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

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 design & Place: A pot study was conducted in CRDat 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: ApotstudywasconductedatnethouseofMicronutrientResearchScheme,AAU, Anand during *kharif* season of 2021-22 to study the “Effect of sulphur nanoparticles on growthandyieldofsoybean”atSNPs/kg@1to8ppmsoilandES@4,6&8ppmS/kgsoil. Thepot experiment was laid out in a control randomized blockdesign 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 recommendedthecorrectconcentrationofSNPs(8ppm)forenhancingsoybeanproduction.

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Keywords-Elemental Sulphur,Fractionation, Sulphur Nanoparticles, Soil Plant analysis Development

1. **INTRODUCTION-** Soybean (*Glycine max* L.*)* is an important leguminous oil seed crop and due to nutritionalvalue,ithasbeenconsideredas“Proteinhopeoffuture”.TheSoybeancontains40-45%proteinand18-20%oil.TheUSA,BrazilandArgentinaaremajorproducersofsoybean. 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

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(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-fertilizerhavehighsurfacearea,increasedsolubility,smallparticlesize<100nm,controlled release of nutrients due to encapsulation and increased nutrient efficiency (Yuvaraj and Subramanian,2015).Sulphurnanoparticles(SNPs) hasagreatpotentialasfertilizercarriertocontrol 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 environmentalfactors.Sulphuruseefficiencyhardlyexceeds25%(Kyllingsbaekand Hansen, 2007).

Sulphur is an essential macronutrient in plant growth and development. Sulphurisnowrecognizedasthefourthmajorplantnutrient(Tandon *etal*.,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),activationofenzymes,winterhardiness,and qualitynutrientin 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, wherethey 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. MATERIALSANDMETHODS- The pot study was conducted at net house of Micronutrient Research Scheme, AAU, Anand during*kharif*seasonof2021-22tostudytheEffectofsulphurnanoparticlesongrowth and yieldcontentofsoybean (NRC-37).

2.1SOIL FERTILITY CONDITION AND COLLECTION/ ~~AND~~ PREPARATION OF SOIL SAMPLE -The soil used under study is representative soils of the middle Gujarat region and islocally known as "*Goradu*" soil. The texture of the soil is loamy sand andmoistureretentive,belongstothesoilorderInceptisols(*TypicUstochrept*).Itresponds well to manuring and is suitable to variety of crop of tropical region. Thetextureofthesoilisloamysandandthesoilusedfortheexperiment was neutral in reaction, medium in available P_2O_5, and medium in available K_2O, DTPA-Zn was sufficient anddeficientinavailable 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 FILLINGAND TREATMENTS-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_5were added through urea and potassium dihydrogen phosphate. 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. RESULTSANDDISCUSSION

3.1 EFFECT OF DIFFERENT LEVELS OF SULPHUR NANO PARTICLES ON GROWTH PARAMETERS OF SOYBEAN

Table1-Effectofdifferentlevelsofsulphurnanoparticlesonperiodicalplantheight, Leaf cholorophyll SPAD value and pod per plantofsoybean

Tr. No.	Plant height (cm)	

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	30 DAS	60 DAS	At harvest	SPAD value	No. of pod/plant
T_1-Control(NPKonly)	39.98	93.70	108.45	18.25	20.75
T_2-RDF + SNPs @ 1 mg S/kgsoil	41.27	96.63	113.13	19.55	22.25
T_3-RDF+SNPs @2mg S/kgsoil	41.95	96.88	115.63	20.93	23.25
T_4-RDF+SNPs@3mg S/kgsoil	45.64	97.35	116.20	21.13	23.25
T_5-RDF+ SNPs@4mg S/kgsoil	45.93	99.28	117.43	21.48	24.00
T_6-RDF+SNPs @5mg S/kgsoil	46.16	97.95	117.63	21.86	24.75
T_7-RDF+SNPs @6mg S/kgsoil	46.60	97.55	118.33	22.01	25.00
T_8-RDF+SNPs @7mg S/kgsoil	46.95	98.40	119.60	22.33	25.00
T_9-RDF+SNPs@8mg S/kgsoil	47.78	99.58	20.43	22.73	26.25
T_{10}-RDF+ES @4mg S/kgsoil	41.13	97.38	116.48	22.03	21.50
T_{11}-RDF+ES @6mg S/kgsoil	43.72	97.28	117.15	21.05	22.25
T_{12}-RDF+ES @8mg S/kgsoil	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

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Regarding plant height at harvest, all treatments showed significant effect on plantheightover control(Table.1).Planthigherwasrecordedhigher at 30, 60 and 90 DAS (47.78cm)(99.58cm)(120.43cm)respectively underT9whichwasstatistically at par with T8 only. The improvement in plant height under treatments T9 and T8 were to the tune of30.37 and 26.67 per cent, respectively, overcontrol (108.45 cm). These results werein a line with those of Thirunavukkarasu & Subramanian (2015). The higher chlorophyllcontent (22.73)at45DAS wasobservedunderT9(8mgSNPs/kgsoil)whichwas statistically atpar with treatments T5, T6, T7, T8 &T10 (21.48, 21.86, 22.01, 22.33, 22.03), respectively. The increasein chlorophyll content undertreatments T9 was to tuneof21.73 per cent over control.

T_9-SNPs@ 8 mg S/kg soil　　T_{12}-ES @ 8 mg S/kg soil　　T_1-Control

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

The beneficial effect of treatments were observed on number of effective pods per plant as comparedtocontrol,whereinsignificantlyhighernumberofpodsperplant(26.25)foundwith T9(8mgSNPs/kgsoil)overtheothertreatmentsbut,it was statistically at par with T7 (6 mg SNPs /kg soil**)** and T8 (7 mg SNPs /kg soil). The increased in pods might be due to increasedsulphuruptakeastheresultofenhanced availabilityofessentialnutrientsinsoildue 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).

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3.2 EFFECT OF DIFFERENT LEVELS OF SULPHUR NANO PARTICLES ON YIELD OF SOYBEAN

Table2-Effectof sulphurnanoparticles onseed,stoverandshellyield of soybean

Tr. No.	Yield (g/pot)			
	No.of pod	Seed	Stover	Shell
T_1-Control(NPKonly)	20.75	9.57	7.55	1.68
T_2-RDF + SNPs @ 1 mg S/kgsoil	22.25	9.65	7.77	1.90
T_3-RDF+SNPs @2mg S/kgsoil	23.25	9.68	8.21	2.08
T_4-RDF+SNPs@3mg S/kgsoil	23.25	9.88	9.04	2.10
T_5-RDF+ SNPs@4mg S/kgsoil	24.00	10.17	9.04	2.10
T_6-RDF+SNPs @5mg S/kgsoil	24.75	10.63	9.38	2.13
T_7-RDF+SNPs @6mg S/kgsoil	25.00	10.80	9.90	2.13

T_8-RDF+SNPs @7mg S/kgsoil	25.00	11.15	10.05	2.18
T_9-RDF+SNPs@8mg S/kgsoil	26.25	11.25	10.38	2.50
T_{10}-RDF+ES @4mg S/kgsoil	21.50	10.63	9.15	2.00
T_{11}-RDF+ES @6mg S/kgsoil	22.25	10.40	8.81	1.85
T_{12}-RDF+ES @8mg S/kgsoil	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

Thedata onseedyield presented inTable .2 revealed that amongdifferent 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 ofsoybean over control (9.57 g/pot). The significantly highest seedyield(11.25g/pot)recordedunderT9,whichwasremainedatparwithT8andT7andthe percentenhancement inseedyieldwastothetuneof17.55duetoT9treatment.Among different SNPstreatments,T9(8mgSNPs/kgsoil)treatmentfoundcomparativelybetterascomparedto T_8 (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 (7.55g/pot).Thesignificantly higherstoveryield (10.38 g/pot)recorded underT9, which was statisticallyatparwith T8& T7. Amongdifferent treatmentsofnano-particles,8 mgSNPs /kg soil (T9) found comparatively better as compared to 7 mg SNPs /kg soil (T8). The shell yield wasnon-significantlyaffectedbydifferenttreatmentsovercontrol.Thehighestshellyield(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 mostwidelydocumentedfactsacrosstheworld(Patel,2009;Behera*etal*.,2021). Since the pore diameter of cell walls of root hairs of plants is in therangeof3.5-3.8nm,onlynanoparticlesoraggregateswithdiameterslessthanthe cellwallporediametercanenterthe cellwallofundamagedcells (Dietz and Herth,2011).

Theplantgrowthandyieldattributesofsoybeanlikesplantheightandnumberofpods perplantsignificantly(*P=0.05*)increasedduetotreatmentT9(RDF+SNPs@8mgS/kg Soil treatmentwhichwasatparwithtreatmentsT4,T5,T6,T7&T8;incaseofplantheightat 30,60DASandatharvestandatparwithtreatmentsT8&T7incaseofpodsperplant. Theleaf chlorophyll content at 45 DAS of soybean was also significantly increased due to T9(RDF+ SNPs@8mgS/kgsoil)whichwas atparwithT10RDF+Elemental-S@4mgS/kgsoil.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& T8in case of seed and stover yield, whereas theapplication ofelemental S @4, 6 & 8 mg S / kg soil significantly decreased seed andstoveryieldsofsoybean.Theshellyieldwasnon-significantlyaffectedbydifferentsulphur application treatments.

4. CONCLUSION- Onthebasisofresults,itcanbeconcludedthattheapplicationofsulphurnano-particles @ 8 mg S/kg soil along with RDF (NPK 30:60:00 kg/ha) significantly increased growth and yieldattributesofsoybeanovercontrol(RDFonly)andelementalsulphur@4,6&8mgS/kg soil.Thesulphurnanoparticlesprovedbetterinincreasingthegrowth,yieldattributesandyields of as compared to elemental sulphur in loamy sand soil.

RDF- Recommended Dose of Fertilizer
SNPs- Sulphur Nano particles
ESs- Elemental Sulphur
SPAD-Soil Plant Analysis Development
DAS -
SMNZ -

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