



Impact of Sulphur Nanoparticles on Growth and Biological Yield of Groundnut-Mustard Crop Sequence Under Sandy Loam Soils of Central Gujarat

Suwa Lal Yadav ^{a*}, K. C. Patel ^b, Dileep Kumar ^b,
Devilal Birla ^c, Sanjay N. Makwana ^c, Indra Raj Yadav ^d,
Manish Yadav ^e, Lakshman ^f, Devendra Kumar Inwati ^{g++}
and Shani Gulaiya ^{g++}

^a Department of Soil Science and Agricultural Chemistry, Agricultural University, Anand, Gujarat 388 110, India.

^b Micronutrients Research Centre, Anand Agricultural University, Anand, Gujarat 388 110, India.

^c Department of Agronomy, Anand Agricultural University, Anand, Gujarat 388 110, India.

^d Department of Soil Science, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh, 474002, India.

^e Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab 141 004, India.

^f Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Uttar Pradesh, 208002, India.

^g Department of Agronomy, Jawahar Lal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, 482004, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i203907

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/106978>

Original Research Article

Received: 22/07/2023

Accepted: 28/09/2023

Published: 07/10/2023

⁺⁺ Senior Technical Assistant;

*Corresponding author: E-mail: suwalalyadav96@gmail.com, suwayadav7489@gmail.com;

ABSTRACT

In the present era of farming, the farmers were not using the secondary fertilizers for supplementing the sulphur nutrient and groundnut and mustard crops require the higher amount of sulphur. While, the traditional sulphur fertilizers have very low nutrient use utilization efficiency, moreover nano fertilizers have high nutrient use efficiency. So, the present experiment was conducted with using the different sources of sulphur. The existing experiment was conducted at Anand Agricultural university, Anand, in 2021-22 using completely randomized design with 11 treatments replication 4 times. The results reveal that the significantly higher plant height at 30 DAS was registered with the application of RDF + sulphur nanoparticles @ 4 mg S/kg (T₁₀), than rest of the treatments. The significantly higher plant height, branches/plant and biological yield of groundnut-mustard cropping sequence was obtained with the fertigation of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₉). It can be concluded that application of 3 mg S/kg soil, 50% at basal & 50% at 30 DAS can be an optimum dose of sulphur in pot experiment through fertigation under sulphur deficient soil.

Keywords: Branches; elemental sulphur; emergence; plant height.

1. INTRODUCTION

Sulphur nanoparticles are miniscule particles of sulphur with dimensions on the nanoscale, typically ranging from 1 to 100 nm in size. These nanoparticles have gained significant attention in scientific research and various applications due to their unique properties and potential uses [1]. Due to their small size and high surface area, sulphur nanoparticles possess enhanced reactivity, making them useful in various applications. This means that they can be more readily absorbed by plant roots, making them a more efficient sulphur source [2]. Sulphur nanoparticles are being explored as a potential fertilizer source in modern agriculture. Sulphur is an essential nutrient for plant growth, and sulphur deficiency can lead to reduced crop yields and quality [3]. Traditionally, sulphur has been supplied to crops through elemental sulphur or sulphate-based fertilizers [4] Sulphur nanoparticles can be applied to crops through various methods, including foliar spraying, soil application, or as a component of controlled-release fertilizers [5,6]

Groundnut (*Arachis hypogaea*), also known as the peanut, is a legume crop grown mainly for its edible seeds. It is classified as both a grain legume and, due to its high oil content, an oil crop [7]. The groundnut plant is an annual herbaceous plant growing 30 to 50 cm (12 to 20 inch) tall. As a legume, it belongs to the botanical family Fabaceae, also known as Leguminosae, and commonly known as the legume, bean, or pea family [8]. Groundnuts are a good source of protein, oil, vitamins, folate, magnesium and fibre [9]. Groundnuts are used in a variety of dishes,

both spicy and sweet. They can be eaten raw, roasted, boiled, or fried. Groundnuts are a valuable crop that provides food and income for millions of people around the world. They are also a good source of nutrients and can be used in a variety of dishes [10].

Mustard is an annual, cool-season crop that is grown for its seeds, which are used as a spice and condiment, and for its oil. Mustard is a member of the Brassicaceae family. Mustard is a relatively easy crop to grow and can be grown in a variety of soils. It prefers full sun and well-drained soil [11]. Mustard plants need regular watering, especially during the flowering and pod development stages. Mustard seeds are used to make mustard oil, which is a cooking oil with a strong flavour [12]. Mustard is a versatile crop that has many uses [11]. It is a good source of nutrients, including vitamins C and K, and it has been shown to have some health benefits, such as reducing inflammation and improving heart health [13].

Sulphur is an essential nutrient for plants and play a vital role as a constituent of amino acids, proteins, and vitamins and photosynthesis, the production of chlorophyll, and make resistance to pests and diseases [14]. Groundnut and mustard are both high-yielding crops that require a lot of sulphur. The sulphur requirement of these crops varies depending on the soil type, climate, and variety of crops grown (Khurana et al., 2018). It plays an important role in flowering and pod development as well as pod setting [15]. Therefore, the present experiment was carried out focusing on above mentioned issues they were emerging in farming.

2. MATERIALS AND METHODS

The SML firm supplied the elemental sulphur fertilizer, which was used as fertigation in accordance with the treatment instructions. It included 90% elemental sulphur on a weight-for-weight basis. The green synthesis process was used to prepare the sulphur nanoparticle at the Department of Nanotechnology, Anand Agricultural University, in Anand, Gujarat. The DLS equipment was used to characterize the nanoparticles' size, pdi, kcps, and zeta potential after preparation. FTIR and UV spectroscopy are also used. The synthetic sulphate nanoparticles were crystalline in form, spherical in shape, and contained 35% sulphate on a weight-per-weight ratio, according to diacid mixture analysis. The graphical representation of synthesis of sulphur nano particles were given in Fig. 1.

During the *kharif* (groundnut) and *rabi* (mustard) seasons of the years 2021–2022, the pot experiment was conducted at Polyhouse, Centre for Advanced Research in Plant Tissue Culture, Anand Agricultural University, Anand (Gujarat). The information on the materials utilised, the experimental procedures performed, and the techniques used throughout the inquiry is given below. Anand is a geologically significant experimental site, located at 22° 32'8.794" N latitude, 72°58'29.29" E longitude, and 45.1 m above mean sea level. This area experiences a semiarid and subtropical climate. With an average annual rainfall of 865 mm, the monsoon season starts by the third week of June and ends by the middle of September. This rainfall is entirely due to the South-West monsoon

currents. Although the region receives an acceptable amount of rainfall on average, partial droughts occur frequently, about once every three to four years. The bulk soil sample was collected, and the various parameters were determined. The texture of the experimental soil was loamy sand, and its reactivity to pH was neutral [16]. EC 7.78, Jackson [16] Organic carbon at 0.30 dS/m [17] Available phosphorus is 3.56 g kg⁻¹ [18] Available potassium is 30.44 kg ha⁻¹ (Jackson, 1973).[16] Available sulphur is 210.04 kg per hectare [19] 5.16 ppm, DTPA extractable Zn, Fe, Mn, and Cu were 0.65, 4.46, 5.88, and 1.05 ppm, respectively [20]. The current study was set up using a four-repetition, completely randomized design. The treatment details of this experiment were as Control (only RDF) (T₁), RDF + Elemental S @ 8 mg S/kg soil (T₂), RDF + Elemental S @ 8 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₃), RDF + Sulphur nanoparticles @ 1 mg S/kg soil (T₄), RDF + Sulphur nanoparticles @ 1 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₅), RDF + Sulphur nanoparticles @ 2 mg S/kg soil (T₆), RDF + Sulphur nanoparticles @ 2 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₇), RDF + Sulphur nanoparticles @ 3 mg S/kg soil (T₈), RDF + Sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₉), RDF + Sulphur nanoparticles @ 4 mg S/kg soil (T₁₀), RDF + Sulphur nanoparticles @ 4 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₁₁). (Note: Sulphur was applied through fertigation as per the treatments and the flow rate of dripper kept at 4 L water per hour). The sulphur applied in both the crops of *kharif* and *rabi* season as per the treatment details.

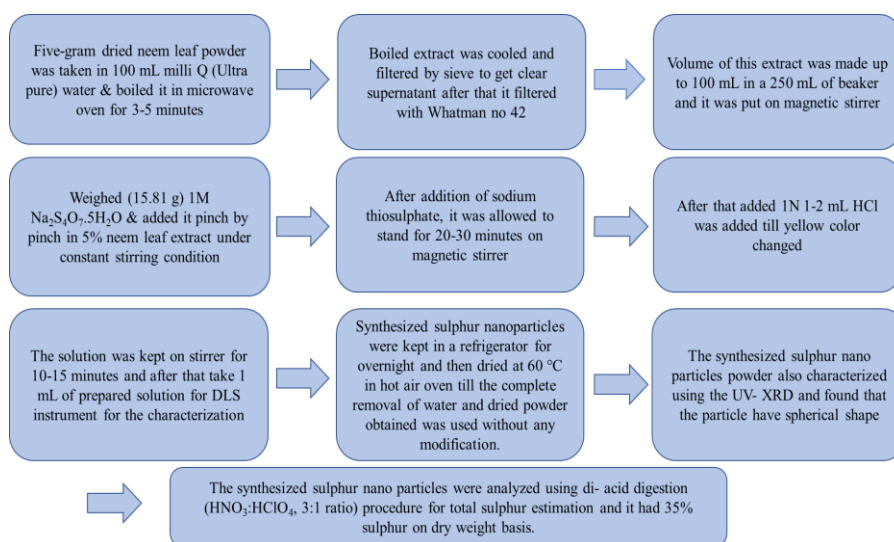


Fig. 1. Synthesis of sulphur nanoparticles

2.1 Statistical Analysis

The F-test was used to perform variance analysis on all micronutrient content and uptake parameters [21]. Duncan's New Multiple Range Test (DNMRT) was used to compare treatment means using SPSS 16.0 software for Windows (SPSS Inc., Chicago, IL, USA).

3. RESULTS AND DISCUSSION

3.1 Growth and Yield Attributes of Groundnut

3.1.1 Days to emergence

The data presented in Table 1 indicated that application of SNPs and elemental sulphur didn't influence significantly the days to emergence of groundnut. The seeds took a consistent 5-6 days to emerged after sowing.

3.1.2 Periodical plant height

The data pertaining to periodical plant height of groundnut measured at 30 and 60 DAS as well as at harvest as affected by sulphur nanoparticles and elemental sulphur application were furnished in Table 1. The data revealed that the periodical plant height of groundnut was significantly affected by application of sulphur nano particles and elemental sulphur.

The findings furnished in Table 1 unveil the significant influence of varying treatments of SNPs and elemental sulphur on plant height at 30, 60 DAS and at harvest. Notably, treatment T₁₀ exhibited the highest plant height at 60 DAS and harvest which was 55.63 and 65.02 cm, respectively except at 30 DAS. The significantly higher plant height at 30 DAS was obtained with the application of RDF + sulphur nanoparticles @ 4 mg S/kg soil (T₉) as a basal. However, it was at par with treatments T₂, T₃, T₉ and T₁₁ at 30 DAS, while at 60 DAS and at harvest T₉ was at par with treatments T₁₀ and T₁₁. Conversely, the control treatment recorded the lowest plant height throughout the crop growth periods (30, 60 DAS and harvest), which was 30.11, 47.18 and 54.65 cm, respectively. The treatment T₉ registered 17.91 and 18.97% at 60 DAS and at harvest, while T₁₀ was 21.18% at 30 DAS higher plant height than control (T₁).

It's possible that the concentration of 3 mg S/kg soil used in T₉ provides the optimal amount of sulphur for the specific soil conditions under pot

experiment of groundnut. Higher doses may not always translate to better results and can sometimes even have negative effects on plant growth. It may be T₉ providing more balanced supply of nutrients, resulting in improved growth parameters of groundnut. Sulphur is involved in the formation of chlorophyll the pigment responsible for photosynthesis. These results emphasize the substantial impact of different levels of sulphur nanoparticles (SNPs) on plant height at all the stages, highlighting the potential of the application of sulphur nanoparticles, in promoting significant growth of groundnut. Due to high specific surface area and reactivity of SPNs, they facilitated the release of sulphur in a form that is readily available to plant for a longer period. The similar findings were reported by Maity et al. [22] Najafi et al. [23] Ragab and Saad-Allah, [24] and Khairan et al. [25] who observed significant increase in shoot and root biomass of groundnut plants treated with sulphur nanoparticles compared to control treatment.

3.1.3 Periodical branches plant⁻¹

The data presented in Table 1, revealed that application of different treatments of SNPs and elemental sulphur significantly affected the branches of groundnut at 60 DAS and at harvest. Among different treatments, treatment T₉ recorded significantly higher branches per plant (8.31 and 8.54) than the rest of the treatments except T₁₁, T₃ and T₁₀ treatments at 60 DAS, while at harvest it was at par with T₁₀ and T₁₁ treatments. The control recorded the lowest branches plant⁻¹ (7.36 and 7.53) at 60 DAS and harvest. The percentage increase in branches plant⁻¹ under T₁₀ was 12.90 and 13.41% over control (T₁). The increase in branches was mainly due to increase in plant height under T₉ over rest of the treatments. The SNPs enhanced plant growth, leading to increased branching over control. The similar findings were reported by Mahajan et al. [26].

3.1.4 Biological yield

The data furnished in Table 2, showed that the significantly higher biological (grain and haulm) yield (65.58 g/pot) was obtained with the application of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₉) over rest of the treatments except T₁₁. While, the lowest biological yield was obtained under control treatment (T₁). The percentage increment in biological yield was in the tune of 14.03% over the control untreated pot.

Table 1. Impact of various treatments on periodical plant height of groundnut-mustard cropping sequence

Treatments	Periodical Plant height (cm)					
	Groundnut			Mustard		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T ₁	30.11±1.36 ^d	47.18±1.60 ^c	54.65±1.83 ^d	27.01±1.01 ^e	81.22±1.72 ^d	104.82±2.72 ^c
T ₂	34.58±0.71 ^{ab}	51.41±2.44 ^{abc}	60.58±1.43 ^{abc}	31.17±0.64 ^{abc}	87.01±2.55 ^{bcd}	114.49±3.53 ^{abc}
T ₃	34.79±0.99 ^{ab}	50.71±0.48 ^{bc}	59.28±0.85 ^{bcd}	31.36±0.78 ^{abc}	89.36±1.40 ^{abc}	114.5±1.07 ^{abc}
T ₄	31.54±0.78 ^{cd}	47.64±0.78 ^c	55.69±0.91 ^{cd}	28.38±0.70 ^{de}	82.01±1.55 ^{cd}	105.84±1.06 ^c
T ₅	31.6±0.25 ^{cd}	49.3±1.09 ^c	57.63±1.58 ^{cd}	28.64±0.64 ^{cde}	84.88±1.88 ^{cd}	109.29±2.43 ^c
T ₆	31.91±0.83 ^{bcd}	49.43±0.75 ^c	57.78±0.88 ^{cd}	28.7±0.78 ^{cde}	85.09±1.63 ^{cd}	109.82±2.00 ^c
T ₇	33.75±0.29 ^{abc}	49.91±1.42 ^{bc}	58.35±1.61 ^{cd}	30.35±0.26 ^{bcd}	85.93±1.97 ^{cd}	110.9±3.78 ^{bc}
T ₈	33.8±0.88 ^{abc}	50.4±1.11 ^{bc}	58.92±1.30 ^{bcd}	30.64±1.05 ^{abcd}	86.77±2.21 ^{bcd}	111.98±3.12 ^{bc}
T ₉	35.06±0.30 ^a	55.63±0.96 ^a	65.02±1.32 ^a	31.6±0.48 ^{ab}	95.76±2.16 ^a	123.59±2.79 ^a
T ₁₀	36.49±0.73 ^a	51.84±1.21 ^{abc}	60.81±1.41 ^{abc}	33.14±0.66 ^a	89.44±2.08 ^{abc}	114.62±2.69 ^{abc}
T ₁₁	35.4±0.76 ^a	54.54±1.28 ^{ab}	63.75±1.50 ^{ab}	31.91±0.69 ^{ab}	93.89±1.96 ^{ab}	121.18±3.76 ^{ab}

The unique lowercase letters linked with the values represent statistically significant differences as assessed by Duncan's multiple range test at a significance level of p 0.05, as well as their standard error of mean uncertainties

Table 2. Impact of various treatments on branching/ plant and biological yield groundnut-mustard cropping sequence

Treatments	Periodical branches/plant				Biological yield (g/pot)	
	Groundnut		Mustard		Groundnut	Mustard
	60 DAS	At harvest	60 DAS	At harvest		
T ₁	7.36±0.16 ^b	7.53±0.26 ^b	11.52±0.24 ^b	13.3±0.28 ^b	57.51	30.49
T ₂	7.73±0.29 ^{ab}	7.91±0.30 ^{ab}	12.11±0.46 ^b	13.98±0.47 ^b	61.90	33.14
T ₃	7.78±0.14 ^{ab}	7.97±0.14 ^{ab}	12.19±0.21	14.08±0.24 ^b	60.42	33.68
T ₄	7.37±0.22 ^b	7.55±0.22 ^b	11.53±0.34 ^b	13.33±0.40 ^b	59.91	30.88
T ₅	7.37±0.10 ^b	7.54±0.10 ^b	11.54±0.16 ^b	13.32±0.18 ^b	60.96	31.60
T ₆	7.4±0.06 ^b	7.58±0.06 ^b	11.59±0.15 ^b	13.38±0.11 ^b	58.91	31.76
T ₇	7.64±0.14 ^b	7.83±0.21 ^{ab}	11.97±0.37 ^b	13.82±0.59 ^b	61.77	32.60
T ₈	7.64±0.17 ^b	7.83±0.17 ^{ab}	11.97±0.27 ^b	13.82±0.31 ^b	59.67	33.07
T ₉	8.31±0.17 ^a	8.54±0.17 ^a	13.23±0.26 ^a	15.47±0.30 ^a	65.58	35.94
T ₁₀	7.85±0.19 ^{ab}	8.04±0.20 ^{ab}	12.3±0.31 ^{ab}	14.2±0.35 ^b	60.83	34.31
T ₁₁	7.91±0.09 ^{ab}	8.1±0.09 ^{ab}	12.38±0.13 ^{ab}	14.3±0.15 ^b	64.52	35.11
SEm ±					1.22	0.61
CD (p=0.05)					3.50	1.76
CV %					3.98	3.70

The distinct lowercase letters associated with the values indicate statistically significant differences as determined by Duncan's multiple range test at a significance level of p ≤ 0.05 along with their standard error of mean uncertainties

The growth and yield attributes as well as yield was found better under T₉ shows that the biological yield ultimately found high in this treatment. And increasing the dose of sulphur found at par with T₉ but not highest. The 3 mg/kg dose of sulphur can be an optimum dose of sulphur for the fertilization of crop.

The similar findings were reported by Samreen et al., 2022; Singh et al., 2016 and Rathore et al., 2015 they reported that application of sulphur increase the growth parameters as well as yield of crops.

3.2 Growth and Yield Parameters of Mustard

3.2.1 Days to emergence

The data presented in Table 1 indicate that the effect of different treatments of SNPs and elemental sulphur was not significant to days of emergence of mustard seed. On an average it took 7 to 8 days for emergence of mustard seed.

3.2.2 Periodical plant HEIGHT (cm)

The data pertaining to periodical plant height measured at different days *i.e.*, 30, 60 DAS and at harvest as affected by sulphur nano-particles and elemental sulphur application were presented in Table 1. The data revealed that the periodical plant height of mustard was significantly affected by application of sulphur nano particles and elemental sulphur. The significantly higher plant height of 33.14 at 30 DAS was registered with the application of RDF + sulphur nanoparticles @ 4 mg S/kg soil (T₁₀) and 95.76 and 123.59 cm at 60 DAS and at harvest, respectively was obtained under T₉, than rest of the treatments. The treatment T₂, T₃, T₉ and T₁₁ was found at par at 30 DAS, while at 60 DAS T₉ was at par with T₃, T₁₀ and T₁₁ treatments. Moreover, at harvest T₂, T₃, T₁₀ and T₁₁ being at par with T₉. The treatment T₁ registered the lowest plant height with values of 27.01, 81.22 and 104.82 cm at 30, 60 DAS and harvest, respectively. The percentage increase in plant height under T₆ and T₉ over control was 22.69, 17.90 and 17.90%, respectively at 30, 60 DAS and harvest.

It's possible that the concentration of 3 mg S/kg soil used in T₁₀ provides the optimal amount of sulphur for the specific soil conditions, of mustard. Increasing the sulphur concentration to 4 mg S/kg soil in T₁₁ may exceed the crops' requirements, leading to reduced effectiveness. And also, T₁₀ have balanced nutrition of other essential nutrient s for the mustard, so the

growth and yield parameters of mustard was more. Sulphur nanoparticles might release sulphur slowly over time, and the lower concentration in T₁₀ may have been more effective in providing a sustained supply of sulphur to the crop.

The findings reported by Hasanuzzaman et al. [27] are in line with the present study, who noted that mustard yield parameters were significantly improved over control due to application of SNPs and elemental sulphur because it plays a vital role in photosynthesis and chlorophyll formation.

3.2.3 Branches plant⁻¹

The data pertaining to branches plant⁻¹ observed at different days *i.e.*, 60 DAS and at harvest as affected by different treatments of sulphur nanoparticles and elemental sulphur had been presented in Table 1. The significantly higher branches plant⁻¹ with the value of 13.23 and 15.45 at 60 DAS and at harvest, respectively, was obtained with the treatment T₉, than rest of the treatments, barring T₁₀ and T₁₁ at 60 DAS, but at harvest it was significantly the higher. Minimum branches plant⁻¹ was observed under control (RDF) (T₁) treatment with values of 11.52 and 13.30 at 60 DAS and at harvest, respectively. The similar findings were reported by Bhupender et al. [28] and Salem et al. [29] they reported that application of sulphur increased the branches plant⁻¹ over control in mustard crop.

3.2.4 Biological yield

The data given in Table 2, revealed that the significantly higher biological (grain and stover) yield (35.94 g/pot) was registered with the fertilization of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₉) over the remaining treatments except T₁₀ and T₁₁. While the lowest biological yield was obtained under control treatment (T₁). The percentage increase in biological yield was in the tune of 17.87% over the control untreated pot.

The growth and yield attributes as well as yield was found better under T₉ shows that the biological yield ultimately found high in this treatment. And increasing the dose of sulphur found at par with T₉ but not highest. The 3 mg/kg

dose of sulphur can be an optimum dose of sulphur for the fertilization of crop. The similar findings were reported by Samreen et al. [30] Singh et al. [31] and Rathore et al., 2015 they reported that application of sulphur increase the growth parameters as well as yield of crops [32-35].

4. CONCLUSION

It can be concluded that application of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T₉) through fertigation gives better results in terms of plant height, branches/plant and biological yield of groundnut-mustard cropping sequence in sulphur deficient soil under controlled condition of pot experimentation.

ACKNOWLEDGEMENT

I would like to thanks to Anand Agricultural University, Anand, Gujarat for providing all the facilities during the experimentation. And also thanks my guide for their kindness and thanks to all the authors for compiling this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sahoo M, Vishwakarma S, Panigrahi C, Kumar J. Nanotechnology: Current applications and future scope in food. *Food Frontiers*. 2021;2(1):3-22.
2. Huber DL. Synthesis, properties, and applications of iron nanoparticles. *Small*. 2005;1(5):482-501.
3. Teng Y, Zhou Q, Gao P. Applications and challenges of elemental sulfur, nanosulfur, polymeric sulfur, sulfur composites, and plasmonic nanostructures. *Critical Reviews in Environmental Science and Technology*. 2019;49(24):2314-2358.
4. Riley NG, Zhao FJ, McGrath SP. Leaching losses of sulphur from different forms of sulphur fertilizers: A field lysimeter study. *Soil Use and Management*. 2002;18(2):120-126.
5. Khan MR, Rizvi TF. Application of nanofertilizer and nanopesticides for improvements in crop production and protection. *Nanoscience and Plant–Soil Systems*. 2017;405-427.
6. Beig B, Niazi MBK, Sher F, Jahan Z, Malik, US, Khan MD, Juliana HPA-P, & Vo, DV. N. Nanotechnology-based controlled release of sustainable fertilizers. A review. *Environmental Chemistry Letters*. 2022;20(4):2709-2726.
7. Semba RD, Ramsing R, Rahman N, Kraemer K, Bloem MW. Legumes as a sustainable source of protein in human diets. *Global Food Security*. 2021;28:100520.
8. Rajput H, Goswami D, Nayik GA. Peanut 26. Antioxidants Veg Nuts-Properties Heal Benefits, 2020;509:16.
9. Tan XL, Azam-Ali S, Goh EV, Mustafa M, Chai HH, Ho WK, Massawe F. Bambara groundnut: An underutilized leguminous crop for global food security and nutrition. *Frontiers in Nutrition*. 2020;7:601496.
10. Mupunga I, Mngqawa P, Katerere DR. Peanuts, aflatoxins and undernutrition in children in Sub-Saharan Africa. *Nutrients*. 2017;9(12):1287.
11. Kayacetin F. Botanical characteristics, potential uses, and cultivation possibilities of mustards in Turkey: A review. *Turkish Journal of Botany*. 2020;44 (2):101-127.
12. Sharma P, Roy M, Roy B. Determining the Effect of Storage, Moisture and Temperature on Vigour and Viability of Rapeseed and Mustard. *Current Topics in Agricultural Sciences*. 2021;5:39-51.
13. Iqbal K, Khan A, Khattak MMAK. Biological significance of ascorbic acid (vitamin C) in human health-a review. *Pakistan Journal of Nutrition*. 2004;3(1):5-13.
14. Uchida R. Essential nutrients for plant growth: nutrient functions and deficiency symptoms. *Plant Nutrient Management in Hawaii's Soils*, 2000;4:31-55.
15. Devi KN, Singh LNK, Singh MS, Singh S B, Singh KK. Influence of sulphur and boron fertilization on yield, quality, nutrient uptake and economics of soybean (*Glycine max*) under upland conditions. *Journal of Agricultural Science*. 2012;4(4):1.
16. Jackson ML. Soil chemical analysis, Prentice Hall of India Pvt. Ltd., New Delhi. 1973;498.
17. Walkley A, Black CA. An examination to different method for determination soil organic matter and proposal for modification of the chromic acid titration method. *Soil Science*. 1934;37:29-38.
18. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soil by extraction by sodium bi-carbonate. Circular, USDA. 1954;939: 1-19.
19. Williams CH, Steinbergs A. Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Australian Journal of Agricultural Research*. 1959;10 (3):340-352.

20. Lindsay WL, Norvell WA. Development of DTPA soil test for zinc, iron, manganese and copper. *Journal of Soil Science Society America*. 1978;42:421-428.
21. Gomez KA, Gomez AA. *Statistical procedures for agricultural research*. John Wiley & Sons; 1984.
22. Maity S, Ray S, Saha A, Sarkar S, Saha B. Comparative effect of nano sulphur and other sources of sulphur on yield and yield attributes of groundnut (*Arachis hypogaea* L.). *Research in Environment and Life Sciences*. 2017;10(5):381-384.
23. Najafi S, Razavi SM, Khoshkam M, Asadi A. Effects of green synthesis of sulfur nanoparticles from *Cinnamomum zeylanicum* barks on physiological and biochemical factors of lettuce (*Lactuca sativa*). *Physiology and Molecular Biology of Plants*. 2020;26(5):1055-1066
24. Ragab GA, Saad-Allah KM. Green synthesis of sulfur nanoparticles using *Ocimum basilicum* leaves and its prospective effect on manganese-stressed *Helianthus annuus* (L.) seedlings. *Ecotoxicology and Environmental Safety*. 2020;191 110242. Available: <https://doi.org/10.1016/j.ecoenv.2020.110242>.
25. Khairan K, Muhammad S, Indra I. Green synthesis of sulfur nanoparticles using *Allium sativum*: Its effects on the growth of *Pogostemon cablin* and the chemical characterization of the patchouli oil after being harvested. *Nanotechnology for Environmental Engineering*, 2022;7(2): 359-375.
26. Mahajan R, Singh N, Parmar P, Sharma D, Jaswal N. Effect of sulphur and zinc on yield attributes and yield of groundnut (*Arachis hypogaea* L.). *Legume Research- An International Journal*. 2016;39(5):798-801.
27. Hasanuzzaman M, Nahar K, Rahman A, Mahmud J, Hossain MS, Masud AAC, Fujita M. Impact of nano-sulfur on the physiological and molecular responses of mustard (*Brassica juncea* L.) plants under salt stress. *Plants*. 2020;9(1):60.
28. Bhupender S, Yogesh S, Rathore BS. Effect of sulphur and zinc on growth, yield and quality of mustard [*Brassica juncea* (L.) Czern and Coss.]. *Research on Crops*. 2012;13(3):963-969.
29. Salem NM, Albanna LS, Awwad AM. Green synthesis of sulfur nanoparticles using *Punica granatum* peels and the effects on the growth of tomato by foliar spray applications. *Environmental Nanotechnology, Monitoring & Management*. 2016;6:83-87.
30. Samreen T, Rashid S, Zulqernain Nazir M, Riaz U, Noreen S, Nadeem F, Tul-Muntaha S. Co-application of Boron, Sulphur, and Biochar for Enhancing Growth and Yield of *Brassica napus* under Calcareous Soil. *Communications in Soil Science and Plant Analysis*. 2022;53(9):1050-1067.
31. Singh O, Kumar S, Shahi UP, Kumar A, Dwivedi A, Kumar V. Growth, Nodulation, Yield and Nutrient Uptake of Urdbean (*Vigna mungo* L. Hepper) as Influenced by Sulphur and Iron Fertilization in Light Textured Soil. *International Journal of Bio-resource and Stress Management*. 2016;7:(693-698).
32. Khurana MPS, Sadana US. Sulfur Nutrition of Crops in the Indo-Gangetic Plains of South Asia. *Sulfur: A Missing Link Between Soils, Crops, And Nutrition*. 2008;50:11-24.
33. Piper CS. *Soil and Plant Analysis*, Academic Press, New York. 1966;367.
34. Rathore SS, Shekhawat K, Kandpal BK., Premi OP, Singh SP, Chand G. *Annals of Plant and Soil Research* 2015;17(1): 1-12 Sulphur Management for Increased Productivity of Indian Mustard: A Review. *Annals of Plant and Soil Research*. 2015; 17(1):1-12.
35. Subbiah BV, Asija GL. A rapid procedure for the determination of available N in soils. *Current Science*. 1956;25 :259-260.

© 2023 Yadav et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<https://www.sdiarticle5.com/review-history/106978>