



Exploring the Potential of Sulphur Nanoparticles in Soybean (*Glycine max*) Cultivation

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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

Background: Nanoparticles treated as “magic bullets” containing nano-fertilizer which will trigger specific cellular organelles in plant to release their contents. Nanoparticle’s behaviour, mobility and their smart delivery system has a strong bearing on the growth and yield of crops.

Study Place: A pot study was conducted at net house of Micronutrient Research Scheme, AAU, Anand during *kharif* season of 2021-22 to study the “Effect of sulphur nanoparticles on growth and yield of soybean”.

Methodology: A pot study was conducted at net house of Micronutrient Research Scheme, AAU, Anand during *kharif* season of 2021-22 to study the “Effect of sulphur nanoparticles on growth and yield of soybean” at SNPs/kg @1 to 8 ppm soil and ES @ 4, 6 & 8 ppm S/kg soil. The pot experiment was laid out in a control randomized block design with four replications comprising of 12 treatments.

Results: Application of 8 ppm SNPs/kg soil in soybean resulted in significantly higher grain yield and nutrient content in comparison to control and other treatments. Thus, the study recommended the correct concentration of SNPs (8 ppm) for enhancing soybean production.

Keywords: Elemental sulphur; fractionation; sulphur nanoparticles; soil plant analysis development.

ABBREVIATIONS

RDF : Recommended Dose of Fertilizer

SNPs : Sulphur Nano particles

ES : Elemental Sulphur

SPAD : Soil Plant Analysis Development

DAS : Days After Sowing

SMNZ : Sulphur Modified Natural Zeolite

1. INTRODUCTION

Soybean (*Glycine max* L.) is an important leguminous oil seed crop and due to nutritional value, it has been considered as “Protein hope of future”. The Soybean contains 40- 45% protein and 18-20% oil. The USA, Brazil and Argentina are major producers of soybean. In India, soybean is one of the fastest growing crops. Soybean is high in protein and a decent source of both carbohydrate and fat and a rich source of various vitamins, minerals, and beneficial plant compounds, such as isoflavones. In India the total area under soybean cultivation is 11.2 million ha with the production and the productivity of 10.5 million metric tons and 937 kg ha⁻¹, respectively (Anon.,2020a). Soybean cultivation is limited to Madhya Pradesh, Maharashtra, Gujarat and Rajasthan state of India. In Gujarat, the total area under soybean cultivation is 1.342 million ha with the production and the productivity of 1.241 million metric tons and 673 kg ha⁻¹, respectively (Anon., 2020b).

Nano-fertilizers could be more soluble or more reactive than bulk fertilizers and they can exactly release their active ingredients in responding to environmental triggers. Nano- fertilizer have high

surface area, increased solubility, small particle size <100 nm, controlled release of nutrients due to encapsulation and increased nutrient efficiency (Yuvaraj and Subramanian, 2015). Sulphur nanoparticles has a great potential as fertilizer carrier to control release of sulphate by the slow release mechanism. Despite several agronomic strategies tested for improving the use S efficiency, it proved less success due to complex soil environmental factors. Sulphur use efficiency hardly exceeds 25% (Kyllingsbaek and Hansen, 2007).

Sulphur is an essential macronutrient in plant growth and development. Sulphur is now recognized as the fourth major plant nutrient (Tandon et al., 2004; Oakley et al., 2007). Plants take up sulphur in sulphate form. Sulphur is essential element in forming protein, enzymes, vitamins and chlorophyll in plants and metabolites including glutathione, glucosinolate and alliin. Sulphur plays important role in formation of three amino acids (cysteine, cystinine, and methionine), activation of enzymes, winter hardiness, and quality nutrient in oilseed (Prasad and Shivay, 2017). Sulphur plays key role in protein synthesis, chlorophyll formation and oil synthesis. Cysteine and methionine are the most important sulphur containing amino acids in plants, where they both occur as free acids and as building blocks of proteins (Mengel et al., 2001). Besides it is involved in various metabolic and enzymatic process including photosynthesis, respiration and legume rhizobium symbiotic nitrogen fixation (Rao, 2001). Nano sulphur allows the plants to efficiently utilize nutrient by rapidly reducing the

soil reaction (pH) and cause increase in yield and quality. With the intensive cultivation of soybean, the lack of sulphur becomes a limiting factor in the yield of this crop over time. Lastly, it is possible to use the nano sulphur not only as a fertilizer but also for plant protection and plant growth stimulants.

2. MATERIALS AND METHODS

The pot study was conducted at net house of Micronutrient Research Scheme, AAU, Anand during *kharif* season of 2021-22 to study the Effect of sulphur nanoparticles on growth and yield content of soybean (NRC-37).

2.1 Collection and Preparation of Soil Sample

The soil used under study is representative soils of the middle Gujarat region and is locally known as "*Goradu*" soil. The texture of the soil is loamy sand and moisture retentive, belongs to the soil order Inceptisols (*Typic Ustochrept*). It responds well to manuring and is suitable to variety of crop of tropical region. The texture of the soil is loamy sand and the soil used for the experiment was neutral in reaction, medium in available P_2O_5 , available K_2O , DTPA-Zn was sufficient and deficient in available sulphur. The weather parameters *viz.*, temperature, average relative humidity, wind velocity and bright sunshine hours observed during the experiment period. The seasonable rainfall was received during study period. In general, the weather conditions were found favourable for normal growth of soybean crop.

2.2 Pot Filling

The 15 kg capacity earthen pots were selected for the pot study. At the time of pot filling, the drainage hole covered with broken pot piece to ensure proper drainage and to avoid water logging. Fifteen kilograms of soil was taken in each pot. The recommended dose of N and P_2O_5 were added through urea and potassium dihydrogen phosphate (30-60-0). The soil was low in organic carbon (0.33 %) and available sulphur (5 ppm) in initial analysis. Fertilizer applied on basis of the weight of hectare furrow slice. The sulphur nanoparticles was applied in soil as basal application before sowing. After proper filling soil in the pots, initially ten healthy seeds of soybean were sown into each pot at proper depth. Thinning was done after germination and finally 2 plants were kept for

study. Pots were regularly watered and weed free condition maintained up to maturity stage for well vegetative growth and development of crop. The observations like plant height at 30 & 60 DAS and at harvest, chlorophyll content at 45 DAS & no. of pods per plant were taken in accordance with the crop growth in pots at maturity stage, seed and stover yield were also recorded from each pot. The treatments were comprised of T_1 (control only NPK), T_2 (T_1 + sulphur nanoparticles @ 1mg S/kg soil), T_3 (T_1 + sulphur nanoparticles @ 2 mg S/kg soil), T_4 (T_1 + sulphur nanoparticles @ 3 mg S/kg soil), T_5 (T_1 + sulphur nanoparticles @ 4 mg S/kg soil), T_6 (T_1 + sulphur nanoparticles @ 5 mg S/kg soil), T_7 (T_1 + sulphur nanoparticles @ 6 mg S/kg soil), T_8 (T_1 + sulphur nanoparticles @ 7 mg S/kg soil), T_9 (T_1 + sulphur nanoparticles @ 8 mg S/kg soil), T_{10} (T_1 + elemental sulphur @ 4 mg S/kg soil), T_{11} (T_1 + elemental sulphur @ 6 mg S/kg soil) and T_{12} (T_1 + elemental sulphur @ 8 mg S/kg soil).

3. RESULTS AND DISCUSSION

3.1 Effect of Different Levels of Sulphur Nano Particles on Growth Parameters of Soybean

Regarding plant height at harvest, all treatments showed significant effect on plant height over control (Table.1). Plant higher was recorded higher at 30, 60 and 90 DAS (47.78 cm) (99.58 cm) (120.43 cm) respectively under T_9 which was statistically at par with T_8 only. The improvement in plant height under treatments T_9 and T_8 were to the tune of 30.37 and 26.67 per cent, respectively, over control (108.45 cm). These results were in a line with those of Thirunavukkarasu & Subramanian (2015). The higher chlorophyll content (22.73) at 45 DAS was observed under T_9 (8 mg SNPs /kg soil) which was statistically at par with treatments T_5 , T_6 , T_7 , T_8 & T_{10} (21.48, 21.86, 22.01, 22.33, 22.03), respectively. The increase in chlorophyll content under treatments T_9 was to tune of 21.73 per cent over control. SPAD gives direct reading of chlorophyll by Placing fully grown green leaf between instrument.

The beneficial effect of treatments were observed on number of effective pods per plant as compared to control, where in significantly higher number of pods per plant (26.25) found with T_9 (8 mg SNPs /kg soil) over the other treatments but, it was statistically at par with T_7 (6 mg SNPs /kg soil) and T_8 (7 mg SNPs /kg

soil). The increased in pods might be due to increased sulphur uptake as the result of enhanced availability of essential nutrients in soil due to the application of SMNZ based sulphur fertilizer. This might be due to more accumulation of amino acids and amide substances and their translocation to reproductive organs which influenced growth and yield due to application of sulphur (Dongarkar et al., 2005)

3.2 Effect of Different Levels of Sulphur Nano Particles on Yield of Soybean

The data on seed yield presented in Table 2 revealed that among different treatments, T₉ (8 mg SNPs /kg soil), T₈ (7 mg SNPs /kg soil) and T₇ (6 mg SNPs /kg soil) recorded significantly higher seed yield of soybean over control (9.57 g/pot). The significantly highest seed yield (11.25 g/pot) recorded under T₉, which was remained at par with T₈ and T₇ and the per cent enhancement in seed yield was to the tune of 17.55 due to T₉ treatment. Among different SNPs treatments, T₉ (8 mg SNPs /kg soil) treatment found comparatively better as compared to T₈ (7 mg SNPs /kg soil). Among different treatments, T₉ (8 mg SNPs /kg soil), T₈ (7 mg SNPs/kg soil) and T₇ (6 mg SNPs /kg soil) significantly increased stover yield over control (7.55 g/pot). The significantly higher stover yield (10.38 g/pot) recorded under T₉, which was statistically at par with T₈ & T₇. Among different treatments of

nano-particles, 8 mg SNPs /kg soil (T₉) found comparatively better as compared to 7 mg SNPs /kg soil (T₈). The shell yield was non-significantly affected by different treatments over control. The highest shell yield (2.5 g/pot) was recorded under T₉ treatment.

This increase in soybean yield is relevant with its productivity after using nano sulphur as compared to mineral sulphur (control) might be due to that application of nano sulphur resulted in increase in the germination rate, germination percentage, seedling fresh and dry weights and root length were improved under salinity (Ashour et al., 2017). The positive effect of sulphur on seed yield is one of the most widely documented facts across the world (Patel, 2009; Behera et al., 2021). Since the pore diameter of cell walls of root hairs of plants is in the range of 3.5-3.8 nm, only nanoparticles or aggregates with diameters less than the cell wall pore diameter can enter the cell wall of undamaged cells (Dietz and Herth, 2011).

The plant growth and yield attributes of soybean likes plant height and number of pods per plant significantly ($P=0.05$) increased due to treatment T₉ (RDF+ SNPs @ 8 mg S/kg Soil treatment which was at par with treatments T₄, T₅, T₆, T₇ & T₈; in case of plant height at 30, 60 DAS and at harvest and at par with treatments T₈ & T₇ in case of pods per plant. The leaf chlorophyll content at 45 DAS of soybean was also significantly increased due to T₉

Table 1. Effect of different levels of sulphur nano particles on periodical plant height, Leaf chlorophyll SPAD value and pod per plant of soybean

| Tr. No. | Plant height (cm) | | | SPAD value | No. of pod/plant |
|---|-------------------|--------|------------|------------|------------------|
| | 30 DAS | 60 DAS | At harvest | | |
| T ₁ -Control (NPK only) | 39.98 | 93.70 | 108.45 | 18.25 | 20.75 |
| T ₂ -RDF + SNPs @ 1 mg S/kg soil | 41.27 | 96.63 | 113.13 | 19.55 | 22.25 |
| T ₃ -RDF + SNPs @ 2 mg S/kg soil | 41.95 | 96.88 | 115.63 | 20.93 | 23.25 |
| T ₄ -RDF + SNPs @ 3 mg S/kg soil | 45.64 | 97.35 | 116.20 | 21.13 | 23.25 |
| T ₅ -RDF + SNPs @ 4 mg S/kg soil | 45.93 | 99.28 | 117.43 | 21.48 | 24.00 |
| T ₆ -RDF + SNPs @ 5 mg S/kg soil | 46.16 | 97.95 | 117.63 | 21.86 | 24.75 |
| T ₇ -RDF + SNPs @ 6 mg S/kg soil | 46.60 | 97.55 | 118.33 | 22.01 | 25.00 |
| T ₈ -RDF + SNPs @ 7 mg S/kg soil | 46.95 | 98.40 | 119.60 | 22.33 | 25.00 |
| T ₉ -RDF + SNPs @ 8 mg S/kg soil | 47.78 | 99.58 | 20.43 | 22.73 | 26.25 |
| T ₁₀ -RDF + ES @ 4 mg S/kg soil | 41.13 | 97.38 | 116.48 | 22.03 | 21.50 |
| T ₁₁ -RDF + ES @ 6 mg S/kg soil | 43.72 | 97.28 | 117.15 | 21.05 | 22.25 |
| T ₁₂ -RDF + ES @ 8 mg S/kg soil | 42.98 | 95.38 | 115.33 | 19.34 | 21.00 |
| SEm± | 0.99 | 0.95 | 0.65 | 0.38 | 0.50 |
| CD at 5% | 2.84 | 2.72 | 1.87 | 1.09 | 1.44 |
| CV (%) | 4.48 | 1.95 | 1.12 | 1.46 | 4.31 |



T₉-SNPs @ 8 mg S/kg soil T₁₂-ES @ 8 mg S/kg soil T₁-Control

Fig. 1. Effect of Sulphur Nanoparticles and ES on growth of Soybean

Table 2. Effect of sulphur nano particles on seed, stover and shell yield of soybean

| Tr. No. | Yield (g/pot) | | | |
|---|---------------|-------|--------|-------|
| | No.of pod | Seed | Stover | Shell |
| T ₁ -Control (NPK only) | 20.75 | 9.57 | 7.55 | 1.68 |
| T ₂ -RDF + SNPs @ 1 mg S/kg soil | 22.25 | 9.65 | 7.77 | 1.90 |
| T ₃ -RDF + SNPs @ 2 mg S/kg soil | 23.25 | 9.68 | 8.21 | 2.08 |
| T ₄ -RDF + SNPs @ 3 mg S/kg soil | 23.25 | 9.88 | 9.04 | 2.10 |
| T ₅ -RDF + SNPs @ 4 mg S/kg soil | 24.00 | 10.17 | 9.04 | 2.10 |
| T ₆ -RDF + SNPs @ 5 mg S/kg soil | 24.75 | 10.63 | 9.38 | 2.13 |
| T ₇ -RDF + SNPs @ 6 mg S/kg soil | 25.00 | 10.80 | 9.90 | 2.13 |
| T ₈ -RDF + SNPs @ 7 mg S/kg soil | 25.00 | 11.15 | 10.05 | 2.18 |
| T ₉ -RDF + SNPs @ 8 mg S/kg soil | 26.25 | 11.25 | 10.38 | 2.50 |
| T ₁₀ -RDF + ES @ 4 mg S/kg soil | 21.50 | 10.63 | 9.15 | 2.00 |
| T ₁₁ -RDF + ES @ 6 mg S/kg soil | 22.25 | 10.40 | 8.81 | 1.85 |
| T ₁₂ -RDF + ES @ 8 mg S/kg soil | 21.00 | 9.83 | 7.76 | 1.75 |
| SEm± | 0.50 | 0.19 | 0.29 | 0.20 |
| CD at 5% | 1.44 | 0.56 | 0.82 | NS |
| CV (%) | 4.31 | 3.78 | 6.44 | 20.1 |

(RDF+ SNPs @ 8 mg S/kg soil) which was at par with T₁₀ RDF + Elemental-S @ 4 mg S/kg soil. The significantly ($P = 0.05$) highest seed and stover yield of soybean recorded under treatment T₉ (RDF+ SNPs @ 8 mg S/kg soil) and was at par with T₇ & T₈ in case of seed and stover yield, whereas the application of elemental S @ 4, 6 & 8 mg S / kg soil significantly decreased seed and stover yields of soybean. The shell yield was non-significantly affected by different sulphur application treatments.

4. CONCLUSION

On the basis of results, it can be concluded that the application of sulphur nano-particles @ 8

mg S/kg soil along with RDF (NPK 30:60:00 kg/ha) significantly increased growth and yield attributes of soybean over control (RDF only) and elemental sulphur @ 4, 6 & 8 mg S/kg soil. The sulphur nanoparticles proved better in increasing the growth, yield attributes and yields of as compared to elemental sulphur in loamy sand soil.

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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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