

Influence of sulphur and zinc levels and zinc solubilizer on productivity, economics and nutrient uptake in groundnut (*Arachis hypogaea*)

HEBA MOHAMED NOMAN¹, D.S. RANA² AND K.S. RANA³

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received : December 2014; Revised accepted : June 2015

ABSTRACT

The field experiments were conducted over 2 consecutive rainy (*kharif*) (July to November) seasons of 2013 and 2014 at New Delhi, to evaluate the effect of 3 sulphur (S) levels (0, 20 and 40 kg S/ha), 4 zinc (Zn) levels (0, 2.5, 5.0 and 7.5 kg Zn/ha) and 2 zinc bio-fertilizer (Native zinc solubilizer) levels (Control and seed treatment with zinc bio-fertilizer) on the performance of groundnut (*Arachis hypogaea* L.). Sandy loam soil of the experimental field was low in available S and DTPA-extractable Zn. Application of S caused marked improvement in plant height, branches/plant, leaf area index (LAI), pods/plant and pod and haulms yields, net returns, S-content in kernel and S and Zn-uptake up to 40 kg S/ha. Based on 2 years average, application of 20 and 40 kg S/ha resulted in 23.4 and 31.4% increase in pod yield, 36.3 and 52.7% in haulms yield, 46.3 and 56.7% in net returns, 66.3 and 92.3% in S-uptake in kernel and 25.9 and 35.3 % in Zn-uptake/ha in kernel over control, respectively. Application of Zn had significant effect on growth and yield attributes, pod and haulms yields, shelling percentage, net returns and Zn-content and uptake in kernel only up to 5.0 kg Zn/ha. Application of 2.5, 5.0 and 7.5 kg Zn/ha resulted in 17.2, 21.1 and 13.6 % increase in pod yield, 36.1, 45.0 and 27.4% in net returns, 17.5, 18.5 and 6.3% in S-uptake and 29.4, 44.9 and 45.5% in Zn-uptake in kernel over control, respectively. Effect of Zn-bio-fertilizer was significant on growth and yield attributes (except kernels/pod), pod and haulms yields, shelling percentage and Zn-content and uptake. Due to application of Zn bio-fertilizer 4.7, 6.2, 9.2, 5.2 and 7.9% increase in pod yield, haulms yield, net returns, S-uptake in kernel and Zn-uptake in kernel was recorded over control. Based on two years average, response to S and Zn application was quadratic and economic optimum dose was worked out to be 39.0 and 4.5kg/ha, respectively. Hence application of 39kg S and 4.5 kg Zn/ha with Zn-solubilizer is recommended for improving the productivity and profitability of groundnut in sandy loam soils low in S and Zn.

Key words : Groundnut, Economics, Economic optimum dose, Nutrient uptake, Productivity, Sulphur, Zinc

The oilseed production in India is not sufficient to meet the demand of vegetable oils and fats and 40% of the demand is met through import. Of the oilseed crops grown globally, groundnut is an important oilseed and food legume crop of tropical and sub-tropical parts. Groundnut kernel is a concentrated source of food, as it contains about 45 % oil and 25% protein and rich in energy. It is considered as poor man almond due to high nutritional value. In the past two decades, the direct consumption of groundnut in India (roasted and salted groundnuts, *chikki*, peanut butter and sauce) has gone up to 40% and currently

about only 45% of the produce is crushed for oil extraction. Major part of groundnut cake is fed to the domestic animals.

India ranks first in the world in respect of area and second in production after China. But the productivity (about 1000 kg/ha) of groundnut is quite low as compared to world average productivity (1500 kg/ha). Nutrient management is one of the most important agronomic factors that affect the yield of all the crops. Continuous and imbalance use of selected fertilizer nutrients have resulted in deterioration of soil health, increasing per unit cost of production and decline in rate of growth of productivity. Sulphur is now widely accepted as fourth major plant nutrient along with N, P and K. It is involved in the synthesis of essential amino acids and oils in oilseeds, being a vital component of co-enzyme involved in oils synthesis. It is also involved in various metabolic and enzymatic processes including photosynthesis, respiration and legume-rhizobium

Based on a part of Ph.D. Thesis of the first author being submitted to Indian Agricultural Research Institute, New Delhi 110 012 (Unpublished)

²Corresponding author Email: dsrana5554@yahoo.com

¹Ph.D. Scholar, ²Principal Scientist, ³Professor of Agronomy; Division of Agronomy, Indian Agricultural Research Institute, New Delhi 110 012

symbiotic nitrogen fixation. This role of sulphur in plant make it of fundamental importance in increasing the productivity of crops especially legume oilseeds in India, where more than 50% of soils have been reported to be deficient in sulphur (Tewatia *et al.*, 2006).

Deficiency of micronutrients in soils is another constraint, which is limiting the productivity of crops. Among the micronutrients, zinc deficiency is most widespread on a wide range of soils under both cold and warm climates (Cakmak *et al.*, 1996). Zinc deficiency in Indian soils is expected to increase from 42% in 1970 to 63% by 2025 due to continuous depletion of soil fertility (Singh 2011). It is established fact that crops respond to zinc application and groundnut is not exception to this. Zinc has specific and essential physiological functions in plant metabolism. At least four enzymes contain zinc: carbon anhydrase (CA), alcohol dehydrogenase (ADH), copper-zinc-superoxide dismutase (Cu-Zn-SOD), and RNA polymerase, which are involved in photosynthetic CO₂ fixation, anaerobic root respiration, detoxification of superoxide radicals and protection of membrane lipids and proteins against oxidation. Zinc is important in protein and growth regulators synthesis. Further bio-fortified seeds are also likely to have an indirect impact in agriculture, as a higher trace mineral content in seeds confers better protection against pests, diseases, and environmental stresses, thereby increasing yield (Welch and Graham, 2004). So, zinc is recognized as one of the most required micronutrient fertilizers in the agricultural production system.

Beside inorganic fertilizers as source of nutrients, bio-fertilizers are being used to meet partially the nutrient requirement of crops. In this series of bio-fertilizers, native zinc solubilizer, has been developed at Indian Agricultural Research Institute, New Delhi to improve the availability of native zinc in the soil. Zinc solubilizer is a new entry in the group of bio-fertilizers and no work has been carried on its efficiency to substitute zinc requirement of crops under field conditions.

Meena *et al.*, (2007) reported that response of groundnut to Zn ranged from 210 to 470 kg/ha and its application increased the nodulation, chlorophyll content and pod yield. In Alfisol at Coimbatore, in Tamil Nadu which was deficient in available Zn and S, maximum groundnut yield was obtained when both Zn and S were applied at 5.5 kg Zn (53%) and 40 kg S/ha (39%) (Krishnasamy and Malik 1994). Use of sulphur and zinc was also found to step-up the productivity and kernel quality of groundnut (Shukla and Behera 2011). The fertilization of groundnut with zinc and sulphur not only enhance the productivity but also bio-fortified the kernel and cake with zinc and protein (Prasad *et al.*, 2012). Information on the combine use of S, Zn and Zn-solubilizer and their effect on ground-

nut productivity, quality and bio-fortification of groundnut kernel with Zn are very limited and therefore present study was planned.

MATERIALS AND METHODS

The field experiments were conducted in two consecutive rainy (*khari*) (July to November) seasons of 2013 and 2014, at the research farm of Indian Agricultural Research Institute, New Delhi in north-western India (28.4° N latitude, 77.1° E longitude and 228.6 m above mean sea level) to evaluate the effect of sulphur and zinc levels and zinc-solubilizer on the performance of groundnut. The mean annual rainfall of Delhi is 672 mm and more than 80% generally occurs during the monsoon season (July-September) with mean annual evaporation of 850 mm. The soil of the experimental site was sandy loam with 0.38% and 0.37% organic carbon, 172 and 175 kg KMnO₄ oxidizable N/ha, 14.5 and 14.2 kg 0.5 N NaHCO₃ extractable P₂O₅/ha, 226 and 230 kg 1.0 N NH₄OAc exchangeable K₂O/ha, 11.2 and 11.7 ppm available S, 0.72 and 0.76 ppm DTPA-extractable Zn, 7.82 and 7.78 pH and 0.30 and 0.32 dS/m EC at the start of the experiment in respective season of 2013 and 2014 (Piper, 1966 and Prasad *et al.*, 2006). The treatments comprised of 24 combinations of 3 sulphur (S) levels (0, 20 and 40 kg/ha), 4 zinc (Zn) levels (0, 2.5, 5.0, 7.5 kg/ha), and 2 Zn-bio-fertilizer (Native Zn solubilizer) levels (control and zinc solubilizer). The experiment was conducted in 3 times replicated split-plot design, assigning levels of S and Zn to main-plots and Zn-bio-fertilizer to sub-plots. Seeds of groundnut 'GG 20' were dibbled at a row to row spacing of 30 cm and plant to plant spacing of 10 cm. Gap filling was done at 10 days after sowing to maintain optimum plant population. Crop received recommended dose of 25 kg N, 60 kg P₂O₅ and 50 kg K₂O/ha through urea, diammonium phosphate and potassium chloride respectively. As per treatments, Zn was applied through zinc sulphate (20% Zn) and S through WDG sulphur (90% sulphur). Addition of sulphur through zinc sulphate was adjusted to maintain sulphur level as per treatments. All the nutrients were applied as basal with last land preparation operation. Pre-emergence application of pendimethalin was done @ 1.0 kg a.i./ha followed by hand weeding at 30 days after sowing. Crop received 3 irrigations during 2013 and 5 irrigations during 2014 in addition to 1148 mm rainfall during 2013 and 451 mm in 2014. The crop was harvested in the first week of November. Growth attributes such as plant height, leaf area index and branches/plant were recorded at 90 days after sowing following standard procedure. Pods/plant was counted based on 5 randomly selected plants while kernels/pod were recorded based on 20 randomly selected pods from each treatments. Pod and haulms yields/ha was calculated based

on pods and haulms yields harvested from net plot of 1.80 m×3.00 m. Harvest index was calculated by dividing the pod yield/ha by pods + haulms yields/ha and expressed as percentage. For the shelling out-turn, 100 gram pods were selected randomly from each plot, shells and kernels were separated by hand, kernels weight was taken and weight so obtained was divided with initial pod weight and multiplied by 100. The shelling out-turn was used to work out kernels yield/ha by multiplying the pods yield/ha of each treatment with respective shelling percentage of the treatments and dividing it by 100. S and Zn content in kernels for each treatment was determined by following standard procedure and used to calculate S and Zn uptake in kernels/ha by multiply content of respective treatment with respective kernel yield/ha. Data of each attributes of respective year was pooled over two seasons, analyzed by standard statistical procedure and presented treatment-wise along with SEM± and CD at 5% level of significance.

RESULTS AND DISCUSSION

Growth and yield attributes

Plant height, branches/plant and leaf area index at 90 days after sowing (DAS) revealed significant improvement with increasing level of S (Table 1). The increase in these parameters was more with increase in S dose from 0 to 20 kg S/ha than increase from 20 to 40 kg S/ha. Pods/plant also showed marked improvement with increasing level of S up to 40 kg S/ha, while kernels/pod and shelling turn-out increased markedly only up to 20 kg S/ha. This may be ascribed to the role of sulphur in various metabolic

and enzymatic processes including photosynthesis, respiration and legume-rhizobium symbiotic nitrogen fixation.

Plant height, LAI, pods/plant and shelling turn-out revealed significant increase up to 5.0 kg Zn/ha, while branches/plant and kernels/pod showed conspicuous improvement only up to 2.5 kg Zn/ha only. Increase in Zn level beyond 5.0 kg Zn/ha fail to induce further increase in these growth and yield attributes, rather there was a depressing effect of 7.5 kg Zn/ha over 5.0 kg Zn/ha. The favorable effect of Zn application on growth and yield attributes are inevitable due to low status of Zn in soil and optimum availability of Zn to the crop due to application of Zn. This is also attributed to the role of Zn in essential physiological functions in plant metabolism, photosynthetic CO₂ fixation, anaerobic root respiration, detoxification of superoxide radicals and protection of membrane lipids and proteins against oxidation. Thate *et al.* (2008) reported increase in growth and yield attributes in groundnut due to S and Zn application.

Favourable effect Zn bio-fertilizer was observed on plant height, branches/plant, LAI, pods/plant and shelling turn-out due to solubilizing effect of bio-fertilizer on native zinc and its availability to crop.

Yield and harvest index

Application of S caused significant increase in pod and haulms yields up to 40 kg S/ha, while increase in harvest index was significant only up to 20 kg S/ha (Table 2). Based on 2 years average, application of 20 and 40 kg S/ha resulted in 23.4 and 31.4% increase in pod yield, 36.3 and 52.7% in haulms yield over control. Improvement in

Table 1. Effect of sulphur and zinc levels and zinc solubilizer on growth and yield attributes of groundnut (data pooled over 2 years)

Treatment	Plant height at 90 DAS (cm)	Branches/plant at 90 DAS	LAI at 90 DAS	Pods/plant at harvest	Kernels/pod at harvest	Shelling percentage
<i>Sulphur level (kg/ha)</i>						
0	32.4	4.55	2.30	14.6	1.52	68.8
20	34.8	5.12	2.92	18.1	1.77	71.2
40	35.5	5.34	3.10	19.4	1.78	71.9
SEM±	0.16	0.04	0.02	0.14	0.016	0.3
CD (P=0.05)	0.46	0.11	0.07	0.40	0.045	0.8
<i>Zinc level (kg/ha)</i>						
0	32.4	4.85	2.43	15.5	1.62	69.1
2.5	34.3	5.04	2.64	17.5	1.72	70.6
5.0	35.4	5.15	2.97	18.3	1.72	71.6
7.5	34.7	4.86	3.05	18.1	1.69	71.4
SEM±	0.18	0.04	0.04	0.16	0.018	0.3
CD (P=0.05)	0.53	0.13	0.11	0.47	0.053	0.9
<i>Zinc solubilizer</i>						
Control	33.9	5.04	2.72	16	1.68	70.3
Zinc solubilizer	34.5	5.17	2.82	17	1.69	71.2
SEM ±	0.13	0.02	0.01	0.12	0.014	0.1
CD (P=0.05)	0.37	0.06	0.04	0.35	NS	0.4

kernel and haulms yields may be traced to improvement in growth and yield attributes and also to improvement in harvest index and shelling percentage. Similar results were reported by Krishnasamy and Malik (1994). Further Gupta and Jain (2009) based on three years on-farm trails in Rajasthan showed that application of 45 kg S/ha to groundnut increased its yield by 661 kg pods/ha (45%) over control.

Effect of Zn-levels was also significant on the yield, harvest index and shelling percentage. Zinc application found to increase pod and haulms yields significantly up to 5 kg Zn/ha (Table 2). Harvest index showed improvement only up to 2.5 kg Zn/ha. Increase in Zn level up to 7.5 kg/ha caused significant decrease in pod and haulms yields/ha over 5.0 kg Zn/ha. Depressing effect of 7.5 kg Zn/ha was also observed on harvest index and shelling percentage. Based on average of 2 years, application of 2.5, 5.0 and 7.5 kg Zn/ha was found to increase pod yield by 17.2, 21.1 and 13.6% and haulms yield by 27.2, 33.8 and 26.8% over control. Improvement in yield due to Zn application may be ascribed to favourable effects of Zn on growth and yield attributes of groundnut. Meena *et al.*, (2007) reported that groundnut is sensitive to the deficiency of Zn and response of groundnut to Zn ranges from 210 to 470 kg/ha, in Zn deficient soils. This improvement in pod yield and yield attributes and shelling turn-out of groundnut due to Zn and S level may be ascribed to low level of these nutrients in the soil on the one hand and role of these nutrients in harnessing the genetic yield potential

of crops. Arunachalam *et al.*, (2012) also reported 12.6% increase in pod yield of groundnut cultivars due to Zn application. Depressing effect of higher levels of Zn may be ascribed to its interaction effect with other plant nutrients. In Zn and S, both synergistic, antagonistic and no interaction have been reported and the relationship between S and Zn is not clear cut (Takkar and Colin, 1989). S and Zn interaction can be positive or negative depending on the degree of their deficiency and crop requirement. Bhal and Lodha (1986) long back reported favourable effects of Zn and S on the groundnut.

Effect of zinc solubilizer was significant on pod and haulms yields and found to improve the pod yield by 4.7% and haulm yield by 6.2%. Effect of zinc solubilizer was not significant on harvest index. Increase in kernel and pod yield due to zinc solubilizer may be ascribed to its favourable effect on growth and yield attributes. Similar effect of bio-fertilizer on yield of pigeonpea was also reported by Pandey *et al.* (2013)

Response equation/curve and optimum economic dose for sulphur and zinc

Based on two years average, pod yield response to S and Zn application was found to be quadratic as per figure 1 and 2 respectively. Based on support price of ₹40/kg of pod and market price of ₹100/kg of sulphur through WDG sulphur and ₹160/kg of Zn through Zn sulphate, the optimum economic dose of S and Zn was worked out be 39.5 kg and 4.5 kg/ha respectively for the groundnut.

Table 2. Effect of sulphur and zinc levels and zinc solubilizer on yield, harvest index, shelling percent and economics of groundnut (data pooled over 2 years)

Treatment	Pod yield (t/ha)	Haulms yield (t/ha)	Harvest index (%)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio
<i>Sulphur level (kg/ha)</i>					
0	1.58	2.50	32.6	29.6	0.8
20	1.95	3.41	34.3	43.3	1.1
40	2.08	3.82	33.5	46.4	1.2
SEm \pm	0.013	0.028	0.1	0.6	0.02
CD (P=0.05)	0.042	0.083	0.4	1.6	0.05
<i>Zinc level (kg/ha)</i>					
0	1.65	2.66	32.7	31.3	0.8
2.5	1.94	3.39	34.3	42.6	1.1
5.0	2.00	3.56	34.0	45.4	1.2
7.5	1.88	3.38	33.5	39.9	1.0
SEm \pm	0.016	0.033	0.2	0.6	0.03
CD (P=0.05)	0.048	0.096	0.5	1.9	0.07
<i>Zinc solubilizer</i>					
Control	1.82	3.15	33.7	38.0	1.0
Zinc solubilizer	1.91	3.35	33.5	41.5	1.1
SEm \pm	0.012	0.028	0.1	0.5	0.02
CD (P=0.05)	0.035	0.081	NS	1.6	0.05

Economics

Favourable effects of S and Zn levels on pod and kernel yields got translated on economics of production of groundnut, resulting in significant increase in net returns

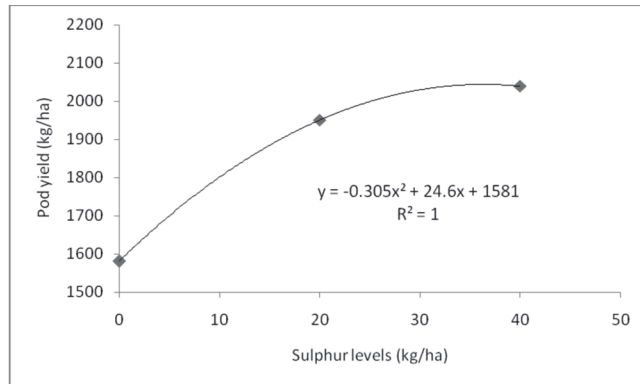


Fig. 1. Response equation/curve of sulphur level to pod yield.

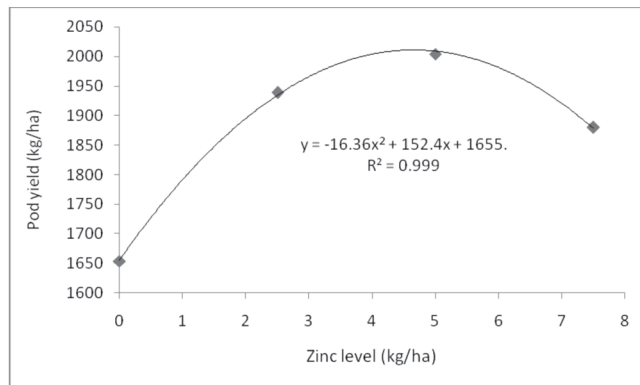


Fig. 2. Response equation/curve of zinc level to pod yield.

and B:C ratio. With application of 20 and 40 kg S/ha net returns showed improvement by 46.3% (₹13,700/ha) and 56.7% (₹16,800/ha) over control respectively. Percent increase in net returns due to 2.5, 5.0 and 7.5 kg Zn/ha over control was 36.1% (₹11,600/ha), 45.0% (₹14,100/ha) and 27.4% (₹8,600) and due to application of Zn solubilizer it was 9.2% (₹3,500) (Table 2). Percent increase in net returns was more as compared to percent increase in kernel yield, which may be ascribed to less addition to total cost of cultivation due to treatments and higher selling price/unit of additional output due to treatments. Meena *et al.* (2013) also reported more increase in net returns than increase in grain yield of maize due to application of zinc. Improvement in net returns and B:C ratio due to application of bio-fertilizers was also reported in pigeonpea by Pandey *et al.* (2013)

Sulphur and zinc concentration in kernel and uptake

Sulphur application caused significant improvement in S-content in kernel. Effect of S application on Zn content was not significant. With application of 20 and 40 kg S/ha, 30.4 and 40.5% increase in S-content of kernel was observed (Table 3). This improvement in S content may be ascribed to more availability of S in the soil, which promoted more uptake of S as compared to increase in plant biomass. Effect of S-application on S-uptake in kernel was more conspicuous than content due to combined effect of improvement in content and kernel yield. This resulted in 66.3 and 92.4% increase in S-uptake due to application of 20 and 40kg S/ha over control respectively. In

Table 3. Effect of sulphur and zinc levels and zinc solubilizer on sulphur and zinc concentration and uptake in kernel of groundnut (data pooled over 2 years)

Treatment	S-concentration in kernel (mg/g)	Zn-concentration in kernel (ppm)	S-uptake in kernel (kg/ha)	Zn-uptake in kernel (g/ha)
<i>Sulphur level (kg/ha)</i>				
0	2.89	26.0	3.15	28.30
20	3.77	25.7	5.24	35.65
40	4.06	25.7	6.06	38.30
SEm±	0.33	0.1	0.16	0.87
CD (P=0.05)	0.95	NS	0.46	2.55
<i>Zinc level (kg/ha)</i>				
0	3.71	22.9	4.27	26.35
2.5	3.65	24.6	5.02	34.10
5.0	3.53	26.7	5.06	38.20
7.5	3.41	28.8	4.54	38.35
SEm±	0.38	0.2	0.18	0.97
CD (P=0.05)	NS	0.5	0.52	2.83
<i>Zinc solubilizer</i>				
Control	3.58	25.4	4.61	32.75
Zinc solubilizer	3.58	26.1	4.85	35.35
SEm±	0.30	0.1	0.13	0.87
CD (P=0.05)	NS	0.3	NS	2.49

contrast to Zn-content in kernel, the effect of S-application on Zn-uptake was significant due to improvement in kernel yield and marginal improvement in Zn-content in kernel. Increase in Zn-uptake due to 20 and 40 kg S/ha was 25.9% and 35.3% over control, respectively. Srinivasarao *et al.* (2008) reported increase in the content and uptake of Zn, B and S due to application of these nutrients to groundnut and other crops.

Effect of Zn-application on the Zn-content in kernel was significant, while it was non-significant on S-content in kernel. Due to application of 2.5, 5.0 and 7.5 kg Zn/ha, percent increase in Zn-content was 7.4, 16.6 and 28.8% over control, respectively (Table 3). This improvement in Zn-content in kernel may be attributed to more availability of Zn in the soil, which improved the uptake of Zn and thereby improvement in Zn content. Favourable effect of Zn-application on kernel yield and Zn content in kernel resulted in marked improvement in Zn-uptake in kernel, which was 29.4, 44.9 and 45.5 % due to application of 2.5, 5.0 and 7.5 kg Zn/ha over control, respectively. Effect of Zn application on S-uptake was also significant due to combined effect of marginal increase in S-content and improvement in kernel yield. With application of 2.5, 5.0 and 7.5 kg Zn/ha an increase of 17.5, 18.5 and 6.3 % in S-uptake was recorded over control, respectively. The results corroborate the finding of Chitdeshwari and Poongthai (2003) and Arunachalam *et al.*, (2012). They reported that basal application of Zn and S enhanced the soil available Zn and S content. Basal application also increased the kernel Zn and S content as well as uptake.

Effect of Zn-bio-fertilizer on S-content and uptake in kernel was not significant. Effect of Zinc-bio-fertilizer on Zn content and Zn uptake in kernel was significant. The percent increase in Zn-content was 2.7% and in uptake it was 7.9%.

Based on the study, application of 5 kg Zn/ha is recommended for groundnut in soil low in Zn. Application of Zn-bio-fertilizer found to improve the yield, but its solubilizing effect is not sufficient to replace fertilizer application of Zn. Groundnut responded to sulphur application up to 40 kg S/ha.

REFERENCES

- Arunachalam, P., Kannan, J., Prabhakaran, G., Prabukumar and Zadda, K. 2012. Response of groundnut (*Arachis hypogaea* L.) genotypes to soil fertilization of micronutrients in alfisol conditions. *Electronic Journal of Plant Breeding* 4(1): 1,043–49.
- Bhal, R. and Lodha, S. 1986. Effect of sulphur and zinc fertilizers on groundnut (*Arachis hypogaea* L.). *Agriculture Journal* 9(3): 71–78.
- Cakmak, I., Yilmaz, A., Kalayci, M., Ekiz, H., Torun, B., Erenoglu, B. and Braun, H.J. 1996. Zinc deficiency as a critical problem in wheat production in central Anatolia. *Plant and Soil* 180: 165–172.
- Chitdeshwari, T. and Poongthai, S. 2003. Yield of groundnut and its nutrient uptake as influence by zinc boron and sulphur. *Agriculture Science Digest* 23 (4): 263–66.
- Graham, R.D., Welch, R.M. and Bouis, H.E. 2001. Addressing micronutrients malnutrition through enhancing the nutrition quality of staple foods: Principles, perspectives and knowledge gaps. *Advances in Agronomy* 70: 77–142.
- Gupta, H. and Jain, L.G. 2009. Effect of sulphur on groundnut-wheat cropping system. *Agriculture Journal* 8(2): 55–62.
- Krishnasamy, S., and Malik, G.R. 1994. The influence of applied sulphur and zinc fertilizer on groundnut productivity. *Soil and Environment* 5(4): 70–75.
- Meena, S.K., Mundra, S.L. and Singh, P. 2013. Response of maize to nitrogen and zinc fertilization. *Indian Journal of Agronomy* 58(1):127–28.
- Meena, S.M., Malarkodi, P. and Senthilvalavan 2007. Secondary and micronutrients for groundnut. *Agricultural Reviews* 28(4): 210–15.
- Pandey, I.B., Singh, S.K. and Tiwari, S. 2013. Integrated nutrient management for sustaining the productivity of pigeonpea (*Cajanus cajan*) based intercropping systems under rainfed conditions. *Indian Journal of Agronomy* 58(2): 192–197.
- Piper, C.S. 1966. Soil and plant analysis. Adelaide, Australia University of Australia. Pp. 59–74.
- Prasad, R. Shivay, Y.S. and Kumar, D. 2012. Bio-fortification / ferti-fortification of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) for ameliorating zinc malnutrition of humans and animals in India. *Indian Journal of Agronomy* 57(3rd IAC Special Issue): 195–98.
- Prasad, R., Shivay, Y.S., Kumar, D. and Sharma, S.N. 2006. *Learning by doing exercises in soil fertility: A practical manual for soil fertility*, Division of Agronomy, Indian Agricultural Research Institute. New Delhi 110 012.
- Shukla, A.K. and Behera, S.K. 2011. Zinc management in Indian agriculture—past, present and future. *Indian Journal of Fertilizers* 7(10): 14–33.
- Singh, M.V. 2011. Scenario of zinc deficiency in Indian soils and its influence on zinc enrichment in crops for improving human and animal health. Presented at the 3rd International Zinc Symposium: Improving Crop Production and Human Health, Hyderabad, India, October 10–14, 2011.
- Srinivasarao, C.H., Wani, S.P. and Rego, G. 2008. Zinc, boron and sulphur deficiencies are holding back the potential of rainfed crops in semi-arid India. *International Journal of Plant Product* 2(1): 55–59.
- Takkar, P.N. and Colin, D.1989. The distribution and correction of zinc deficiency. *Zinc in Soils and Plants. Chapter* 11: 151–159.
- Tewatia, R.K., Choudhary, R.S. and Kalwe, S.P. 2006. TSI-FAI-IFA sulphur project—salient findings. (In) *Proceedings of TSI-FAI-IFA Symposium-cum-workshop on Sulphur in Balanced Fertilization*, held at New Delhi pp.15–25.
- Tathe, A.S., Patil, G. D. and Khilari, J.M. 2008. Effects of sulphur and zinc on groundnut in vertisols. *An Asian Journal of Soil Science* 3(1): 178–80.
- Welch, R.M. and Graham, R.D. 2004. Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany* 55: 353–56.