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Response of Nano DAP on Crop Growth, Yield and Quality of Groundnut (*Arachis hypogaea*) in East and South Eastern Coastal Plain Zone of Odisha, India

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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

The study conducted during *rabi* (Jan–May, 2024) at Instructional farm, OUAT, Bhubaneswar, Odisha, India to investigate the effect of nano Diammonium Phospahe (DAP) on growth, yield and quality of groundnut (*Arachis hypogaea*) in an acid *Inceptisols.* The experiment was laid out with 11 treatments combination in randomised block design with three replications. Treatments T_{10} (T_4 + ST with Nano DAP at 10 ml L^{-1} of water and FS with Nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) resulted in higher pod yields followed by T_7 (T_4 + ST with Nano DAP at 7.5 ml L^{-1} Water +Twice FS with Nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) which was the yield obtained with 100% of STD for N and P as soil application. Whereas the lowest yield was obtained in T_{11}(absolute control). The findings revealed that the highest benefit-to-cost (B:C) ratio of 2.19 was associated with treatment T_{10} (T_4 +ST with Nano DAP at 10 ml L^{-1} of water and FS with Nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) followed by T_7 (2.17) [T_4+ST with Nano DAP at7.5 ml L^{-1} Water+Twice FS with Nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS] with reduced application of STD of conventional fertilizers at 50% along with foliar application of nano DAP found economically more sustainable. The results regarding the effect of nano DAP on post-harvest soil showed no significant changes in any of the soil parameters.

Keywords: Nano DAP; groundnut; growth; yield; economics.

1. INTRODUCTION

“Groundnut is an important oil and protein source and is considered as king of vegetable oilseed crop occupying a preeminent position in the national edible oil scenario. It contains 45–50% oil 26% protein and around 11% starch” (Rajagopal et al., 2000). About two-thirds of the world’s groundnut production is used for extracting edible oil, while the remaining serves as an important source of protein for both human and animal consumption (Sonawane et al., 2016). “Phosphorus is a crucial primary nutrient that promotes root development, allowing plants to absorb water and nutrients from deeper soil layers. It not only encourages root growth but also speeds up the maturation of oilseed crops. This nutrient is essential for synthesizing oils, proteins, and nucleic acids, and it plays a role in forming glucosinolates, which, upon hydrolysis, increase oil content, ultimately affecting both pod and oil yields” (Jeeterwal et al., 2015). In oilseed crops, especially groundnut, phosphorus is typically applied through SSP or DAP, with the entire dose given at planting.

Nanotechnology is emerging as a transformative tool in agriculture, potentially leading to a new agricultural revolution (Sandeep et al., 2019). Nano fertilizers are produced by encapsulating nutrients in nanoform, delivering them as nano-sized emulsions. These nanoscale nutrients penetrate plant leaves more effectively, activate nutrient pathways, and offer higher nutrient use efficiency (NUE) compared to bulk fertilizers. Nanoparticles accelerate seed germination, elevate agricultural yields, and enhance chlorophyll content. Nanoparticles offer a promising alternative to traditional smart fertilizers, enhancing crop yield and soil health (Zulfiqar et al., 2019). They are increasingly being studied as fertilizers to improve both the quantity and quality of crop production compared to conventional fertilizers (Dimkpa et al., 2017). “In addition to increasing the availability of phosphorus and other vital nutrients for crops, nano phosphatic fertilisers have the potential to make a substantial contribution to the efforts to decrease the usage of chemical fertiliser” (Balachandrakumar et al. 2024; Bakry et al., 2022) fertiliser particle size reduction will increase the effectiveness of additions, increasing feriliser interaction with plants and hence increasing nutrient uptake. Losses due to volatilization, leaching and runoff occur when bulk fertilisers like DAP and other related fertilisers are applied (Sahoo et al., 2024).

Nano fertilisers are more soluble in water and may improve plant uptake and distribution of fertliser (Devappa et al. n.d). According to Yadav et al. (2014), depending on the size and shape, as well as the morphology of the plant, nanoparticles may be absorbed by the roots and moved to the shoots via vascular networks. Nanotechnology has received significant scientific and commercial attention in modern agriculture as one of the main enables that has the ability to revolutionise agronomic practices by enhancing fertiliser usage and nutrient uptake in plants (Roy et al., 2023). Enhancing fertilizer efficiency involves increasing contact between the fertilizer and plants, reducing particle size to boost particle number per weight, and improving the specific surface area to enhance nutrient uptake (Brady, 1983). Very little information exists on the application of nano DAP to soil and foliar application on groundnut crop under field conditions. Keeping the above factors in view the present experiment was undertaken to study the effect of nano DAP on growth, yield and quality of groundnut and its impact on nutrient uptake and economics.

2. MATERIALS AND METHODS

A field experiment was carried out during *rabi* (January, 2024–May, 2024) 2023–24 at Instructional farm, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar of Khordha district in Odisha, India to study the effect of nano DAP on growth, yield and quality of groundnut (variety: Devi) in an acid *Inceptisols*. The soil samples (0–15 cm) were collected. The initial soil pH was found 5.36 indicating a strongly acidic reaction. The soil organic carbon content was low (0.3 g kg^{-1}), while available nitrogen was low (162 kg ha^{-1}), available phosphorus (22.3 kg ha^{-1}) and available potassium (193.5 kg ha^{-1}) were found to be medium and available sulphur was low (11.8 kg ha^{-1}), respectively.

Field experiment was carried out in Randomized Block Design (RBD) with eleven (11) treatments. A set of eleven treatments were repeated in the plots with following treatment details: T_1 - No N and P, T_2 -100% of STD for N and P as soil application, T_3 - 75% of STD for N and P as soil application, T_4 -75% of STD for N and P as soil application, T_5 - T_4 + Seed treatment (ST) with Nano DAP at 7.5 ml L^{-1} water + Foliar spray (FS) with nano DAP at 2.5 ml L^{-1} of water at 35 Days after sowing (DAS), T_6 - T_4 + ST with nano DAP at7.5 ml L^{-1} water + FS with nano DAP at 5 ml l^{-1} of water at 30 DAS, T_7- T_4+ST with nano DAP at7.5 ml L^{-1} water + twice FS with nano DAP at 2.5 ml L^{-1} of water at35 DAS and 50 DAS, T_8 - T_4+ST with nano DAP at 10 ml L^{-1} water + FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS, T_9 - T_4 + ST with nano DAP at 10 ml L^{-1} water +FS with nano DAP at 5 ml $litre^{-1}$ of water at 35 DAS, T_{10} - T_4 + ST with Nano DAP at 10 ml L^{-1} water + FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS, T_{11} - Absolute control.

Initial soil assessments encompassed key attributes such as pH, electrical conductivity (EC), organic carbon (OC), and available nitrogen (N), phosphorus (P), and potassium (K) and sulphur. Additional measurements included the determination of SPAD values. Plant analyses were conducted, focusing on the quantification of total nitrogen (N), phosphorus (P), and potassium (K). Furthermore, a diverse range of biochemical analyses were performed on oil content, and crude protein percentage. The soil parameters, both pre and post-harvest, underwent a thorough analysis, encompassing soil texture, pH, electrical conductivity (EC), organic carbon (OC), nitrogen (N), phosphorus (P), and potassium (K). The determination of soil texture employed the Bouyoucos Hydrometer method, as outlined by Piper, 1947. Soil pH was measured utilizing a pH meter, specifically the "SYSTRONICS" (model M.K VI) following Jackson's guidelines. EC was measured at room temperature (25°C) using the "SYSTRONICS" conductivity meter (model 306), based on Jackson's method from 1973. Organic carbon (OC) was analyzed through the wet digestion method proposed by Walkley and Black in 1934. The available nitrogen content in soil samples was assessed using the alkaline potassium permanganate (KMnO4) technique, as described by Subbiah and Asija in 1956, and measured by a nitrogen auto analyzer, Pelican-classic DX (Pelican make). Brays technique (Bray & Kurtz, 1945) was employed to determine the available phosphorus content of soil samples, measured calorimetrically with spectrophotometer a (model SYSTRONICS 106). The available potassium content of the experimental soil samples was determined using a SYSTRONICS digital flame photometer (model 128). The available sulphur of soil sample was determined by $CaCl_2$ extraction method described by Williams and Steinbergs (1959). SPAD readings were taken using an SPAD meter (SPAD 502 plus Chlorophyll Meter), and leaf area was calculated employing a leaf area meter. Crude protein estimation involved multiplying the nitrogen content of a sample by the nitrogen-to-protein conversion factor of 6.25. To estimate the total nitrogen (N), phosphorus (P), and potassium (K) content of plant samples, leaf and fruit samples were digested and distilled using the micro Kjeldahl technique described by Jackson (1973), utilizing the auto-analyzer's digestion unit, Pelican-classic DX (Pelican make). Phosphorus concentration was determined using the Vando-Molybdo phosphoric acid yellow colour method spectro-photometrically, as mentioned by Jackson (1973), with a "SYSTRONICS" spectrophotometer (model 106), while potassium concentration was determined using a digital flame photometer "SYSTRONICS" (model 128). The Soxhlet extraction method was used to determine the oil content in seeds as described by Soxhlet et al. (1879).

3. RESULTS AND DISCUSSION

3.1 Initial Soil Characteristics of the Experimental Site

The experiment was conducted at OUAT, instructional farm during rabi season of 2023–24 with the objective to find out the effect of nano DAP application on growth, yield and quality of groundnut. Before the start of the experiment, a composite soil sample was taken from the experimental field and various parameters of these soil samples were analysed. The results were presented in Table 2. It was found that the soils were sandy loam in texture with a sand content of (77.2%), silt content of (6.9%), and clay content of (14.8%). It was strongly acidic in reaction with a pH value of (5.36), non-hazardous salt content (electrical conductivity value of 0.15 dSm^{-1}), low organic carbon content (0.3%), low in available N (162 kg ha^{-1}), high in available P (22.3kg ha^{-1}) and medium in available K (193.5 kg ha^{-1}).

3.2 Effect of Nano DAP on Growth Parameters of Groundnut Crop

The data presented Fig. 1 showed the effect of nano dap on dry matter production. These findings clearly demonstrated that dry matter production increased as the crop progressed through its growth stages. Furthermore, significant differences in dry matter production were observed among the various treatments. Treatment T_{10} (T_4 + Seed treatment with nano DAP at 10 ml L^{-1} of water and Foliar spray with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) exhibited the highest dry matter production, while the lowest was recorded in T_{11} (absolute control). This might be due to the fact that foliar spray of nano DAP might have favourably influenced carbohydrate metabolism and also enhanced the synthesis of amino acids, RNA and DNA, as well as leaf area, which has increased photosynthesis and thus increased the plant's ability to promote vegetative growth and dry matter. Nano DAP fertilizer has higher nutrient use efficiency which led to higher growth and dry matter production. These findings were in accordance with Aziz and Zrar (2021) and similar results were also reported by Sharma et al. (2022) and Maheta et al. (2023).

3.3 Effect of Nano DAP on Chlorophyll Content of Groundnut Crop

The data in Fig. 2 illustrated the impact of nano DAP on chlorophyll content. These results clearly indicated that chlorophyll levels increased as the crop advanced through its growth stages. Additionally, significant differences in chlorophyll content were noted among the various treatments. Treatment T_{10} (T_4 + Seed Treatment with nano DAP at 10 ml L^{-1} of water and Foliar spray with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) recorded the highest chlorophyll content, while T_{11} (absolute control) had the lowest. The results indicated that soil and / or foliar application of nano phosphorus fertilizer enhanced the growth parameters of groundnut compared to control and produced better and at par growth parameters with 100% STD applied treatment. This enhancement might be attributed to the ability of nano-sized particles to promote the absorption and utilization of nutrients like nitrogen and phosphorus. Their large surface area and smart delivery system, which allowed for a controlled release of nutrients, increased the nutrient use efficiency of the crop. This has been concluded by Ajirloo et al. (2015) in tomatoes, Merghany et al. (2019) in cucumbers, Al Jabri et al. (2020) in okra, and AL-Kaby et al. (2021) in okra.

3.4 Effect of Nano DAP Application on Qualitative Parameters of Groundnut

The results showed in Figs. 3,4 and 5 illustrated the impact of nano DAP on root diameter, nodule number and nodular nitrogen content of groundnut crop. The results clearly indicated that there was significant increase in root diameter, nodule number and nodular nitrogen content of groundnut crop were observed. Treatments that included nano DAP were particularly effective, with T10 (T_4+ Seed treatment with nano DAP at 10 ml L^{-1} of water + foliar spray with nano DAP at 2.5 ml L^{-1} of water at 35 and 50 DAS) achieving the highest root diameter of 11.9 cm, while T_{11} (Absolute control) recorded the lowest at 6.9 cm. “This might be due to application of nano DAP which attributed to the better and / or at par growth parameters observed in groundnut with the combined application of nano phosphorus fertilizers along with inorganic fertilizers might be attributed to slow and continued release of P, which coincided with crop nutrient demand” (Manikandan and Subramanian, 2015 in Rajendran et al., 2017). The superior and sustained phosphorus supply delivered by these nano-materials at various physiological intervals may have intensified metabolic functions in the plants, including protein synthesis, photosynthetic activity, cellular division, respiration, and energy storage, consequently improving below-ground root growth. These results highlighted the benefits of using nano DAP in conjunction with scheduled fertilizer applications to enhance root diameter.

3.5 Effect of Nano DAP on Yield Attributing Character

The data in Table 1 highlighted the effect of nano DAP on yield attributes of groundnut crop. These results clearly showed that the number of pods and yield of pod increased as the crop progressed through its growth stages. Moreover, significant differences in pod number were observed among the various treatments. Treatment T_{10} (T_4+ST with nano DAP at 10 ml L^{-1} of water and FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) recorded the highest pod count, whereas T_{11} (absolute control) had the lowest. The increased nutrient uptake contributed to optimal growth of plant parts. “Phosphorus uptake led to increased net CO_2 fixation with increased rate of photosynthesis and thereby more photosynthates to develop a greater number of pods $plants^{-1}$” (Devi et al., 2012). The selective uptake and translocation of nano particles as indicated by Dhoke et al. (2012) suggested that “nano particles have high reactivity because of large surface area, more density of reactive area and increased reactivity of these area on the particles surface and there features simply their absorption in plants” (Zheng et al., 2005). Similar findings were observed by Manjili et al. (2014) and Abdelghany et al. (2022).

So far pod yield, significantly highest pod yield was recorded in T_{10} (T_4+ST with Nano DAP at 10 ml L^{-1} of water and FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS), followed by T_7 (T_4+ST with nano DAP at 7.5 ml L^{-1} water + twice FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS). The lowest pod yield was observed at T_{11} (absolute control). Combined application of conventional fertilizer and nano DAP increased the pod yield by 69% over control. Higher pod yield might be due to ensured optimum and balanced nutrient availability throughout the crop growth period. The greater nutrient uptake supports optimal growth and enhances metabolic activities such as photosynthesis, increasing the production and movement of photosynthates to economically important plant organs. This, in turn, boosts biomass, yield-related traits, and ultimately yield by promoting more efficient translocation of assimilates to the seeds. Similar results were reported by Choudhary et al. (2018), Kumari et al. (2017) and Prakash et al. (2023).

3.6 Effect of Nano Dap on Biochemical Properties

The data in Table 4 highlighted the effect of nano DAP on biochemical properties of groundnut crop. Oil content was not significantly different due to the foliar application of nano DAP when compare to 100% STD of N and P as soil application and it is depicted in Fig. 7. The highest oil content was found in T_{10} (T_4+ST with Nano DAP at 10 ml L^{-1} of water and FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) and lowest in T_{11}(absolute control). It might be due to supplying essential nutrients according to plant needs could lead to an increase in seed oil percentage due to enhanced enzymatic activity and effectively increased photosynthesis and translocation of assimilates to the seed. This might have resulted in a higher oil content compared to the absolute control, but the highest oil yield was recorded due to the higher seed yield and oil content produced. Similar results were reported by Yacoub et al. (2020). “The increase in oil content was mainly due to increase in glucoside formation (allyisothiocynate) also the oil content increased due to increase in P level, probably because it was a constituent of phospholipids and was essential for its synthesis” (Singh & Singh, 1988).

The results found that foliar spray of nano DAP increased the protein content of groundnut and depicted in Fig. 7. The highest protein content was found with T_{10} (T_4+ST with nano DAP at 10 ml L^{-1} of water and FS with nano DAP at 2.5 ml l^{-1} of water at 35 DAS and 50 DAS) followed by T_7 (T4+ST with nano DAP at 7.5 ml L^{-1} water + twice FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS) whereas lowest observed under T_{11}(absolute control). This result could be attributed to the fact that nitrogen played a vital role in amino acid synthesis, which, in turn, served as the fundamental framework for the formation of proteins in plants. Similar results were observed by Duraisamy and Mani (2001) and Nget et al. (2022).

3.7 Influence of nano DAP on post-harvest soil nutrients

Soil samples were collected from the experimental plots after the groundnut crop harvest, and various soil properties, including available nutrients (N, P, K and S), were analysed. The results of the analysis were summarized in Table 3.

Table 1. Effect of nano DAP application on yield and yield attributing character of groundnut

Treatments	Pod number	Shelling (%)	Pod yield (kg ha^{-1})
T_1: No N and P	13.0	63.6	1420
T_2:100%of STD for N and P as soil application	19.9	80.6	2330
T_3:75% of STD for N and P as soil application	14.6	74.7	2010
T_4:50% of STD for N and P as soil application	13.6	73.8	1740
T_5:T_4+Seed treatment (ST) with nano DAP at 7.5 ml L^{-1} water +Foliar spray (FS) with nano DAP at 2.5 ml L^{-1} water at 35 Days after sowing (DAS)	14.9	75.2	2130
T_6:T_4+ST with nano DAP at 7.5 ml L^{-1} water + FS with nano DAP at 5 ml L^{-1} water at 30 DAS	15.1	75.8	2240
T_7:T_4+ST with nano DAP at 7.5ml L^{-1} water+ Twice FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	20.2	81.3	2390
T_8:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS	16.6	79.2	2280
T_9:T_4+ST with nano DAP at 10 ml L^{1} water+FS with nano DAP at 5 ml L^{-1} water at 35 DAS	18.0	79.5	2320
T_{10}:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	21.9	85.6	2410
T_{11}:Absolute control	11.4	68.3	1310
SEm(±)	**0.59**	**3.25**	**112.14**
CD (*p*=0.05)	**1.70**	**9.41**	**324.36**
CV	**5.69**	**6.73**	**8.60**

Table 2. Effect of nano DAP application on biochemical properties of groundnut

Treatments	Oil content (%)	Crude protein (%)
T_1: No N and P	38.3	7.1
T_2:100%of STD for N and P as soil application	41.1	10.1
T_3:75% of STD for N and P as soil application	40.3	8.8
T_4:50% of STD for N and P as soil application	38.7	8.6
T_5:T_4+Seed treatment (ST) with nano DAP at 7.5 ml L^{-1} water +Foliar spray (FS) with nano DAP at 2.5 ml L^{-1} water at 35 Days after sowing (DAS)	40.6	9.1
T_6:T_4+ST with nano DAP at 7.5 ml L^{-1} water + FS with nano DAP at 5 ml L^{-1} water at 30 DAS	40.8	9.4
T_7:T_4+ST with nano DAP at 7.5ml L^{-1} water+ Twice FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	42.4	10.5
T_8:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS	39.6	9.6
T_9:T_4+ST with nano DAP at 10 ml L^{1} water+FS with Nano DAP at 5 ml L^{-1} water at 35 DAS	41.0	9.8
T_{10}:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	42.8	10.6
T_{11}:Absolute control	35.9	7.0
SEm(±)	2.05	0.38
CD (*p*=0.05)	5.92	1.11
CV	8.03	6.58

Table 3. Influence of Nano DAP on post-harvest soil parameters

Treatments	Available nutrient content (kg ha^{-1})			
	Nitrogen	Phosphorus	Potassium	Sulphur
T_1: No N and P	160.20	20.3	198.7	13.1
T_2:100%of STD for N and P as soil application	173.88	24.8	226.7	19.8
T_3:75% of STD for N and P as soil application	169.72	22.6	211.7	16.0
T_4:50% of STD for N and P as soil application	168.97	21.8	208.7	15.7
T_5:T_4+Seed treatment (ST) with nano DAP at 7.5 ml L^{-1} water +Foliar spray (FS) with nano DAP at 2.5 ml L^{-1} water at 35 Days after sowing (DAS)	170.97	22.7	200.9	16.7
T_6:T_4+ST with nano DAP at 7.5 ml L^{-1} water + FS with nano DAP at 5 ml L^{-1} water at 30 DAS	171.50	23.4	208.7	16.8
T_7:T_4+ST with nano DAP at 7.5ml L^{-1} water+ Twice FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	173.57	26.7	237.6	20.6
T_8:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS	171.58	23.5	216.0	19.2
T_9:T_4+ST with nano DAP at 10 ml L^{1} water+FS with nano DAP at 5 ml L^{-1} water at 35 DAS	172.16	24.6	225.2	19.8
T_{10}:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	174.93	28.8	243.3	23.7
T_{11}:Absolute control	155.20	19.9	195.4	12.9
SEm(±)	9.27	1.09	10.86	0.73
CD (*p*=0.05)	26.82	3.16	31.42	2.11

Table 4. Effects of nano DAP spray on groundnut B:C ratio

Treatments	B:C ratio
T_1: No N and P	1.35
T_2:100%of STD for N and P as soil application	2.07
T_3:75% of STD for N and P as soil application	1.83
T_4:50% of STD for N and P as soil application	1.62
T_5:T_4+Seed treatment (ST) with nano DAP at 7.5 ml L^{-1} water +Foliar spray (FS) with nano DAP at 2.5 ml L^{-1} water at 35 Days after sowing (DAS)	1.95
T_6:T_4+ST with nano DAP at 7.5 ml L^{-1} water + FS with nano DAP at 5 ml L^{-1} water at 30 DAS	2.05
T_7:T_4+ST with nano DAP at 7.5ml L^{-1} water+ twice FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	2.17
T_8:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS	2.08
T_9:T_4+ST with nano DAP at 10 ml L^{1} water+FS with nano DAP at 5 ml L^{-1} water at 35 DAS	2.12
T_{10}:T_4+ST with nano DAP at 10 ml L^{-1} water+FS with nano DAP at 2.5 ml L^{-1} water at 35 DAS and 50 DAS	2.19
T_{11}:Absolute control	1.28

The combined application of fertilizers with nano DAP influenced the available nutrients (NPK) after harvest of groundnut crop. The soil available N, P and K were maximum (174.93, 28.8 and 243.3 kg ha^{-1}, respectively) in T_{10} (T_4+ST with nano DAP at 10 ml L^{-1} of water and FS with nano DAP at 2.5 ml L^{-1} of water at 35 DAS and 50 DAS). The lowest status of available NPK was recorded in T_{11} (Absolute control). Regarding the impact of nano DAP on various properties of post-harvest soil, no significant changes in any soil characteristics were noted when compare to 100% of STD of N and P as soil application in groundnut. Similar findings were reported by Karunakaran et al. (2010).

The findings recorded in Fig. 6 also revealed that the highest benefit-to-cost (B:C) ratio of 2.19 was associated with treatment T_{10} with reduced application of STD of conventional fertilizers at 50% along with foliar application of nano DAP found economically more sustainable.

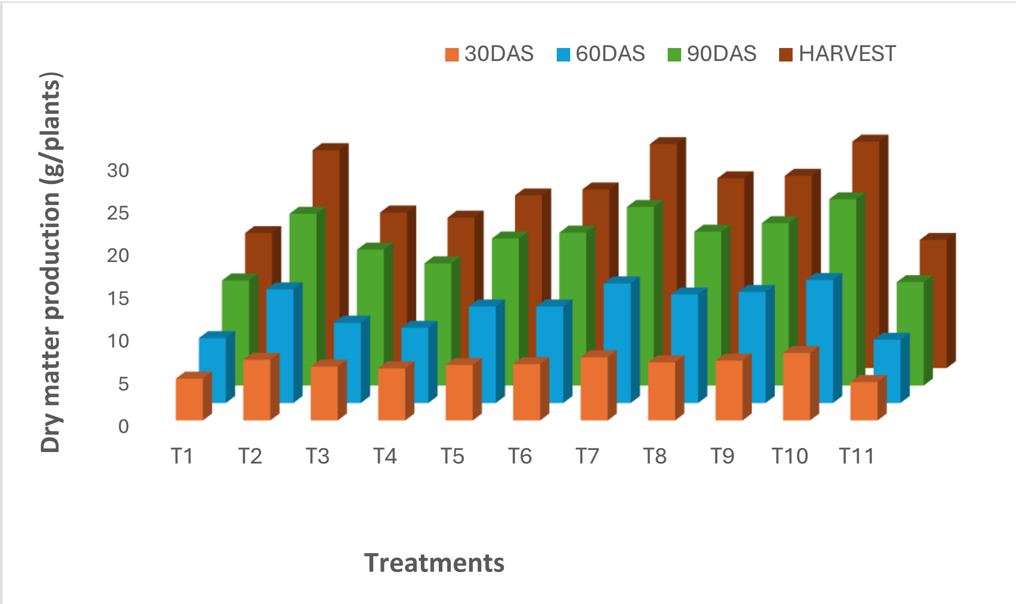

Fig. 1. Influence of nano DAP on pant dry matter of groundnut

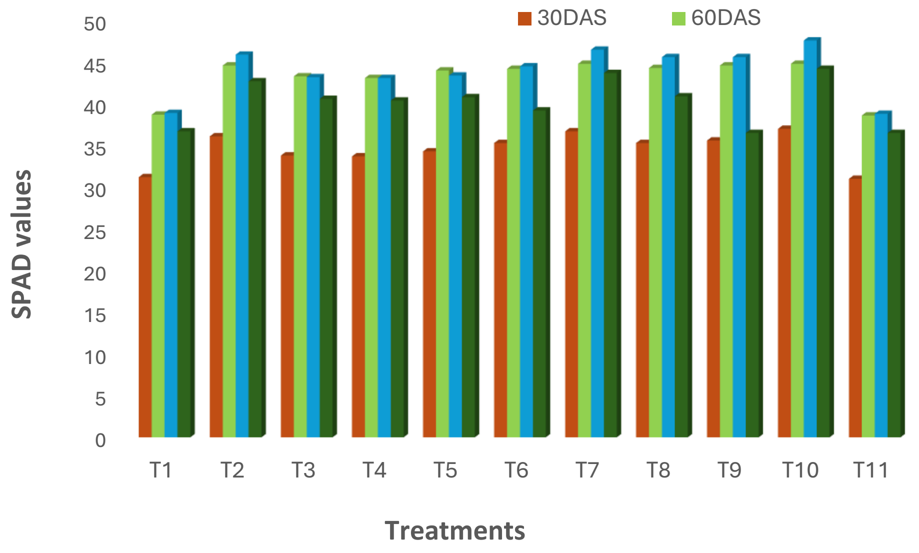

Fig. 2. Influence of nano DAP on chlorophyll content (SPAD value) of groundnut

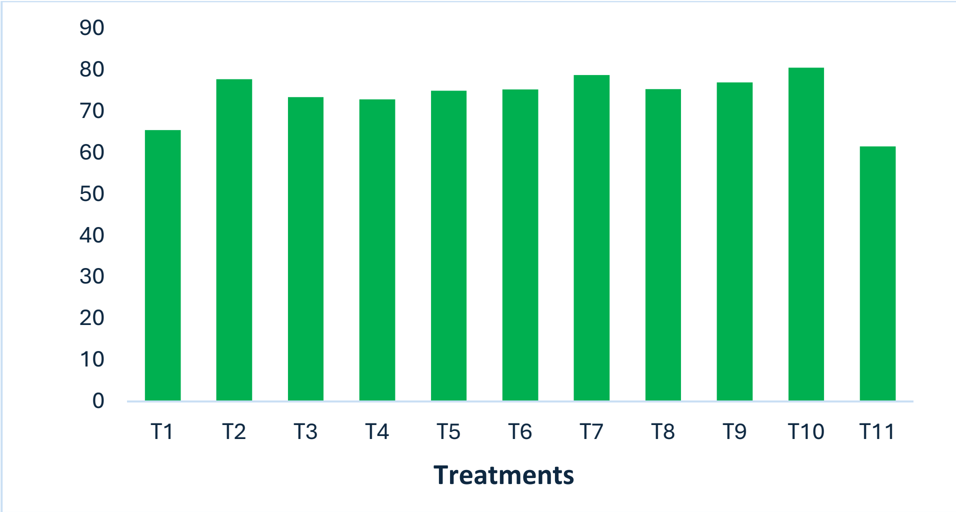

Fig. 3. Influence of nano DAP on number of nodules per plant

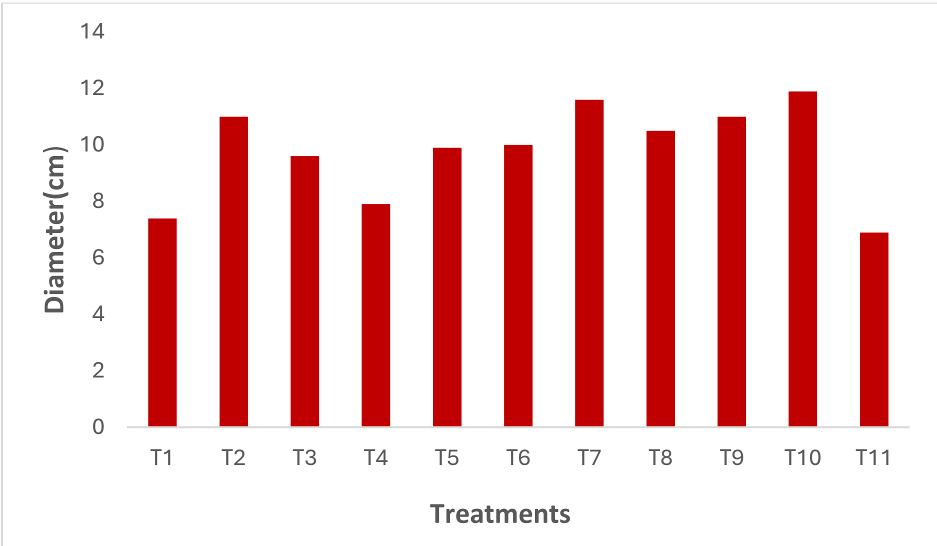

Fig. 4. Influence of nano DAP on root diameter of groundnut

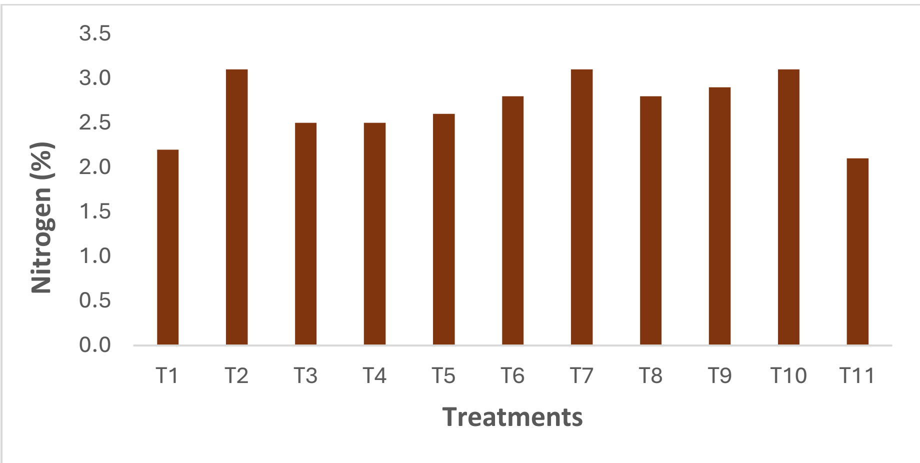

Fig. 5. Influence of nano DAP on nodular nitrogen (%)

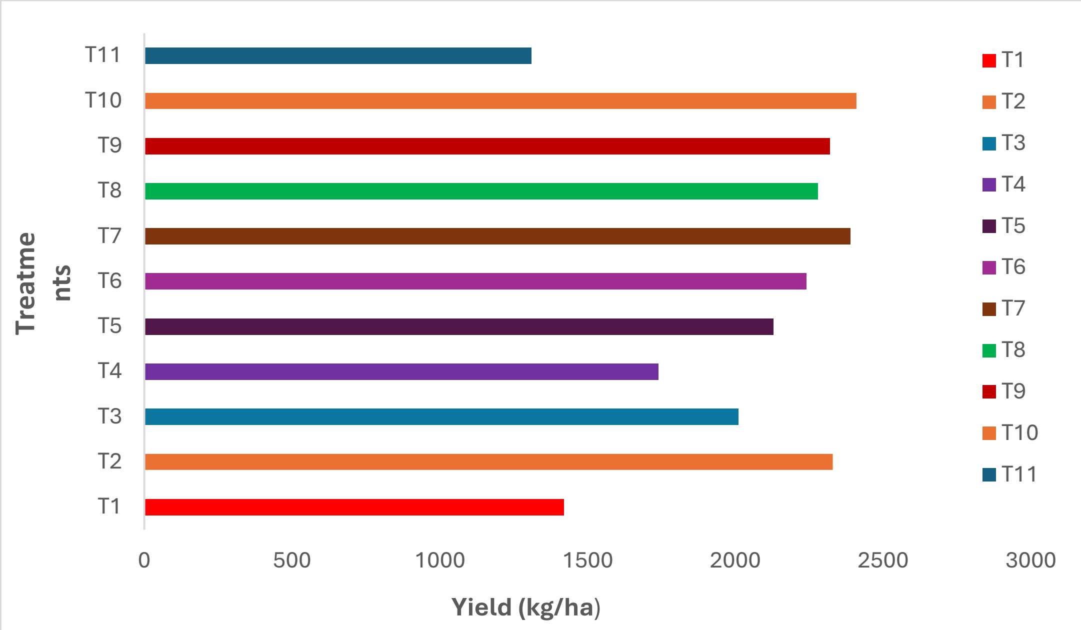

Fig. 6. Influence of nano DAP on pod yield of groundnut

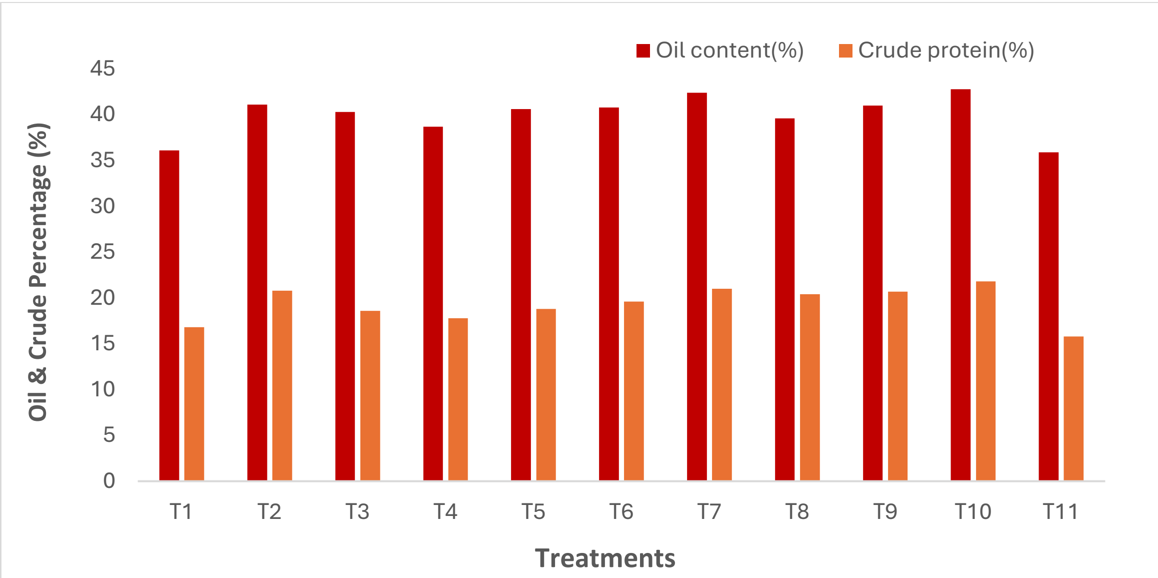

Fig. 7. Influence of nano DAP on oil content and crude protein

4. CONCLUSION

It may be concluded that for effective management of groundnut crop 50 percent reduction of conventional fertilizer by foliar application of nano DAP @ 2.5 ml $L^{-1}$of water at 35 DAS and 50 DAS along with seed treatment with nano DAP at 10 ml L^{-1} of water may be considered as a sustainable nutrient management practice that not only reduce the cost of cultivation but also reduce the dependency over the conventional fertilizers by 50 percent and benefitting soil health.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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