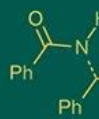


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Effect of nano-DAP on nutrient dynamics and yield of soybean

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Abstract

The present investigation entitled “Studies on efficiency of Nano-DAP fertilizer on yield, nutrient uptake and quality of soybean (*Glycine max* L.) under entisol” during *kharif* season of year, 2022-2023 at research farm Department of Soil Science and Agricultural Chemistry, College of Agriculture, Osmanabad. The experiment was layout in RBD with three replications and recommended variety of Soybean MAUS-158 as a test crop along with ten treatments.

The results in nutshell indicated that available nitrogen, phosphorus, potassium and sulphur content in soil after harvest of soybean crop was influenced significantly and recorded maximum availability N, P, K and S with the application of 100 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS over control. It was clearly noted that foliar application of Nano-DAP with increase in fertilizer doses showed beneficial effect on grain yield and straw yield with the application of 100 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS recorded maximum grain yield of soybean as compared to rest of the treatments. The significant maximum values of content, uptake and total uptake of Nitrogen, Phosphorus, potassium, was noticed in grain and straw with the application of 100 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS. However potassium and sulphur content in grain and straw was not significantly influenced with the application of varied levels of fertilizer application along with Nano DAP.

Keywords: RDNP, nano-DAP, foliar application and uptake of NPK

1. Introduction

The soybean (*Glycine max* L.), popularly known as the miracle crop or the golden bean. The soybean was first introduced to Europe in the USA and China in the 17th and 18th centuries. The legume family Fabaceae includes soybean, which is also referred to in India as Bhat, Kulthi, kalitur, Bhut, and Bhatman, among other names. Roughly 60 percent of the world's supply of vegetable protein and 30 percent of the world's oil are found in it, which has roughly 40 percent protein and 20 percent oil. It is grown in tropical, subtropical, and temperate climates Soybean account for about 60 percent of the total global oil seed production of 390-425 mt with cotton seed, the closest competitor. Turkey is ranked first in productivity, but the USA is ranked first in both area (30.91 m hectares) and production (91.42 mt). India is fifth in crop production (9.91 mt) and fourth in area (9.5 m hectares). In India MP ranks 1st in area (5.12 m ha) and production (5.85 mt) compare with other states. It also known as “Soya state.” (Jadhavar & Rajput 2023) [6].

Soybean is a rich source of nutrition. From nutritional point of view, it contains about 40-45 percent protein, well balanced amino acids, 18-22 percent cholesterol free oil with 85 percent unsaturated fatty acids, especially omega 6 and omega 3 fatty acids, 6-7 percent total mineral, 5-6 percent crude fibre, 24-26 percent carbohydrates and good amounts of vitamins in its seed. Soybean is the leading source of edible oils constituting about 30 percent of the world supply among other oilseed crops. Soybean oil is considered a future fuel source and efforts are made to increase soybean-derived diesel production. Being a leguminous crop, soybean is also capable of with stand moisture stress and helps in improving the soil fertility and productivity. Soybean cultivation improves soil health because of its atmospheric nitrogen fixing ability and deep root system. Symbiotically soybean fixes 125-150 kg N ha⁻¹ and leaves about 30-40 kg N ha⁻¹ for succeeding crop (Ryan, *et al.*, 2018) [13].

Nutrient use efficiency (NUE) is a critical parameter for determining sustainability of crop production systems.

Under the current fertilization practices involving conventional fertilizers, the NUE ranges 30–40 percent for N-fertilizers and 18–20 percent for P-based fertilizers. Apparently, only a fraction of these nutrients is available for crop growth and yield formation. In contrast, a relevant amount of fertilizers is released into the environment annually, resulting in eutrophication and groundwater contamination that threatens environmental resources, public health, and economic investments. Thus, it will be essential to introduce agro technological innovations and revolutionary agri inputs. Nanotechnologies have the potential to produce a significant boost in crop yield along with improvement of food production systems. This innovation can lead to more precise application of nutrients along with saving of the nutrients. (Tiwari, *et al.*, 2022) ^[16]

Nano-fertilizers are synthesized or modified form of traditional fertilizers, fertilizers bulk materials or extracted from different vegetative or reproductive parts of the plant by different chemical, physical, mechanical or biological methods with the help of nanotechnology used to improve soil fertility, productivity and quality of agricultural produces. Nanoparticles can be made from fully bulk materials. At nano scale physical and chemical properties are different than bulk material. The nano-fertilizers have higher surface area it is mainly due to very less size of particles which provide more site to facilitate different metabolic process in the plant system result production of more photosynthetic. Due to higher surface area and very less size they have high reactivity with other compound. They have high solubility in different solvent such as water. Particle size of nano-fertilizers is less than 100 nm which facilitates more penetration of nano particles into the plant from applied surface such as soil or leaves. Nano fertilizer has large surface area and particle size less than the pore size of root and leaves of the plant which can increase penetration into the plant from applied surface and improve uptake and nutrient use efficiency of the nano fertilizer. 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-fertilizers which leads to more penetration and uptake of the nutrient. (Singh, M.D. 2017) ^[14].

Di-ammonium phosphate (DAP) is the world's most widely used phosphorus fertilizer, containing 18 percent N and 46 percent phosphorus. Soybean is known to be highly nitrogen demanding crop, since the end product is very rich in protein. Biological N₂ fixation and mineral soil or nitrogen fertilizer are the main source of meeting the nitrogen requirement of high-yielding soybean. Phosphorus

deficiency can limit nodulation, growth and yield of soybean and phosphorus fertilizer application can overcome the deficiency.

2. Materials and Methods

This study was conducted at the research farm of the Soil Science and Agricultural Chemistry Department, College of Agriculture, Osmanabad, during the kharif season of 2022-2023, focusing on the soybean variety MAUS-158. The experimental site featured uniform, leveled topography and is situated in a subtropical climate characterized by dry conditions and a monsoon period from late June to September. The region experiences higher humidity in October and November, with winter temperatures ranging from 12 °C to 15 °C and summer temperatures between 28 °C and 36 °C. Average annual precipitation is recorded at 550-650 mm, primarily during the monsoon season.

The soil at the site consists of slightly brown Entisols, located in the eastern Marathwada region at an altitude of 653 m above sea level. This investigation aimed to assess the efficiency of nano-DAP fertilizer on the yield, nutrient uptake, and quality of soybean (*Glycine max* L.). The study employed a Randomized Block Design with ten treatment combinations and three replications, incorporating a recommended dose of nitrogen, phosphorus, potassium, sulfur, and nano-DAP in liquid form. Treatment details are outlined in Table 1.

Available nitrogen was determined by alkaline potassium permanganate method as described by Subbiah and Asija (1956) ^[15], available phosphorus was determined by Olsen's method as described by Jackson (1973) ^[5], available potassium was determined by Flame Photometer (Piper, 1966) ^[11] and available sulphur was determined by turbidimetric method (Williams and Steinberg, 1959).

Total nitrogen in plant was determined by micro kjeldahl's method (Jackson, 1973) ^[5], total phosphorus in dry matter was determined by Vanadomolybdate phosphoric acid yellow colour method (Jackson, 1973) ^[5], Potassium content in plant sample was determined on Flame Photometer as suggested by Jackson (1973) ^[5] and Sulphur content was determined on ultraviolet spectrophotometer as described by Tondon (1993) ^[17].

The uptakes nutrients (N, P, K, and S) by soybean crop were calculated by using following formula

$$\text{Uptake of Nutrients (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{seed and stover yield ha}^{-1}}{100}$$

Table 1: The details of treatment along with symbol

Sr. No	Treatment
1	T ₁ -Control
2	T ₂ -100% RDF + S.T
3	T ₃ -S.T + F.S. @ 0.4% Nano-DAP at 30,45 and 60 DAS
4	T ₄ -25% RDNP + S.T + F.S. @ 0.4% of Nano-DAP at 30 & 60 DAS
5	T ₅ -25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30, 45 & 60 DAS
6	T ₆ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS
7	T ₇ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS
8	T ₈ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS
9	T ₉ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS
10	T ₁₀ -100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS

3. Results and Discussion

3.1 Nitrogen availability

The data in respect of impact of Nano-DAP on available nitrogen in soil under soybean at various growth stages was presented in table 2. The data showed significant result in availability of nitrogen in soil after harvest of soybean was ranged from 157.24 to 234.37 kg ha⁻¹, respectively. Among different treatments, the higher availability N (234.37 kg ha⁻¹) was recorded in treatment T₁₀ (100 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS) at par with treatments T₉ (75 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 and 45 DAS) (232.26 kg ha⁻¹) and T₂ (100 percent RDF + S.T) availability N (228.33 kg ha⁻¹). The lowest availability nitrogen (157.24 kg ha⁻¹) was found in treatment T₁ (control).

The increase in the availability of nitrogen, in soil due to increase in dose of fertilizer along with foliar application of Nano-DAP. Might be due to the activity of microbes are root nodules which the atmospheric nitrogen fixation, ultimately in increase in nitrogen status of soil.

The soil application with fertilizer foliar spray Nano-DAP significantly build-up available nitrogen status. These results are in line with the results noted by Jaybhay, *et al.*, (2021)^[7]. Lakshmy, *et al.*, (2020)^[8].

3.2 phosphorus availability

The results regarding effect of soil and foliar application of nano DAP on available phosphorous status in soil are presented in table 2. Available phosphorous content in the soil after harvest of soybean ranged 9.55 to 20.57 kg ha⁻¹, respectively. Among different treatments, the higher availability phosphorous (20.57 kg ha⁻¹) was recorded in treatment T₁₀ (100 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS) at par with by treatments T₉ (75 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30,45 DAS) availability phosphorous (19.42 kg ha⁻¹), T₂ (100 percent RDF + S.T) availability phosphorous (19.30 kg ha⁻¹) and followed by T₈ (75 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS) availability phosphorous (18.40 kg ha⁻¹), T₇ (50 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 & 60 DAS) availability phosphorous (16.24 kg ha⁻¹) and treatment T₆

(50 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS) availability phosphorous (14.86 kg ha⁻¹). The lowest available phosphorous (9.55 kg ha⁻¹) was found in treatment T₁ (control).

The availability phosphorus increases due to the seed treatment with Nano-DAP and soil, foliar application of Nano-DAP at 30 and 45 DAS which significantly higher microbial activity and root activity in the rhizosphere and improved soil physical and chemical properties.

Similar results were reported by Krishna, *et al.*, (2019)^[9] found that among the all treatments, the highest available phosphorous (25.00 kg ha⁻¹) was obtained in 0.5 percent KNO₃ + 2 percent DAP + micronutrient spray along with RDF (T₇). Lakshmy, *et al.*, (2020)^[8] found that the significant effects on available phosphorus in soil by the foliar nutrition the highest available phosphorous in soil (22.70 kg ha⁻¹) was observed in the treatment 2 percent DAP + RDF, and lowest water spray + RDF (17.43 kg ha⁻¹). Baglane R.A. (2023)^[1] found that the phosphorus availability in soybean was found to be influenced significantly due to T₂ 100 percent RDF of NPK (17.80 kg ha⁻¹) and lowest in to T₁ control (14.20 kg ha⁻¹).

3.3 Potassium availability

The data in respect of impact of soil and foliar application of Nano-DAP on available potassium in soil under soybean presented in table 2. The data showed significant variations in availability of potassium in soil after the harvest of soybean.

Available potassium content in the soil after harvest of soybean ranged 267.63 to 355 kg ha⁻¹ respectively. Among different treatments, the higher availability K (355 kg ha⁻¹) was recorded in treatment T₁₀ (100 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS). The treatments T₁₀ was at par with the treatment T₉ (75 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30, 45 DAS) availability potassium (349 kg ha⁻¹), T₂ (100 percent RDF + S.T) available potassium recorded (347.33 kg ha⁻¹), and treatment. and lowest found in treatment T₁ control (267.63 kg ha⁻¹). This may be happened due the use of conventional fertilizer (75 and 100 percent RDNP) at the time of sowing gives better result in potassium availability in soil.

Table 2: Effect of foliar application of Nano-DAP on Soil available nutrients after harvest of soybean.

Treatment details	Soil available nutrient (kg ha ⁻¹)			
	N	P	K	S
T ₁ -Control	157.24	9.55	267.63	9.24
T ₂ -100% RDF	228.33	19.30	347.33	14.70
T ₃ -S.T + F.S. @ 0.4% Nano-DAP at 30,45 and 60 DAS	163.71	10.40	276.67	10.46
T ₄ -25% RDNP + S.T + F.S. @ 0.4% of Nano-DAP at 30 & 60 DAS	169.14	12.52	289.00	12.55
T ₅ -25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30,45 & 60 DAS	184.82	14.10	298.33	12.81
T ₆ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	195.00	14.86	318.67	13.59
T ₇ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	208.61	16.24	326.67	13.84
T ₈ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	219.12	18.40	342.33	14.00
T ₉ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	232.26	19.42	349.00	14.72
T ₁₀ -100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	234.37	20.57	355.00	15.00
SE±	2.11	0.54	3.89	0.77
CD at 5%	6.28	1.59	11.55	2.30

Similar results were reported by Krishna, *et al.*, (2019)^[9] found that among the all treatments, the highest available K (278 kg ha⁻¹) was obtained in 0.5 percent KNO₃ + 2 percent DAP + micronutrient spray along with RDF (T₇) and lowest in treatment T₁₁ control available K (240 kg ha⁻¹). Lakshmy, *et al.*, (2020)^[8] concluded that the highest available

potassium in soil (237.73 kg ha⁻¹) was recorded with the application 2 percent 19:19:19 (NPK) + RDF followed by 0.5 percent MOP + RDF (236.60 kg ha⁻¹) and 2 percent DAP + RDF (234.67 kg ha⁻¹). Baglane. R.A. (2023)^[1] found that the potassium availability was found to be influenced

significantly due to T₂ 100 percent RDF of NPK (276.80 kg ha⁻¹) and lowest in to T₁ control (270.00 kg ha⁻¹).

3.4 Sulphur availability

The data shows significant result in availability of sulphur at harvest due to soil and foliar application of nano DAP presented in table 2. Which range from 9.24 to 15.00 kg ha⁻¹. Among different treatments, the higher availability sulphur recorded in treatment T₁₀ (100 percent RDNP + S.T + F.S @ 0.4 percent of Nano-DAP at 30 DAS) 15.00 kg ha⁻¹ and treatment T₁₀ at par with the treatment T₉ (14.72 kg ha⁻¹), T₂ (100 percent RDF) 14.70 kg ha⁻¹, treatment T₈ 14.00 kg ha⁻¹ and Lowest availability of sulphur recorded as 9.24 kg ha⁻¹ in control T₁.

The data make it abundantly clear that the treatments T₇ and T₆ which increase the sulphur availability (13.84 and 13.59 kg ha⁻¹) they could not be recorded to the level of significance in respect to T₁₀. But they better than the treatment T₅, T₄, and T₃ which received the 25 percent RDNP with seed treatment and foliar application of Nano-DAP at 30, 45 and 60 DAS of soybean

This may be happened due, soil application of conventional fertilizer with foliar spray of Nano-DAP result availability of sulphur more into that treatment which received RDF with Nano-DAP compared which not received respectively, similar results were reported by Lakshmy, *et al.*, (2020) [8] found that the significant effects on available sulphur in soil by the foliar nutrition the highest available sulphur in soil (16.54 kg ha⁻¹) was observed in the treatment 2 percent DAP + RDF.

3.4.1 Nitrogen content and uptake by soybean.

Data presented in table 3. which shows the content and

uptake of nitrogen influenced by various treatments of Nano-DAP fertilizer. From the data it was observed that the nitrogen content in grain and straw ranged between 5.16 to 5.74% and 1.00 to 1.97%, respectively. Similarly, the uptake of nitrogen by grain and straw varied from 48.97 to 109.64 kg ha⁻¹ and 19.64 to 74.51 kg ha⁻¹, respectively.

The substantially increased nitrogen content and uptake by grain 5.74%, 109.64 kg ha⁻¹ and straw 1.97%, 74.51 kg ha⁻¹ was due to treatment T₁₀ (100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS) and was noted at par with the treatment T₉ (75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30,45 DAS) nitrogen content and uptake by grain (5.72%, 107.69 kg ha⁻¹) and straw (1.88% and 67.85 kg ha⁻¹), treatment T₂ (100% RDF + S.T) nitrogen content and uptake by grain (5.71%, 106.86 kg ha⁻¹) and straw (1.85 and 65.18 kg ha⁻¹), respectively.

The data make it abundantly clear that the application of treatments T₈ (75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS), T₇ (50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS), treatment T₆ (50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS), treatment T₅ (25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30, 45 and 60 DAS), treatment T₄ (25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 and 45 DAS) and T₃ (S.T + F.S @ 0.4% of Nano-DAP at 30, 45 and 60 DAS), they at par with T₁₀ in respect to the nutrient content in seed and straw but they could not be recorded the level of significance in respect to the grain and straw uptake and total uptake.

Similarly, data show that the total uptake of nitrogen found in treatment T₁₀ (184.15 kg ha⁻¹) and was noted at par with the treatment T₉ (175.54 kg ha⁻¹) and T₂ (172.04 kg ha⁻¹), and lowest nitrogen total uptake found in treatment T₁ control (68.61 kg ha⁻¹).

Table 3: Effect of foliar application of nano DAP fertilizer on content (%) and uptake on N (kg ha⁻¹) by grain and straw of soybean crop after harvest.

Treatment details	N Content (%)		N Uptake (kg ha ⁻¹)		Total
	Seed	Straw	Seed	Straw	
T ₁ –Control	5.16	1.00	48.97	19.64	68.61
T ₂ -100% RDF	5.71	1.85	106.86	65.18	172.04
T ₃ -S.T + F.S. @ 0.4% Nano-DAP at 30,45 and 60 DAS	5.31	1.40	59.34	31.93	91.27
T ₄ -25% RDNP + S.T + F.S. @ 0.4% of Nano-DAP at 30 & 60 DAS	5.61	1.48	68.03	37.01	105.04
T ₅ -25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30, 45 & 60 DAS	5.63	1.51	75.21	38.82	114.03
T ₆ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	5.66	1.58	83.74	43.52	127.26
T ₇ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	5.66	1.60	89.06	47.72	136.78
T ₈ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	5.70	1.66	99.20	53.00	152.20
T ₉ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	5.72	1.88	107.69	67.85	175.54
T ₁₀ -100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	5.74	1.97	109.64	74.51	184.15
SE±	0.11	0.09	2.15	3.85	4.15
CD at 5%	0.32	0.28	6.40	11.44	12.33

The nitrogen uptake of soybean was found to be increased with the judicious application of soil, seed treatment with Nano-DAP and foliar application of Nano DAP which might be due to Nano-fertilizer have large surface area and particle size is 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 content and uptake by seed and straw.

Nearly similar results were found by Paikra, *et al.*, (2018) [10] found that the significant effects foliar application of RDF + spray of DAP @ 2 percent at pod initiation Nutrient uptake or concentration percent of soybean recorded highest it might be due to the application of micronutrients in the form of foliar spray responded well and might be helpful to

absorb other nutrients also in balance amount resulted more concentration of N (190.1 kg ha⁻¹). Lyngdoh, *et al.*, (2019) [9] revealed that the significant effects total nitrogen uptake (302.95 kg ha⁻¹) was observed in RDF + DAP 2 percent spray. The significant increase in nitrogen uptake may be due to the synergistic effect of nitrogen and phosphorus in soybean.

3.4.2 Phosphorous content and uptake by soybean.

Data presented in table 4. which shows the content and uptake of phosphorous influenced by various treatments of Nano-DAP fertilizer. From the data it was observed that the phosphorous content in grain and straw ranged between 0.32 to 0.64% and 0.11 to 0.22%, respectively. Similarly, the

uptake of nitrogen by grain and straw varied from 3.08 to 12.14 kg ha⁻¹ and 2.20 to 8.33 kg ha⁻¹, respectively.

Phosphorus content from grain and straw shows significant effect Nano-DAP T₁₀ (100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS) phosphorus content from grain and straw, noted as 0.64 and 0.22% and was at par with treatments T₂ (100% RDF + S.T), values noted as 0.60 and 0.20%, treatment T₉ (75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30,45 DAS), values noted as 0.61 and 0.21%, treatment T₈ (75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS) values recorded as 0.57 and 0.19%, and lowest in treatment T₁ control (0.32 and 0.11%), respectively.

The significantly increased phosphorous uptake by grain 12.14 kg ha⁻¹, straw 8.33kg ha⁻¹ and total 20.47 kg ha⁻¹, was due to treatment T₁₀ (100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS) and was noted at par with the treatment T₉ (75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 and 60 DAS) phosphorous uptake by grain 11.55 kg ha⁻¹, straw 7.51 kg ha⁻¹ and total 19.05 kg ha⁻¹ and T₂ (100% RDF + S.T) phosphorous uptake by grain 11.16 kg ha⁻¹, straw 6.95 kg ha⁻¹ and total 18.10 kg ha⁻¹ and lowest phosphorous uptake by grain 3.08 kg ha⁻¹, straw 2.20 kg ha⁻¹

and total 5.28 kg ha⁻¹, are found in treatment T₁ (control), respectively.

Increase in phosphorous content in seed and straw due to the seed treatment and foliar application of Nano-DAP at the different growth stage of soybean crop. But changes occurred in straw, seed and total uptake of phosphorous due to the adequate amount of phosphorous at the time of sowing through conventional fertilizer and foliar spray of Nano-DAP at 30 and 45 DAS of soybean show better results compared with low amount of RDNP provided at time sowing.

This result is agreed with the findings of Paikra, *et al.*, (2018) [10] revealed that the foliar application of RDF + spray of DAP @ 2% at pod initiation nutrient uptake or concentration (%) of soybean recorded highest P₂O₅ (30.00 kg ha⁻¹) and lowest into the T₉ RDF only P₂O₅ (26.00 kg ha⁻¹). Lyngdoh, *et al.*, (2019) [9] concluded that the significantly higher uptake of total phosphorus was observed in RDF + DAP at 2 percent spray pod initiation stage (35.42 kg ha⁻¹). Lakshmy, *et al.*, (2020) [8] revealed that the highest P content in soybean seed (0.48%) and Maximum P in stover (0.47%) was recorded with the application of 2% 19:19:19 (NPK) + RDF followed by 2% DAP + RDF (0.46%), 0.2% Boron + RDF (0.45%) and 0.5% MOP + RDF (0.44%).

Table 4: Effect of foliar application of Nano-DAP on content (%) and uptake on P₂O₅ (kg ha⁻¹) by grain and straw of soybean.

Treatment details	P Content (%)		P Uptake (kg ha ⁻¹)		Total
	Seed	Straw	Seed	Straw	
T ₁ -Control	0.32	0.11	3.08	2.20	5.28
T ₂ -100% RDF + S.T	0.60	0.20	11.16	6.95	18.10
T ₃ -S.T + F.S. @ 0.4% Nano-DAP at 30,45 and 60 DAS	0.36	0.12	4.04	2.82	6.86
T ₄ -25% RDNP + S.T + F.S. @ 0.4% of Nano-DAP at 30 & 60 DAS	0.38	0.13	4.61	3.26	7.86
T ₅ -25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30,45 & 60 DAS	0.44	0.14	5.84	3.67	9.51
T ₆ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	0.49	0.15	7.20	4.22	11.42
T ₇ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	0.53	0.16	8.29	5.16	13.45
T ₈ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	0.57	0.19	9.88	6.06	15.94
T ₉ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	0.61	0.21	11.55	7.51	19.05
T ₁₀ -100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	0.64	0.22	12.14	8.33	20.47
SE ±	0.03	0.02	0.60	0.57	0.65
CD at 5%	0.10	0.05	1.77	1.69	1.92

3.4.3 Potassium content and uptake by soybean.

The data on potassium content in grain and straw and total uptake is depicted in table 5. It was seen from the data that the content and uptake of potassium was influenced remarkably with the foliar application of Nano-DAP ranged from in grain (1.43 to 1.72%) and by straw (0.57 to 0.72%). The uptake of phosphorus in grain and straw varied from 13.60 to 32.79 kg ha⁻¹ and 11.21 to 27.17 kg ha⁻¹, respectively.

The potassium content in seed and straw was increased considerably with the foliar application of Nano-DAP fertilizer but not reached to its level of significance. Among the different treatments T₁₀ (100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS) recorded maximum potassium content in grain (1.72%) and by straw (0.72%). The minimum values of potassium content in seed 1.43% and straw 0.57% was found in treatment T₁ control. As compared to the treatment T₁ the potassium content in both grain and straw was slightly increased in the treatments T₂, T₉, T₈, T₇, T₆, T₅, T₄ and T₃, respectively.

Further data indicated that uptake of potassium was significantly increased in seed (32.79 kg ha⁻¹) and straw (27.17 kg ha⁻¹) with the application of treatment T₁₀ and

was found at par with treatment T₂ (30.96 kg ha⁻¹ and 25.02 kg ha⁻¹), treatment T₉ (31.67 kg ha⁻¹ and 25.97 kg ha⁻¹). Whereas, the lowest potassium uptake was reported in both grain (13.60 kg ha⁻¹) and straw (11.21 kg ha⁻¹) was in treatment T₁ (control) compared to other treatments.

Similar trend was observed in case of total potassium uptake by soybean and the higher values of total potassium uptake (59.96 kg ha⁻¹) was noted in treatment T₁₀ and was at par with treatment T₉ (57.65 kg ha⁻¹) and T₂ (55.98 kg ha⁻¹), while the minimum total uptake of potassium (24.81 kg ha⁻¹) by soybean was observed in treatment T₁ control.

The increase in potassium uptake due to soil and foliar application of Nano-DAP might be due to the increase in yield of soybean. The similar observations were earlier recorded by Lyngdoh, *et al.*, (2019) [9] found that the significantly higher total potassium uptake (108.88 kg ha⁻¹) was observed in DAP at 2 percent spray. This higher uptake might be attributed due to significantly higher dry matter accumulation as a result of the application of other deficient nutrients such as N, P, S and B. Lakshmy, *et al.*, (2020) [8] concluded that the significantly higher seed and straw content increases due to application of 2% DAP + RDF (2.04%) and (2.14%).

Table 5: Effect of foliar application of Nano-DAP on content (%) and uptake on potassium (kg ha⁻¹) by grain and straw of soybean.

Treatment details	K Content (%)		K Uptake (kg ha ⁻¹)		Total
	Seed	Straw	Seed	Straw	
T ₁ – Control	1.43	0.57	13.60	11.21	24.81
T ₂ -100% RDF + S.T	1.66	0.71	30.96	25.02	55.98
T ₃ -S.T + F.S. @ 0.4% Nano-DAP at 30,45 and 60 DAS	1.53	0.60	17.05	13.91	30.95
T ₄ -25% RDNP + S.T + F.S. @ 0.4% of Nano-DAP at 30 & 60 DAS	1.55	0.62	18.84	15.51	34.35
T ₅ -25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30,45 & 60 DAS	1.57	0.65	21.00	16.77	37.77
T ₆ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	1.59	0.67	23.55	18.57	42.12
T ₇ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	1.60	0.69	25.21	20.55	45.75
T ₈ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	1.65	0.69	28.52	22.10	50.62
T ₉ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	1.68	0.72	31.67	25.97	57.65
T ₁₀ -100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	1.72	0.72	32.79	27.17	59.96
SE ±	0.11	0.03	1.77	1.23	2.07
CD at 5%	NS	NS	5.26	3.64	6.14

3.4.5 Sulphur content and uptake by soybean.

The data on sulphur content in grain and straw and total uptake is depicted in table 6. It was seen from the data that the content and uptake of potassium was influenced with the foliar application of Nano-DAP ranged from in grain (0.400 to 0.493%) and by straw (0.190 to 0.260%). The uptake of phosphorus in grain and by straw varied from 3.80 to 9.42 kg ha⁻¹ and 3.71 to 9.83 kg ha⁻¹, respectively.

The sulphur content in seed and straw was increased with the foliar application of Nano-DAP fertilizer but not reached to its level of significance. Among the treatments T₁₀ (100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS) recorded maximum sulphur content in grain (0.493%) and by straw (0.260%). The lowest values of sulphur recorded in seed 0.400% and straw 0.190% was found in treatment T₁ control. As compared to the treatment T₁ the potassium content in both grain and straw was slightly increased in the all remaining treatments, respectively.

Further data show that significantly increased sulphur uptake in treatment T₁₀ the maximum uptake values of

sulphur recorded in seed (9.42 kg ha⁻¹) and straw (9.83 kg ha⁻¹) and it was found at par with T₉ (9.02 kg ha⁻¹ and 9.0 kg ha⁻¹), treatment T₂ (8.88 kg ha⁻¹ and 8.68 kg ha⁻¹), T₈ (8.03 kg ha⁻¹ and 7.42 kg ha⁻¹) and lowest sulphur uptake in seed and straw recorded control T₁ (3.86 kg ha⁻¹ and 3.71 kg ha⁻¹), respectively.

Due to application of soil and foliar application of Nano-DAP sulphur total uptake shows significant results higher values of total sulphur uptake (19.25 kg ha⁻¹) was noted in treatment T₁₀ and was at par with treatment T₉ (18.02 kg ha⁻¹) and T₂ (17.56 kg ha⁻¹). while the minimum total uptake of sulphur in T₁ (7.56 kg ha⁻¹). The similar observations were earlier recorded by Choudhari, *et al.*, (2016) [3] concluded that the Foliar spray of 2% DAP at flowering and capsule development recorded significantly increase sulphur content in seed (0.115%) and straw (0.096%) and total S uptake (4.16 mg ha⁻¹) as compared to no foliar spray. Lakshmy, *et al.*, (2020) [8] found that the maximum content of S in seed (0.37%) was recorded from the application of 2% 19:19:19 (NPK) + RDF.

Table 6: Effect of foliar application of Nano-DAP fertilizer on content (%) and uptake on sulphur (kg ha⁻¹) by grain and straw of soybean.

Treatment details	S Content (%)		S Uptake (kg ha ⁻¹)		Total
	Seed	Straw	Seed	Straw	
T ₁ –Control	0.400	0.190	3.86	3.71	7.56
T ₂ -100% RDF + S.T	0.477	0.247	8.88	8.68	17.56
T ₃ -S.T + F.S. @ 0.4% Nano-DAP at 30,45 and 60 DAS	0.417	0.200	4.54	4.68	9.22
T ₄ -25% RDNP + S.T + F.S. @ 0.4% of Nano-DAP at 30 & 60 DAS	0.450	0.207	5.47	5.06	10.53
T ₅ -25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30,45 & 60 DAS	0.450	0.210	6.04	5.38	11.42
T ₆ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	0.453	0.220	6.74	6.08	12.82
T ₇ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	0.467	0.233	7.38	6.99	14.37
T ₈ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	0.470	0.230	8.03	7.42	15.45
T ₉ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	0.480	0.250	9.02	9.00	18.02
T ₁₀ -100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	0.493	0.260	9.42	9.83	19.25
SE ±	0.02	0.03	0.79	0.70	0.44
CD at 5%	NS	NS	2.34	2.07	1.30

3.4.6 Grain Yield

The effect of soil and foliar application of Nano-DAP along with RDNP on straw yield is summarized in Table 7. The results clearly indicate that Nano-DAP had a beneficial effect on grain yield, significantly increasing yield compared to the control. Grain yield ranged from 951.39 to 1910 kg ha⁻¹, with a remarkable 49% increase in yield compared to the control (T₁).

The treatment T₁₀ (100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS) produced the highest grain yield of 1910 kg ha⁻¹, followed by treatment T₉ (75% RDNP + S.T +

F.S @ 0.4% Nano-DAP at 30 and 60 DAS), which recorded a grain yield of 1882 kg ha⁻¹. Treatment T₂ (100% RDF + S.T) also showed a high grain yield of 1871.35 kg ha⁻¹. In contrast, the lowest grain yield (951.39 kg ha⁻¹) was observed in the control treatment (T₁).

The data clearly show that the grain yield decreases as the RDNP soil application decreases, when combined with the foliar application of Nano-DAP. Furthermore, the grain yields from treatments T₅, T₄, and T₃ were not significantly different from the control, indicating that these combinations did not effectively improve yield.

The increase in soybean yield can be attributed to the foliar application of Nano-DAP, which offers a larger surface area due to its small particle size. This larger surface area enhances the plant's ability to facilitate key metabolic functions, resulting in improved photosynthesis and increased production of photosynthates. When the recommended basal fertilizer dose is complemented with foliar Nano-DAP at critical growth stages, such as pod initiation, it can effectively boost soybean yield. Foliar fertilization not only increases nutrient use efficiency but also enhances the frequency with which nutrients are absorbed, leading to greater growth and higher yield.

These findings align with previous studies. Jaybhay *et al.* (2021) ^[7] reported that a combination of RDF + 2% urea at the pod initiation stage (3098 kg ha⁻¹) resulted in significantly higher soybean seed yield, which was comparable to RDF + 2% DAP (3050 kg ha⁻¹). Dikey *et al.* (2020) ^[4] found that foliar application of RDF + 2% DAP resulted in a significantly higher grain yield (1736 kg ha⁻¹) compared to the control (1355 kg ha⁻¹). Similarly, Lyngdoh *et al.* (2019) ^[9] observed that the highest seed yield (3772 kg ha⁻¹) was recorded with RDF + 2% DAP spray at pod initiation, while the lowest yield (1927 kg ha⁻¹) was found in treatments with organic fertilizers.

3.4.7 Straw yield

The influence of different levels of RDNP combined with foliar application of Nano-DAP on straw yield is presented in Table 7. The data clearly show that the straw yield of soybean increased with the foliar application of Nano-DAP, ranging from 1957.37 to 3778.94 kg ha⁻¹.

The highest straw yield (3778.94 kg ha⁻¹) was recorded in treatment T₁₀ (100% RDNP + S.T + F.S @ 0.4% Nano-DAP at 30 DAS), followed by treatment T₉ (75% RDNP + S.T +

F.S @ 0.4% Nano-DAP at 30 and 60 DAS), which produced a straw yield of 3608.02 kg ha⁻¹. Treatment T₂ (100% RDF + S.T) yielded 3524.11 kg ha⁻¹, while the control (T₁) recorded the lowest straw yield of 1957.37 kg ha⁻¹.

The increase in straw yield with the foliar application of Nano-DAP can be attributed to the rapid absorption of the Nano-fertilizer by the plant, facilitating easier nutrient translocation. This enhanced nutrient uptake likely improved photosynthesis rates, leading to greater dry matter accumulation and higher straw yield. Additionally, foliar application of Nano-DAP may have increased the harvest index, as the synergistic effect with conventional fertilizers improves nutrient absorption and optimizes plant growth.

The long-distance transport of metabolites in plants is regulated primarily by hormones, which control the movement of nutrients and metabolites from vegetative parts to reproductive structures. This process may have contributed to the observed increase in straw yield of soybean.

These findings are consistent with the results of previous studies. Lyngdoh *et al.* (2019) ^[9] reported that the highest straw yield (4569 kg ha⁻¹) was achieved with RDF + 2% DAP spray at the pod initiation stage, compared to the lowest straw yield (2577 kg ha⁻¹) recorded with RDF from organic sources. Biradar *et al.* (2023) ^[2] found that the application of RDF + 19:19:19 @ 1% spray at 30 DAS, followed by 13:00:45 @ 1% spray at 45 DAS, resulted in the highest straw yield of 3601.90 kg ha⁻¹, while the control treatment produced the lowest value (1842.10 kg ha⁻¹). Rathore (2022) ^[12] also observed a significant increase in straw yield (3076 kg ha⁻¹) with the application of 50% basal NPK, seed treatment with Nano-DAP @ 5 ml kg⁻¹, and foliar spray with Nano-DAP @ 2 ml L⁻¹ at 30 days, compared to the control.

Table 7: Grain and straw yield (kg ha⁻¹) of soybean as influenced with application of nano DAP

Treatment details	Yield (kg ha ⁻¹)	
	Grain	Straw
T ₁ -Control	951.39	1957.37
T ₂ -100% RDF	1871.33	3524.11
T ₃ -S.T + F.S. @ 0.4% Nano-DAP at 30,45 and 60 DAS	1116.98	2286.27
T ₄ -25% RDNP + S.T + F.S. @ 0.4% of Nano-DAP at 30 & 60 DAS	1211.83	2489.78
T ₅ -25% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30,45 & 60 DAS	1336.00	2568.48
T ₆ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	1479.33	2758.87
T ₇ -50% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	1573.33	2956.40
T ₈ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	1736.00	3206.21
T ₉ -75% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 & 60 DAS	1882.00	3608.02
T ₁₀ -100% RDNP + S.T + F.S @ 0.4% of Nano-DAP at 30 DAS	1910.00	3778.94
SE ±	16.29	149.94
CD at 5%	48.40	445.52

4. Conclusion

The available N,P,K and S content in soil after harvest of soybean crop was influenced significantly and recorded maximum with the application of 100 percent RDNP with foliar application of Nano-DAP @ 0.4% at time of 30 DAS of soybean which was showed at par with application of RDNP @ 100 percent alone and RDNP @ 75 percent with 2 foliar spray of Nano DAP at 30 and 45 DAS of soybean found at par results in respect of all biometric observation.

The maximum uptake of N, P₂O₅ and K₂O was found in soybean with one and two foliar application of Nano-DAP @ 0.4 percent along with 100 percent RDNP and 75 percent RDNP. Similar or at par results recorded with the application of RDNP @ 100 percent alone and RDNP @ 75

percent with 2 foliar spray of Nano DAP at 30 and 45 DAS of soybean

The application of 100 per RDNP through soil and one foliar spray of Nano-DAP produced significant increase in grain yield (1910.00 kg ha⁻¹) and straw yield (3778.94 kg ha⁻¹) over all other treatments except application of RDNP @ 100 percent alone and RDNP @ 75 percent with 2 foliar spray of Nano DAP at 30 and 45 DAS of soybean.

Based on the experimental results it can be concluded that one spraying of Nano-DAP at 30 DAS along with 100 percent RDNP can increase crop yield, nutrient uptake, yield and quality of soybean. However by reduction of 25 percent dose of RDNP with additional 2 spray of Nano DAP at 30 and 60 DAS to soybean complete the nutrients requirement

at different growth stages which gives better yield and quality and save the cost of fertilizer input to soybean.

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