallesha (2013) [14] in pigeonpea, Ram and Katiyar (2013) [18] in mungbean, Singh *et al*. (2015) [8] in chickpea, and Roy *et al*. (2017) in greengram.

Application of RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent recorded higher gross returns (Rs. 78845 ha^{-1}) but treatment with RDF (Nano Urea) + soil application of $ZnSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 5 kg ha^{-1} recorded higher net returns of Rs. 39346 ha^{-1} and B: C ratio (2.02) Fg:4. From this study we can conclude that RDF (Nano Urea) + foliar application of $ZnSO_4$ @ 0.5 percent + $ZnSO_4$ @ 0.5 percent was efficient in increasing growth, yield and quality of pigeonpea but economically RDF (Nano Urea) + soil application of $ZnSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 5 kg ha^{-1} was better with higher B: C ratio of 2.02 in pigeonpea.

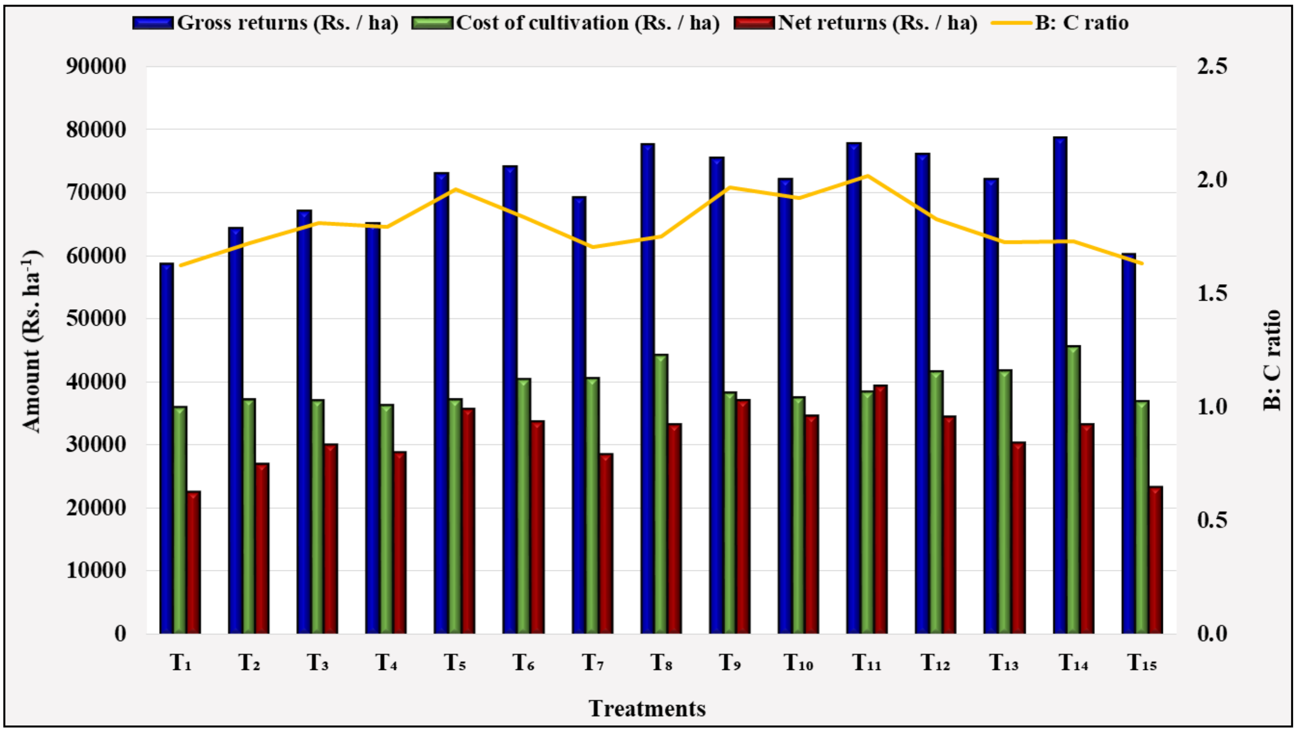

Fig 4: Economics of pigeonpea cultivation as influenced by foliar application of nano urea

Conclusion

The study demonstrates that the application of RDF (Nano Urea) combined with foliar sprays of ZnSO4 significantly enhanced the growth, yield, and nutrient use efficiency of pigeonpea compared to the use of normal urea alone. The increased plant height, branch number, dry matter accumulation, and higher seed and stalk yields were attributed to the efficient nutrient uptake and utilization provided by the nano fertilizers. These fertilizers facilitated quicker absorption and better nutrient availability during critical growth stages, resulting in improved photosynthesis, reduced flower drop, and better seed formation. The findings suggest that integrating nano fertilizers with micronutrient foliar applications can optimize pigeonpea productivity, offering a promising approach for sustainable agriculture.

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