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Impact of Nanoscale Zinc Oxide Particle on the Growth, Yield and Soil Properties under Agency Area of Andhra Pradesh

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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

Field experiment was carried out on silt clay loam soils at Regional Agricultural Research station, Chintapalle, Visakhapatnam, Andhra Pradesh during 2018-2020 to study the yield of response of rainfed groundnut with different levels of Nano particulate zinc oxide application along with NPK Fertilizers. The experiment consisting of eight treatments, three replications with RDF design. Results of nano particulate zinc oxide on pod yield showed that (24.36 Q/ha) in the RDF+ nano scale zinc oxide level @ 200 ppm at 25 and 45 DAS was increased over to that of normal recommended dose of N,P,K fertilizers (100% RDF) which recorded pod yield of 17.14 Q/ha only. Application of $ZnSO_4$ through soil along with RDF showed good results (17.24 Q/ha) than RDF + Foliar application of $ZnSO_4$ @ 2g/lit at 25 and 45 DAS (20.66 Q/ha). Application of micronutrient (ZnO) had helped in further increase in grain yields at both levels of ZnO (150% and 200% ZnO at 25 and 45 DAS). Among different treatments, significantly higher yield (24.36 Q/ha) was recorded

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with application of RDF + Foliar application of ZnO @ 200 ppm at 25 and 45 DAS than the only with RDF (17.4 Q/ha). With respect to method of application of ZnSO4 through soil and foliar application ZnSo4 @ 2g/lit at 25 and 45 DAS was found to be higher both levels of RDF (Pod yield of 14.6 Q/ha at RDF + Soil application of ZnSO4 @ 50 kg ha-1 and 17.24 Q/ha at RDF+ foliar application of ZnSO4@ 2g/lit at 25 and 45 DAS). With respect to other plant characteristics, comparatively more plant height (43.53 cm) at RDF + foliar application of ZnO @ 200 ppm at 25 and 45 DAS. Regarding yield attributes significantly higher test weight (30.9 g) were recorded at RDF + 200 ppm ZnO at 25 and 45 DAS. Post –harvest soil sample analysis showed highest availability of nutrients in respect of soil, the results revealed that there was no significance difference among the treatments regarding Avail. N, Available K and pH. The lowest Phosphorus (17.20 kg ha^{-1}) was recorded with RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS and highest (24.46 kg ha^{-1}) was recorded in T_9 (RDF+ Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS).

An investigation was initiated at Department of Soil science, Regional Agricultural Research Station, Chintapalle to examine the effects of nano zinc oxide on Groundnut (*Arachis hypogea* L.) growth, yield and Zn content in Leaves, stem and roots. A field experiment consisted of nine treatments comprised of T_1: control, T_2: RDF, T_3: RDF+ Soil application $ZnSO_4$@ 50 Kg/ha, T_4: RDF+ Foliar application $ZnSO_4$ 2 g/L at 25 & 45DAS, T_5: RDF+ Foliar application of nanoscale ZnO 150 ppm at 25 & 45 DAS, T_6: RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS, T_7: RDF+ Foliar application of nanoscale ZnO 400 ppm at 25 & 45 DAS, T_8: RDF+ Foliar application of nanoscale ZnO 50 ppm at 25 & 45 DAS, T_9: RDF+ Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS.

Keywords: Nano particles; zinc oxide; groundnut; HAT zone; foliar application.

1. INTRODUCTION

"Zinc (Zn) is typically the second most abundant transition metal in organisms after iron and the only metal represented in all six enzyme classes (oxidoredutases, transferases, hydrolases, lyses, isomerase and ligases" [1]. "Zinc is an essential micronutrient for humans, animals and plants. Higher plants generally absorb Zn as a divalent cation (Zn^{+2}), which acts either as the metal component of enzymes or as a functional structural or a regulatory co-factor of a large number of enzymes. A number of researchers have reported the essentiality and role of zinc for plant growth and yield" [2-5]. "Based on analysis of 298 soil samples collected from different countries in the world, Zn deficiency has been found to be the most widespread micronutrient deficiency" [6,7]. "In India, Zn is now considered the fourth most important yield-limiting nutrient after nitrogen (N), Phosphorus (P) and Potassium (P). In India alone, 50% of the soils that groundnut is grown in show Zn deficiency, which is causing considerable yield loss" [8]. Half of the cultivated soils in Turkey have Zn deficiency [9] considerable increases in grain yield by Zn application was also demonstared in India [10]. "Zinc is required for chlorophyll production, pollen function, fertilization and germination" [11-13]. "Zinc plays an important role in biomass production" [11]. "Among the micronutrients, Zn and Mn can affect the susceptibility of plants to drought stress" [14]. "A number of mechanisms may underlie Zn deficiency" [15]. "Depending on experimental conditions and the plant species, the most important mechanisms may be Zn utilization in tissues, called internal efficiency and Zn uptake called external efficiency" [16]. Zinc is intermediate in its mobility or phloem export. Longnecker and Robson [17] suggested that "zinc efficiency depends on the amount supplied and the nature of plant species". "Zinc moves from leaves to roots, stem and developing grain and from one root to another" [15]. Higher uptakes of other nutreints are also known to increase the demand of Zn.

Graham et al. [18] reported that "over 3 billion people across the world from micronutrient deficiencies and suggested that a considerable amount of research in the 21 st century should be devoted to develop technologies for enhanced uptake and accumulation of micronutrients in edible plant parts. Groundnut is an important legume food crop of India grown in about 8 million ha of land. Groundnut cultivation occurs in 108 countries around the world. The average productivity of groundnut in India around 1178 kg ha^{-1}, which is far less than the world's average 1400 kg ha^{-1}". "The low productivity is mainly due to the fact that the crop is mostly grown in rainfed low fertility soils. Micronutrients, particularly Zn, will play an important role in stepping up the productivity of groundnut. In a field experiment on groundnut nutrition, the yield losses due to Zn deficiency were found to be 13.3% to 20% "[19]. "More recently, substantial arable crop responses to Zn fertilization have been reported in Australia, India and Turkey, where wheat grain yields have increased by over 600% since the mid-1990s with the concomitant annual economic benefit of US $ 100 million" [20]. "Particle size may affect agronomic effectiveness of Zn fertilizers. Decreased particle size also increases the specific surface area of a fertilizer, which should increase the dissolution rate of fertilizers with low solubility in water such as zinc oxide (ZnO)" [21]. "Granular zinc sulphate ($ZnSO_4$) (1.4 to 2 mm) was somewhat less fine $ZnSO_4$ (0.8 to 1.2 mm) whereas granular ZnO was completely ineffective" [22]. "Gradual increase in Zn uptake could be observed with decreasing granule size and only the powder form produced plants with Zn concentrations in the sufficient range. Since granules of 1.5 mm weigh less than granules of 2.0 or 2.5 mm, smaller granules were used for the same weight, resulting in a better distribution of Zn, and the higher surface area of contact of Zn fertilizer resulted in better Zn uptake"[23]. Therefore ample work has been done and emphasis was made o the particle size to increase the efficiency of the fertilizers for better uptake and higher yields.

"Nanomaterials are proposed to be the materials for the new millennium. Carbon –based and metal based nanoparticles are most the commonly engineered and are often studied. Nanoparticles of size below 100 nm fall in the transition zone between individual molecules and the corresponding bulk materials, which generate both positive and negative biological effects in living cell" [24]. There is a growing body of study on the biological impacts of nanoparticles on higher plants. Several investigations are being conducted on the biological production of nanomaterials. Only a few investigations on the detrimental effects of nanoparticles on plants in low doses have been published.

The present study was taken up to investigate the promontory inhibitory effects of various concentrations of ZnO nanoparticles on growth, development and final yield of groundnut (*Arachis hypogaea* L.) Nanoparticles with small size and large surface area are expected to be the ideal candidates for use as a Zn fertilizer in plants. Farmers are employing both for soil and foliar applications, but the efficacy is low. As a result, this study was initiated in order to acquire new information on the efficacy of nanoscale zinc oxide on groundnut growth and yield. The biggest concern for global food and nutrition security is providing nutritious food to the world's growing population. As a result, in the future, it is critical to raise not only production but also good quality food with the necessary amount of nutrients, with protein being the key difficulty. Zinc is a micronutrient that is required by humans, animals, and plants. Indian soils are zinc deficient, and food crops grown on these soils, as well as people living in this area, are zinc deficient. High altitude area of Visakhapatnam having more rainfall. Soil application of fertilizers lost due to heavy rains. Most of the nutrients leachate from soil resulting poor yields. To address this nutritional issue and increase crop output, bulk forms of ZnSO4 are typically given to soil or foliage as an exogenous source. However, bulk forms are frequently fixed in the soil, rendering them unavailable to the rhizosphere and harmful to soil microbes and plants. Sustainable agriculture primarily seeks to reduce the use of chemical fertilisers, limit nutrient losses during fertilisation, and boost yields through efficient nutrient management. Recently, nanotechnology is coming into focus because nano particles (NPs) are small in size (<100 nm) having high surface area and reactivity. According to recent research, powder or nano-sized particles are effective in absorption and translocation. However, the physiological aspects of Nano zinc administration and accumulation in grain crops are limited. As a result, the current study was carried out to explore the effects of various concentrations of Zinc Oxide (ZnO) NPs on growth, yield and grain Zn content in groundnut.

2. MATERIALS AND METHODS

2.1 Characterization of ZnO Nanoparticles

ZnO nanoparticles of mean size of 25 nm diameter were used in the study. Nano crystal line zinc Oxide has been prepared by using the oxalate decomposition technique. Zinc oxalate was prepared by mixing equimolar (0.2 M) solution of zinc acetate and oxalic acid. The resultant precipitate was collected and rinsed extensively with double deionized water and dried in air. The oxalate was then ground and decomposed in air by placing it in a pre-heated furnace for 45 minutes at 500^0C. The characterization of the samples was done by transmission electron microscopy (HRTEM, JEOL 3010; Peabody, MA, USA), scanning electron microscopy (SEM FEI, Malvern, UK) and energy dispersive analysis of X-rays (EDAX, FEI Quanta200; FEI). The TEM samples were prepared by drop casting the suspension on carbon coated Cu grids.

2.2 Site of the field experiment

The field experiment was conducted during *Kharif* seasons 2018-19, 20219-20 2020-21, in Regional Agricultural Research Station, Chintapalle, ANGRAU. The experiment was laid down in randomized block design replicated three times. The gross plot size 8*6 m^2. Nine treatments T_1: control, T_2: RDF, T_3: RDF+ Soil application $ZnSO_4$@ 50 Kg/ha, T_4: RDF+ Foliar application $ZnSO_4$ 2 g/L at 25 & 45DAS, T_5: RDF+ Foliar application of nanoscale ZnO 150 ppm at 25 & 45 DAS, T_6: RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS, T_7: RDF+ Foliar application of nanoscale ZnO 400 ppm at 25 & 45 DAS, T_8: RDF+ Foliar application of nanoscale ZnO 50 ppm at 25 & 45 DAS, T_9: RDF+ Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS were imposed.

The initial soil parameters were pH 6.1, Electrical conductivity 0.43 dS m^{-1}, Available Nitrogen 390 kg ha^{-1}, Available Phosphorus 18 kg ha^{-1}, Available potassium 379 kg ha^{-1}, Iron 7.86 ppm, Manganese 41.28, Zinc 0.26 and Copper 0.96 ppm. Soil texture was silt clay loam and Water holding capacity was 33%.

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

The plant height (43.53 cm) was recorded in RDF + Foliar application of nanoscale ZnO 200 ppm @ 25 and 45 Days after Sowing showed highest plant height compared to soil application of $ZnSO_4$. Highest root length was noted in treatment RDF along with Foliar application of nanoscale ZnO 200 ppm @ 25 and 45 Days after Sowing i.e 11.14 cm followed by RDF + Foliar application of $ZnSO_4$ 2g/L @ 25 and 45 Days after Sowing i.e 11.07 cm. The highest number of branches per plant was noticed in treatment with RDF+ Foliar application of nanoscale ZnO 200 ppm @ 25 and 45 Days after Sowing (7.6) compared to all other treatments. Similar results were observed by Prasad et al. [25], he suggested that "ZnO NPs are absorbed by plants to a larger extent as compared to $ZnSO_4$ bulk. They also observed beneficial effects of NPs in enhancing plant growth, development and yield in peanut at lower doses, but at higher concentrations ZnO NPs were detrimental just as the bulk nutrients". Racuciu and Creanga [26] when they analyzed "the influence of magnetic nanoparticles coated with tetramethylammonium hydroxide on the growth of zea mays plants in early ontogenetic stages. Small concentrations of aqueous Ferro fluid added in culture medium had a stimulating effect on the growth of plantlets while higher concentrations of aqueous Ferro fluid induced an inhibitory effect". "It was noted that water repellence potential of leaf surface acts as one of the limiting factors, which can affects the Zn uptake through spray application processes" [27]. The increase in vegetative growth in Groundnut (*Arachis hypogea* L) might be due to fundamental role Zinc in protecting and maintaining structured stability of cell membrane [28,29]. "Zn is used for protein synthesis, membrane function, cell elongation and tolerance to environmental stress" [29]. "Plants emerging from seeds with low zn have poor seedling vigour and field establishment on zn- deficient soils" [29].

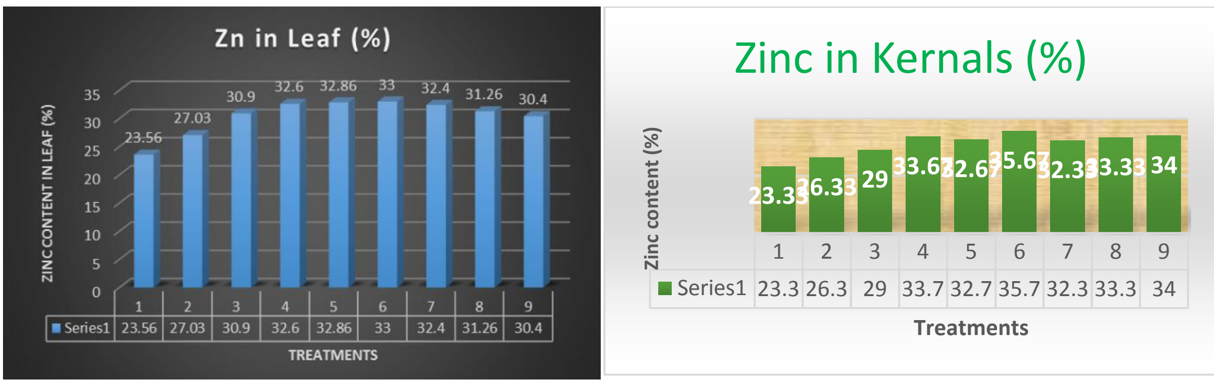

Fig. 1. Concentration of Zinc present in leaf and kernals

Table 1. Effect of Nano particulate zinc oxide on growth parameters (Pooled data)

Treatments	Plant height (cm)	Root length (cm)	No of branches per plant
T_1: control	26.46	8.04	4.2
T_2: RDF	35.50	9.80	5.1
T_3;RDF+ Soil application $ZnSO_4$@ 50 Kg/ha	39.00	10.80	6.6
$T_{4:}$ RDF+ Foliar application $ZnSO_4$ 2 g/L at 25 & 45DAS	41.60	11.07	5.5
$T_{5:}$ RDF+ Foliar application of nanoscale ZnO 150 ppm at 25 & 45 DAS	42.40	9.84	7.4
$T_{6:}$ RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS	43.53	11.14	7.6
$T_{7:}$ RDF+ Foliar application of nanoscale ZnO 400 ppm at 25 & 45 DAS	35.13	9.46	6.7
$T_{8:}$ RDF+ Foliar application of nanoscale ZnO 50 ppm at 25 & 45 DAS	40.33	10.19	5.8
$T_{9:}$ RDF+ Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS	37.20	10.67	7.0
CD (0.05%)	7.48	1.73	1.41
SEm$\pm$	21.41	4.91	3.2

Table 2. Effect of Nano particulate zinc oxide on yield and yield attributes (Pooled data)

Treatment	No of pods per plant	no of unfilled pods	Shelling percentage
T_1: control	11.00	8.3	61.94
T_2: RDF	13.66	6.3	62.87
T_3;RDF+ Soil application $ZnSO_4$@ 50 Kg/ha	14.00	5.0	63.19
$T_{4:}$ RDF+ Foliar application $ZnSO_4$ 2 g/L at 25 & 45DAS	16.00	6.3	64.22
$T_{5:}$ RDF+ Foliar application of nanoscale ZnO 150 ppm at 25 & 45 DAS	17.00	5.0	70.77
$T_{6:}$ RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS	18.00	5.3	72.48
$T_{7:}$ RDF+ Foliar application of nanoscale ZnO 400 ppm at 25 & 45 DAS	15.66	7.3	63.46
$T_{8:}$ RDF+ Foliar application of nanoscale ZnO 50 ppm at 25 & 45 DAS	15.00	5.6	72.30
$T_{9:}$ RDF+ Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS	16.66	5.6	69.10
CD (0.05%)	3.58	1.68	**7.96**
SEm$\pm$	9.80	5.89	22.9

Table 3. Effect of Nano particulate zinc oxide on yield and yield attributes (Pooled data)

Treatment	Pod yield (Q ha^{-1})	Test weight (g)	100 Pod weight (g)
T_1: control	11.04	20.4	75.8
T_2: RDF	17.14	28.1	87.8
T_3;RDF+ Soil application $ZnSO_4$@ 50 Kg/ha	17.24	26.4	81.2
$T_{4:}$ RDF+ Foliar application $ZnSO_4$ 2 g/L at 25 & 45DAS	20.66	22.4	92.8
$T_{5:}$ RDF+ Foliar application of nanoscale ZnO 150 ppm at 25 & 45 DAS	23.75	24.9	98.7
$T_{6:}$ RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS	24.36	30.9	96.7
$T_{7:}$ RDF+ Foliar application of nanoscale ZnO 400 ppm at 25 & 45 DAS	17.91	27.9	96.0
$T_{8:}$ RDF+ Foliar application of nanoscale ZnO 50 ppm at 25 & 45 DAS	19.08	23.2	94.9
$T_{9:}$ RDF+ Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS	19.19	28.6	96.6
CD (0.05%)	6.81	3.72	13.45
SEm($\pm$)	18.60	9.54	32.35

Table 4. Effect of nanoscale Zinc Oxide on plant and kernel zinc

Treatment	Zn (%) plants	Zn (%) kernels
T_1: control	23.56	23.33
T_2: RDF	27.03	26.33
T_3;RDF+ Soil application $ZnSO_4$@ 50 Kg/ha	30.90	29.00
$T_{4:}$ RDF+ Foliar application $ZnSO_4$ 2 g/L at 25 & 45DAS	32.60	32.67
$T_{5:}$ RDF+ Foliar application of nanoscale ZnO 150 ppm at 25 & 45 DAS	32.86	33.67
$T_{6:}$ RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS	33.00	35.67
$T_{7:}$ RDF+ Foliar application of nanoscale ZnO 400 ppm at 25 & 45 DAS	32.40	32.33
$T_{8:}$ RDF+ Foliar application of nanoscale ZnO 50 ppm at 25 & 45 DAS	31.26	33.33
$T_{9:}$ RDF+ Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS	30.40	34.00
CD (0.05%)	**2.62**	**7.24**
SEm$\pm$	7.43	21.5

3.2 Yield

The results revealed that pod yields of groundnut were greatly influenced by nanoscale zinc, increased grain yield upon application of RDF along with foliar application of Nanoscale ZnO 200 ppm at 25 & 45 DAS has showed highest pod yield (24.36 Q ha^{-1}) followed by treatment RDF+ Foliar application of nanoscale ZnO 150 ppm at 25 & 45 DAS i.e 23.75 Q ha^{-1} compared to all other treatments. RDF along with foliar application of ZnO 200 ppm at 25 & 45 DAS has showed highest test weight (30.9 g) which is on par with RDF. The highest 100 pod weight (98.7 g) was recorded with application of RDF+ Foliar application of nanoscale ZnO 150 ppm @ 25 and 45 Days after sowing. Which was on par with 200 ppm nano ZnO and RDF. Similar results reported by Prasad et al., [25].

"Foliar fertilization is more effective than soil application. Foliar zinc application significantly increased grain zinc concentration of groundnut indicating high mobility of zinc within plants. RDF + Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS gave significantly higher peanut pod yield compared to no spraying. However soil application of ZnSO4 50 Kg per ha at sowing gave yields on par with no ZnSO4 application. This indicates that groundnut response to foliar application but not to soil application" [30]. "The effectiveness of various synthetic and natural chelates has been widely investigated" [31]. "A significant increase in number of pods per plant (14.97%), shelling percentage (3.56%) and pod yield (22%) due to the application of P and Zn were reported" by Majumdar et al. [32].

3.3 Leaf and Kernel Samples

The post-harvest leaf and kernel sample analysis revealed a significant increment in zinc content in leaves and kernel. The highest zinc content in leaf (33.0%) was recorded with application of RDF along with foliar application of Nano ZnO 200 ppm at 25 & 45 DAS Compared to soil application of $ZnSO_4$. The highest zinc content in kernel (35.6%) recorded with RDF along and foliar application of Nano ZnO 200 ppm at 25 & 45 DAS followed by the spraying of 100 ppm Nano scale ZnO @ 25 and 45 DAS and RDF compared to all other treatments.

The results suggested that the micronutrients, Zn can be delivered into peanuts seeds through ZnO nanoparticles. A higher amount of Zn was present in the seed when treated with nanoscale ZnO. This improves the germination, root growth, shoot growth and pod yield of the nano scale ZnO treated palnts.

The results point to the use of nanoscalematerials in agriculture, especially in peanut, one of the main source of livelihood in certain parts of the world. The results emphasized that nanoscale nutrients can be supplied to the crops either through seed dressing or by foliar application with much decreased doses to get the desired results.

"Concentrated liquids suspensions of ZnO are used for foliar application but their performance is strongly determined by the size range specification of the ZnO particles present in the formulation" [33]. "Leaf water repellency of adaxial or abaxial surface is a main limiting factor, which can affect the Zn uptake through spray application processes" [34,27]. "The permeability of the cuticle to water and to lipophilic organic molecules increases with mobility (distribution co-efficient) and solubility (partition co-efficient) of these compounds within the transport-limiting barrier of the cuticles. Ions being highly water soluble might have some hindrance in penetrating the lipophilic cuticle. This may be act as limiting factor in Chelated $ZnSO_4$. But our custom-made nano particle ZnO, which is having less hydrophilicity and being more dispersible in lypophilic substances compared to the ions, can penetrate through the leaf surface" [35] compared to ZnSO4. "Also the mobility of the nanoparticles is known to be very high which ensures the phloem transport and ensures the nutrient to reach all parts of the plant. The presence of Nano particles both in the extracellular space and within some cells in the living plant cubital pepo was reported" [36]. Because of their smaller size and lower water solubility (which prevents rapid falling off when compared to ionic supplements), nanoparticles have a higher bioavailability than ZnSO4. As previously observed, the nanoscale ZnO fertilizer's inherent small size and associated large surface area may improve uptake.

4. CONCLUSION

Regarding soil properties, the results revealed that there was no significance difference among the treatments regarding Avail. N, Available K and pH. The lowest Phosphorus (17.20 kg ha^{-1}) was recorded with RDF+ Foliar application of nanoscale ZnO 200 ppm at 25 & 45 DAS and highest (24.46 kg ha^{-1})was recorded in T_9 (RDF+

Foliar application of nanoscale ZnO 100 ppm at 25 & 45 DAS) .

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERNCES

1. Auld DS. Zinc coordinationsphere in biochemical size sites. Biometals. 2001;14(3-4):271-313.
2. Camp AF, Fludge BR. Zinc as a nutrient in plant growth. Soil Sci. 1945;60(2):157-64.
3. Lindsay WL. Zinc in soils and plant nutrition. Adv Agron. 1972;24:147-86.
4. Mengel L, Kirkby. Principles of plant nutrition. Basel, Switzerland: International Potash Institute; 1978.
5. Fageria NK, Baligar VC, Clark RB. Micronutrients in crop production. Adv Agron. 2002;77:185-268.
6. Sillanpaa M. Micronutrients assessment at the country level: an international study. FAO Soils bulletin 63. Rome: Food and Agriculture Organization of the United nations; 1990.
7. Sillanpaa M, Vlek PLG. 6. Micronutrients and the agroecology of tropical and Mediterranean regions. Fertilizer Res. 1985;7(1-3):151-67.
8. Singh AL. Mineral nutrition of groundnut. In: Hemantha A, editor rajan,. Advances in plant pathology. Jodhpur, India: Scientific Publishing.1999;161-200.
9. Eyupoglu FN. Kurucu and U. Sanisa. In: [annual report]. Report No. R-118. Ankara, Turkey: Soil and Fertilizer Research Institute; 1993. Status of plant available micronutrients in Turkish soils. p. 25-32.
10. Tandon HLS. Major nutritional constraints to crop production and the soil fertility management strategies in different agro climatic regions of asis. In: Proceedings of the International Potash Institute colloquium on potassium in Asia: balanced fertilization to Increase and sustain agricultural production.1995;43-72. Basel, Switcherland: International Potash Institute.
11. Kaya C, Higgs D. Response of Tomato (Lycopersicon esculentum L.) culture at low zinc. Sci Hortic. 2002;93:53-64.
12. Pandey N, Pathak GC, Sharma CP. Zinc is critically required for pollen function and fertilization in lentil. J Trace Elem Med Biol. 2006;20(2):89-96.
13. Cakmak I. Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant Soil. 2008;302(1-2):1-17.
14. Khan HR, McDonald GK, Rengel Z. Zinc fertilization improves water use efficiency, gain yield and seed Zn content in chickpea. Plant Soil. 2003;249(2):389-400.
15. Rengel Z. Geotypic differencesin micronutrient use efficiency in crops. Commun Soil Sci Plant Anal. 2001;32(7-8):1163-86.
16. Genc Y, McDonald GK, Graham RD. Contribution of different mechanism to zinc efficiency in bread wheat during early vegetative stage. Plant Soil. 2006;281(1-2):353-67.
17. Longnecker NE, Robinson AD. Distribution and transport of zinc in plants. In: Robson AD, editor. Zinc in soils and plants. Dordrecht, and Netherlands: Kluwer Academic Publishers. 1993;79-91.
18. Graham RD, Welch RM, Bouis HE. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspective and knowledge gaps. Adv Agron. 2001;70:77-142.
19. Singh AL. Babu and N.B. Singh. Mineral Disorders of Groundnut. New Delhi, India: Indian Council of Agricultural Research Publications;2004.
20. Cakmak I. Identification and correction of widespread zinc deficiency in Turkey- A success story (A NATO – science for Stability Project). Proceedings of the International Fertilizer Society. 2004;552:1-26.
21. Mortvedt JJ. Crop response to level of water soluble zinc in granular zinc fertilizers. Fert Res. 1992;33(3):249-55.
22. Allen SE, Terman GL. Response of maize and Sudan grass to zinc in granular micronutrients. Trans Comm. 1996;II and IV: 255-266.
23. Liscano JFCEW, Norman RJ Jr., Slaton NA. Zinc availability to rice from seven granular fertilizers. AAES Res Bull. 2000;963:1-31.
24. Nel A, Xia T, Mädler L, Li N. Toxic potential of materilas at the nanolevel. Science. 2006;311(5761):622-7.
25. Prasad TNVKV, Sudhakar P, Sreenivasulu Y, Latha P, Munaswamy V, Reddy KR et al. Effect of nanoscale zinc oxide particles

on the germination, growth and yield of peanut. J Plant Nutr. 2012;35(6):905-27.
26. Racuciu M, Creanga RD. TMA-OH coated magnetic nanoparticles internalized in vegetal tissues. Romnian J Phys. 2007;52:395-402.
27. Holder CD. Leaf water repellency of species in Guatemala and Colorado (USA) and its significance to forest hydrology studies. J Hydrol. 2007;336(1-2):147-54.
28. Webb WRMMJ, Loneragan JF. Zinc in membrane function and its role in phosphorus toxicity. In: Scafe A, editor. Proceedings of the ninth plant nutrition colloquinum. Wallingford, UK: CA B International. 1982;710-5.
29. Cakmak I. Role of zinc in protecting plant cells from reactive oxygen species. New Phytol. 2000;146(2):185-205.
30. Channabasavanna AS, Setty RA. Effect of nitrogen ferrous sulphate and zinc sulphate on groundnut yield in deep black soils. Indian J Agron. 1993;38:329-30.
31. Alvarez JM, Gonzalez D. Zinc transformations in neutral soil and zinc efficiency in maize fertilization. J Agric Food Chem. 2006;54(25):9488-95.
32. Majumdar BMS, Venkatesh BL, Kumar K, Singh CS. Effect of phosphorus and zinc nutrition on groundnut in an acid haludalf of Meghalaya. Annals of Agriculture Research New Series.2001;22: 354-9.
33. Moran K. Micronutrient products types and their development. International fertilizer society. Proceedings of the 545. England: York: international fertilizer society; 2004.
34. Watanabe T, Yamaguchi I. Evaluation of wettability of plant leaf surfaces. J Pestic Sci. 1991;16(3):491-8.
35. Da Silva LC, Oliva MA, Azevedo AA, De Araujo MJ. Response of resting plant species to pollution from an iron palletization factory. Water Air Soil Pollut. 2006;175:241-56.
36. González-Melendi P, Fernández-Pacheco RF, Coronado MJ, Corredor E, Testillano PS, Risueño MC et al. Nanoparticles as smart treatment-delivery systems in plants: assessment of different techniques of microscopy for their visualisation in plant tissue. Ann Bot. 2008;101(1):187-95.

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