academicJournals

Vol. 8(50), pp. 6681-6688, 26 December, 2013
DOI: 10.5897/AJARx12.015
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Review

Zinc deficiency in Indian soils with special focus to enrich zinc in peanut

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Accepted 4 December, 2013

In India, zinc (Zn) is now considered as fourth most important yield limiting nutrient in agricultural crops. Zn deficiency in Indian soils is likely to increase from 49 to 63% by 2025. India is leading in groundnut acreage but behind the China in production due to less productivity. Apart from rain-dependant cultivation and mineral nutrition play a vital role in groundnut productivity. Among the nutrients, Zn deficiency cause yield loss to the maximum of 40% in groundnut. The average response of groundnut to zinc fertilization ranged from 210 to 470 kg ha^{-1}. Hence, it is ideal to follow suitable crop improvement and agronomic management strategies to enhance the uptake and availability of Zn in peanut. There are reports emerging that genetic variability exists among the peanut genotypes for zinc response and accumulation in kernel. This implies that high zinc dense confectionary peanut genotypes can be exploited for the further breeding programmes. In addition, Zn fertilization strategies viz., soil application of enriched Zn, seed coating and foliar application can be suitably adapted with available sources of Zn fertilizer to enhance Zn availability and uptake by peanut under changing climate. This article attempts to examine the status of Zn deficiency in semiarid tropics and approaches to enhance Zn content in peanut kernel through crop improvement and agronomic manipulation.

Key words: Zinc deficiency, peanut, biofortification, zinc rich genotype.

INTRODUCTION

Globally, India is leading in peanut acreage, but behind China in production due to low productivity. India's peanut average productivity is 938 kg ha^{-1}, which is far behind the most of the peanut growing countries with the highest productivity of 3540 kg ha^{-1} in USA and the world mean productivity is 1348 kg ha^{-1} (Thamaraikannan et al., 2009). The low productivity in India is mainly due to rain-dependent cultivation, poor soil fertility and mismanagement of plant nutrients especially micronutrients.

Peanut is a poorman's nut due to its high-energy, protein and minerals at a comparatively low cost, is consumed by a large number of people world-wide, and is also a rich source of micronutrients including Zn which makes the crop more important. The 100 g peanut contains 567 Kcal of energy with carbohydrate of 16.13 g, protein of 25.8 g, total fat of 49.24 g, dietary fibre of 8.5 g and Cholesterol free. Among the vitamins and minerals, peanut has high folic acid content (240 µg) and 3.27 mg of zinc, respectively (USDA National Nutrient data base). Peanut is a good source of zinc (Singh, 2007); the kernels are eaten after roasting, frying, salting or boiling and in many preparations and confectionery products. However, in India, due to low productivity the per capita availability of peanut is less, that is, 10 kg peanut per capita are available for domestic consumption. Fat and oil

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consumption averages less than 5 kg per capita per year.

Zinc deficiency severely affects growth and yield of oilseed crop. Among oilseeds, peanut in particular, suffers from Zn deficiency. As peanut is a good source of Zn, consumption of high Zn density peanut genotypes may be a solution to ensure adequate level of zinc in Indian population (Singh and Lal, 2007). Zinc is an important micronutrient, plant response to Zn deficiency occurs in terms of decrease in membrane integrity, susceptibility to heat stress, decreased synthesis of carbohydrates, cytochromes nucleotide auxin and chlorophyll. Further, Zn-containing enzymes are also inhibited, which include alcohol dehydrogenase, carbonic anhydrase, Copper-zinc superoxide dismutase, alkaline phoshatase, phosphosipase, carboxypeptidase and RNA polymerase (Marschner, 1993). Depending on the zinc level, zinc deficiency status of plants can be classified, that is less than 10 mg kg^{-1} is definite zinc deficiency and more than 20 mg kg^{-1} is sufficient Zn. This article attempts to examine critically the scanty and scattered reports available on the status of Zn deficiency in Semiarid Tropics and approaches to improve zinc use efficiency in terms of pod yield and seed zinc content in peanut.

SOIL VERSUS ZINC NUTRITION

Zinc deficiency: An India concern

In India, zinc is now considered the fourth most important yield-limiting nutrient after, nitrogen, phosphorus and potassium, respectively. Analysis of 256,000 soils and 25,000 plant samples from all over India showed that 48.5% of the soils and 44% of the plant samples were potentially zinc-deficient and that this was the most common micronutrient problem affecting crop yields in India. Deficiency of zinc has increased in Southern States due to extensive use of NPK without micronutrients. Periodic assessment of soil test data also suggests that zinc deficiency in soils of India is likely to increase from 49 to 63% by the year 2025 as most of the marginal soils brought under cultivation are showing zinc deficiency (Singh, 2006). Farming families consuming their zinc deficient crop produce leads to low zinc in their blood plasma compared to those which were fed on produce received from farms fertilized with zinc regularly. Zinc supplementation is therefore essential for maintaining high zinc content in soil, seed and blood plasma of human and animals (Singh et al., 2009).

Soil factors affecting availability of zinc

Although genotypic factors are important in determining either tolerance or susceptibility of a crop cultivar to zinc deficiency, it is soil factors which are responsible for low available zinc supply. In general, the soils most commonly associated with zinc deficiency problems in plants mainly due to the factors like neutral to alkaline in reaction, especially where the pH is above 7.4, high calcium carbonate content in topsoil or in subsoil exposed by removal of the topsoil during field leveling or by erosion, coarse texture (sandy soil) with a low organic matter status, permanently or intermittently waterlogged soil, high available phosphate status, high bicarbonate or magnesium concentrations in soil or irrigation water and acid soil of low zinc status developed on highly weathered parent material (Figure 1).

Calcareous soils with a high content of calcium carbonate (>15%) are typical soils of semi-arid and arid climates. Presence of calcium carbonate decreases the availability of zinc due to higher soil pH. The main types of salt affected soils are the saline soils (Solonchaks), sodic soils (Solonetz) and both mainly occur in arid and semi-arid regions. Saline soils contain high concentrations of soluble salts which restrict the types of crops which can be grown and reduces the availability of zinc. The poor availability of zinc caused by water logging can be due to a relatively high pH, zinc being present as the insoluble sulphide (ZnS) and elevated concentrations of ferrous, bicarbonate, and phosphate ions (Doberman and Fairhurst, 2000).

Interactions between zinc and other plant nutrients

High soil phosphate levels are one of the most common causes of zinc deficiency in crops by cations added with phosphate salts can inhibit zinc absorption from solution, H^+ ions generated by phosphate salts inhibit zinc absorption from solution and phosphorus enhances the adsorption of zinc into soil constituents. Nitrogen appears to affect the zinc status of crops by both promoting plant growth and by changing the pH of the root environment. In many soils, nitrogen is the chief factor limiting growth and yield and therefore, not surprisingly, improvements in yield have been found through positive interactions by applying nitrogen and zinc fertilizers. Several macronutrient elements, including calcium, magnesium, potassium and sodium are known to inhibit the absorption of zinc by plant.

Interactions of zinc with other micronutrients

Zinc interact with copper, iron, manganese and boron influence their concentration in plants by a) zinc-copper interactions occur due to copper and zinc sharing a common site for root absorption or copper nutrition affects the redistribution of zinc within plants, b) iron-zinc interactions study resulted increasing zinc supplies to plants have been observed to increase the iron status, to decrease it and to have no effect on it (Loneragan and

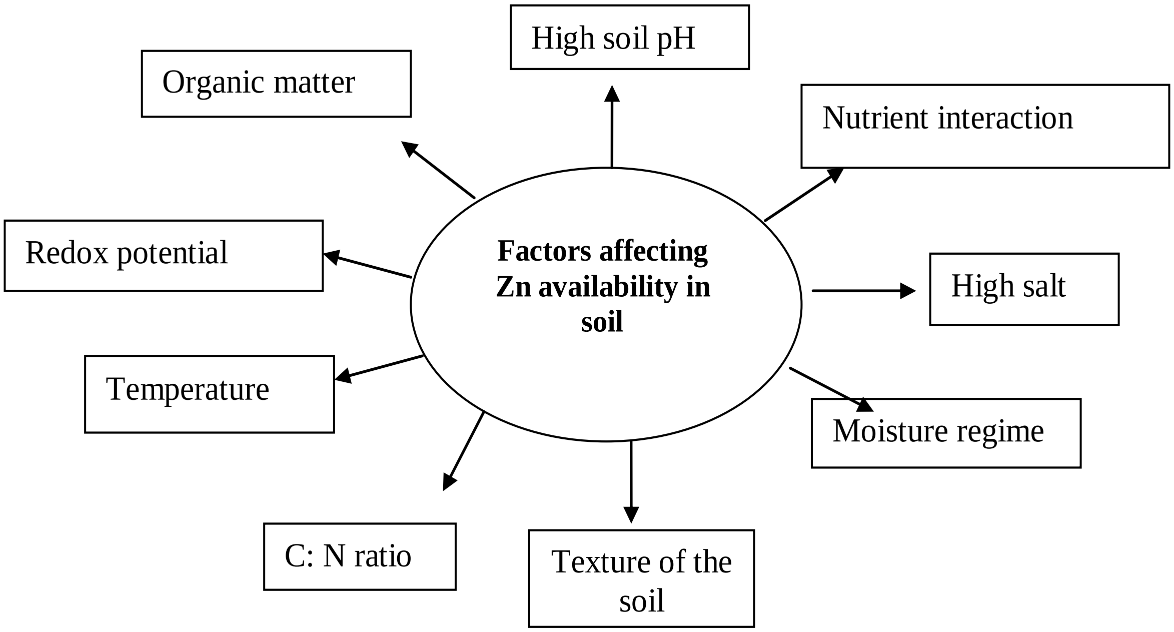

Figure 1. Important soil chemical and physical factors affecting availability of Zn to roots.

Webb, 1993). In contrary to the previous report, Zn application had adverse effect on Fe concentration and Fe uptake in plants (Imtiaz et al*.,* 2003). Mn and boron interaction resulted positive and negative response in availability in soil and uptake and distribution in the plant.

PEANUT

An Indian scenario

In India, peanut is being grown to an area of 8 million ha, production of 7.5 million tonnes, with an average productivity of 938 kg ha^{-1} during 2006 to 2007 (Thamaraikannan et al., 2009). The South West monsoon decides the fate of peanut in India, because around 75% of peanut crop grown under rainfed conditions during Kharif season (June - September). The peanut crop is mainly grown in the States of Gujarat, Tamil Nadu, Andhra Pradesh, Karnataka and Maharashtra, which accounts for 89% of area and production in India. Though Gujarat is leading in area and its production is not appreciable due to low productivity compared to other States (Figure 2).

In Central India, multi-nutrient deficiencies are widely causing poor crop yields (Singh, 2009). The yield reduction reported in peanut due to zinc deficiency is 30 to 40%. The average response of peanut to Zn ranged from 210 to 470 kg ha^{-1} (Takkar and Nayyar, 1984). An increase in energy value as well as total lipids and crude protein in peanut was registered with zinc application (Nayyar, 1990).

Zinc deficiency and its associated consequence in peanut

In India, Zn deficiency was recorded about 50% of the peanut growing soils causing considerable yield losses (Singh, 1999; Singh et al., 2004). Zinc is the one of the eight trace element needed for the normal plant growth and reproduction. Zinc is needed for peanut as a tracer and aids in the use of other trace elements by the plants. The Zn deficiency in peanut caused irregular mottling and yellow-ivory interveinal chlorosis in the upper leaves. Under severe deficiency, the entire leaflets became chlorotic. The main symptoms of zinc deficiency are decreased internodal length and restricted development of new leaves. Deficient plants accumulate reddish pigment in stems, petioles and leaf veins (Alloway, 2008). In zinc deficient soils, fertilization of Zn increase the nodulation, chlorophyll content and pod yield. ILZRO (1975) reported that deficiency causes reduced pegging but no distinct leaf symptoms. Zinc deficiency in peanuts is often associated with high soil pH, high soil calcium contents and high soil phosphorus concentrations. Chahal and Ahluwalia (1977) studied the zinc uptake at various growth stages of peanut in non-calcareous typic Torripsamment, low in available Zn. Highest amount of Zn was accumulated in shoot portion at mid-flowering stage and declined severely at 75 days of plant growth. Zinc concentration in shoot portion increased again at maturity. The maximum zinc translocation from the shoot portion to fruits occurred between 50 and 75 days growth period. Phosphorous application showed an antagonistic effect on zinc uptake. In peanut, 35 days after pod

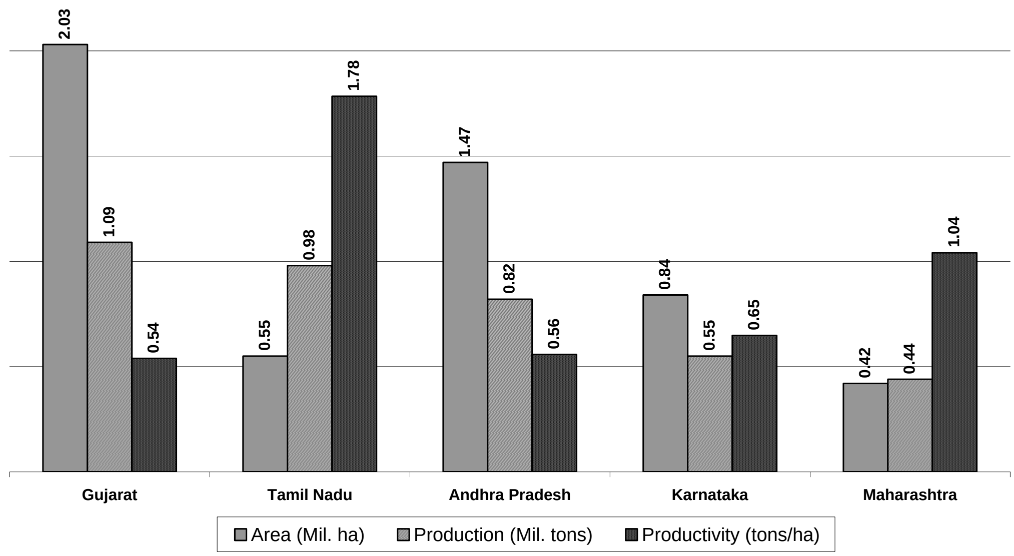

Figure 2. Area, production and productivity of major peanut producing States of India during 2006-2007.

formation is an active period for oil-filling.

The active oil-filling stage was associated with a decrease in the starch, soluble sugars and proteins so as to make available energy and carbon skeleton for the synthesis of oil. The oil content in the matured kernels was decreased by 11, 12 and 25% with Zn, S and Zn+S deficiency, respectively (Sukhija et al., 1987). The blade of the young fully expanded leaf is recommended for diagnosis of Zn deficiency in peanuts and 8-10 mg Zn/kg of drymatter is the critical value. When diagnosing the leaf sample and whole plant of peanut critical concentration is varied between 15 to 25 mg Zn kg^{-1} of drymatter (Bell et al., 1990).

STRATEGIES TO ENHANCE ZINC IN PEANUT KERNEL

Exploiting genetic variability for zinc in peanut

Selecting and breeding of food crops which are more efficient in the uptake of trace minerals from the soil and load more trace minerals into their seeds have benefits agricultural productivity and human nutrition. The micronutrient use efficiency by crop plants is genetically controlled and the physiological and molecular mechanisms of micronutrient efficiency are just beginning to understand (Khoshgoftarmanesh et al., 2010). There was limited attempts have been made in this direction peanut. Few attempts were made to exploit the inherent variability available in peanut for zinc accumulation potential in peanut.

The study conducted at Directorate of Groundnut Research, Junagath to assess the variability in zinc among the seventy peanut genotypes. The Zn concentration in seeds of peanut genotypes ranged from 11 to 77 mg kg^{-1} with a mean value of 45 mg kg^{-1}. Nineteen genotypes with more than 50 mg kg^{-1} of Zn in their seeds were categorized as high zinc-density genotypes (Lal and Singh, 2007). The genotypes recorded with maximum zinc concentrations are NRCG-4659 (77 mg kg^{-1}), PBS-14032 (76 mg kg^{-1}) and NRCG-6820 (73 mg kg^{-1}) with the pod yield of 1273 kg, 1247 kg and 1313 kg per hectare, respectively. The data of various parameters indicated that seeds from most of the high Zn-density genotypes were also rich in P, Ca and Fe, which are also required in a daily diet.

Singh et al. (2007) reported that the pod yield ranged from 857 to 1527 kg ha^{-1} in the peanut genotypes studied with GG-5 and ICGV-86590 identified as high yielding commercial peanut cultivars and good sources of zinc. Arunachalam et al. (2012) estimated the kernel zinc content in 21 peanut genotypes by basal application of 25 kg ha^{-1} of $ZnSO_4$. The variability for zinc content in peanut kernel ranges from 28.7 mg kg^{-1} (ICGV 07219) to 70.2 mg kg^{-1} (ICGV 07225) with a mean of 56.3 mg kg^{-1}. The genotypes have recorded high zinc content were ICGV 07225 (70.2 mg kg^{-1}), ICGV 07220 (69.8 mg kg^{-1}), ICGV 07222 (69.4 mg kg^{-1}), Narayani (66.4 mg kg^{-1}), ICGV 07247(65.4 mg kg^{-1}), TLG 45 (62.6 mg kg^{-1}) and JL 24 (60.6 mg kg^{-1}).

Agronomic management to enhance zinc in peanut

Zinc fertilization is also required on a regular basis on many alluvial soils and soils of peanut belt in India, and also for high yielding areas in the southern regions.

Soil application

Peanut responded with higher pod yield wherever soil application of zinc was practiced in alluvial soils. The response of peanut to zinc fertilization ranged from 210 to 470 kg ha^{-1}. Application of zinc varies with soil type and it ranged from 0.5 to 1.5 kg per hectare (Takkar and Nayyar, 1984; Takkar et al., 1989). Zinc plays as an activator of many enzymes in plants and is directly involved in the biosynthesis of growth substances like auxin which produce more cells and dry matter that in turn will be stored in seeds as a sink. Thus, the increase seed yield is more expected (Devlin and Withan, 1983).

Patil et al. (2003) observed significant increase in peanut yield by soil application of Fe and Zn along with recommended dose of fertilizer in black soils. Chitdeshwari and Poongothai (2003) reported that, the response of peanut to the soil application of zinc 5 kg ha^{-1} + boron 1 kg ha^{-1} + sulphur 40 kg ha^{-1} significantly increased the pod yield to the tune of 24.2% for TMV 7 and 14.8% for JL 24 over control. The micronutrient response of peanut studied in different States of India under rainfed conditions concluded that an application of Zn, B and S along with N+P was economical. Application of Zn through drip irrigation increased chlorophyll content, pod numbers and yield. It also increased fertilizer-use efficiency and kept the soil loose for peg penetration and pod development. The drip irrigation application was superior over the other soil and foliar Zn applications by precise application at appropriate times with desired concentration, uniform distribution, less damage to crop and soil and ultimately higher yield (Singh, 2007).

The soil application of 5, 1, 0.5 kg ha^{-1} Zn, B, and molybdenum (Mo), respectively along with NPK increased the peanut yield to 30% (Nayak et al., 2009). Muthukumararaja and Sriramachandrasekharan (2012) observed increased in yield with zinc fertilization in zinc deficient soil. The soil application of 10 kg ha^{-1} Fe and 5 kg ha^{-1} Zn was recommended by All India Coordinated Research Project on micronutrients (Singh, 2010).

The requirement and response to zinc application varies with the soil types. Application of 40 kg Zn ha^{-1} recorded high pod yield, protein content and zinc uptake by peanut, whereas application of 20 kg Zn ha^{-1} recorded the highest oil content and sulphur uptake in vertisol (Tathe et al., 2008). An application of 10 kg of zinc in swell-shrink soils, 5 kg in zinc to alluvial red and lateritic soils per hectare was found optimum in ameliorating zinc deficiency (Singh, 2008). Basal application of 25 kg ha^{-1} of $ZnSO_4$ in alfisol increased the pod yield per plant in peanut varieties *viz*., TMV 7 from 19.2 to 21.4 g, TMV (Gn) 13 from 18.4 to 22.5 g and VRI (Gn) 6 from 35.7 to 38.6 g (Arunachalam et al., 2012).

Foliar application

There are reports that positive response of peanut yield to the foliar application. But the quantum and time of zinc spray were varied in different studies. Gobarah et al. (2006) reported highest peanut seed yield, oil and protein with the application of P_2O_5 along with foliar spray of zinc. Sixty peanut cultivars were evaluated for foliar application of zinc, the 0.2% $ZnSO_4$ solution was applied on the peanut foliage, thrice at 40, 55 and 70 days after emergence at 500, 1000 and 1000 L ha^{-1}, respectively. On an average of 16% increase in the seed Zn concentration of peanut cultivars was recorded due to foliar application of Zn (Singh et al., 2007). Deficiency of Zn can also be effectively controlled with 2 to 4 spray of 0.5% zinc sulphate salt solution on standing crops (Singh, 2008). Foliar spraying of 1 g L^{-1} zinc recorded highest seed yield (2910 kg ha^{-1}) with increase in pod yield, plant height, 100 seed weight, seed length and seed width. The application of 80 kg ha^{-1} nitrogen along with zinc foliar application enhanced the seed yield to 3742 Kg ha^{-1} (Pendashtek et al., 2011).

Seed treatment and nano-coating of zinc

Seed treatment with Teprosyn Zn + P at the recommended level (8 ml kg^{-1} seed) increased the pod yield of peanut over NPK control. Seed treatment gave higher zinc use efficiency than soil application of zinc sulphate at the rate of 5.5 kg Zn ha^{-1} or two foliar spray of Zn at 30 and 45 days after flowering, also increased the peanut pod yield at similar magnitude (Singh et al., 2003).

An attempt was made by the Prasad et al. (2012) to study the effect of nanoscale zinc oxide on peanut. Peanut seeds treated with 1000 ppm ZnO showed better germination than the seeds treated with bulk $ZnSO_4$. Peanut seeds treated with nanoscale ZnO showed the maximum seedling vigour index at 1000 ppm and increased concentration of ZnO to 2000 ppm has decreased the vigour index. Nanoscale ZnO showed large root growth of seedling compared to bulk $ZnSO_4$ and control. Prasad and coworkers suggested that the growth promoting effect of nanoscale ZnO at optimum concentrations and inhibitory effect at high concentrations on root and shoot growth and pod yield in peanut. Seed treated with nanoscale ZnO enhanced the zinc level in seeds, which increased the germination, root growth, shoot growth, dry weight and pod yield. Significant zinc uptake by the leaf and kernel was observed with the foliar application of nanoscale ZnO compared to chelated zinc sulfate.

ZINC FERTILIZERS

There are different forms and source of zinc available as listed in Table 1. The solubility of several zinc minerals decreases in the following order namely Zn $(OH)_2$ (amorphous) > $Zn(OH)_2$ > $ZnCO_3$ (smithsonite) > ZnO

Table 1. Commonly used zinc fertilizers.

Compound	Formula	Zn content (%)
Inorganic zinc fertilizers		
Zinc sulphate monohydrate	$ZnSO_4.\ H_2O$	36
Zinc sulphate heptahydrate	$ZnSO_4.7H_2O$	22
Zinc oxysulphate	$ZnSO_4\ x ZnO$	20-50
Basic zinc sulphate	$ZnSO_4.4Zn(OH)_2$	55
Ammoniated zinc sulphate	$Zn(NH_3)4SO_4$	10
Zinc oxide	ZnO	50-80
Zinc carbonate	$ZnCO_3$	50-56
Zinc chloride	$ZnCl_2$	50
Zinc nitrate	$Zn(NO_3)_2.3H_2O$	23
Chelated zinc fertilizers		
Disodium zinc EDTA	Na_2Zn EDTA	8-14
Sodium zinc EDTA	NaZn EDTA	9-13
Sodium zinc HEDTA	NaZnH EDTA	6-10
Zinc polyflavonoid	-	5-10
Zinc lignosulphonate	-	5-8

(zincite) > Zn $(PO_4)_2.4H_2O$) (willemite) > soil Zn > Zn Fe_2O_4 (franklinite). All of the Zn $(OH)_2$ minerals, ZnO and $ZnCO_3$ are about 105 times more soluble than soil zinc (adsorbed to solid surfaces) and would therefore makes highly suitable fertilizer sources of zinc.

Zinc forms soluble complexes with chloride, phosphate, nitrate and sulphate ions, but the neutral sulphate ($ZnSO_4$) and phosphate ($ZnHPO_4$) species are the most important and contribute to the total concentration of zinc in solution. The $ZnSO_4$ complex may increase the solubility of Zn^{2+} in soils and accounts for the increased availability of zinc when acidifying fertilisers, such as ammonium sulphate [(NH_4 $(SO_4)_2$)] are used.

The soil and seed application of $ZnCl_2$ and $ZnSO_4$ showed a positive response with germination, pod number, pod yield and oil content. However, both fertilizers were detrimental to peanut seedlings when applied as seed dressing (Singh, 2007). Application FYM enriched Zn observed improvement in the available zinc status of deficient soils is probably the result of an increase in soluble, organically-complexed forms of zinc. Low molecular weight organic acids namely, humic acid and fulvic acid form soluble complexes with zinc and contribute to the total soluble concentration in a soil. Barrow (1993) reported that organic ligands reduced the amounts of zinc adsorbed in soil and the effect was most pronounced with those ligands, including humic acids which complexed zinc most strongly. Soluble forms of organically-complexed zinc can result in zinc becoming increasingly mobile and plant available in soils.

In many cases, complexation of organic zinc with organic ligands will result in decreased adsorption onto mineral surfaces. Enriching the $ZnSO_4$ with organic sources such as farmyard manure, composted coirpith and poultry manure atleast 20 to 30 days. Application of enriched $ZnSO_4$ as a basal was found to be economically viable and sustainable. In case of severe deficiency of zinc foliar application of $ZnSO_4$ at 0.2 to 0.5% is recommended to temporarily arrest the deficiency.

CONCERNS AND FUTURE DIRECTIONS

Soil and foliar application of zinc meet out only 30 to 40% of zinc requirement of crop plants while the remainder gets absorbed in clay colloids and become immobile and some parts may goes out to the environment due to soil and edaphic factors. As only a small quantum of applied zinc is utilized by the crop plants. To enhance zinc uptake by plants and to increase the seed zinc concentration are depends on use of zinc responsive peanut varieties along with better agronomic management. These kinds of approaches are economic way to combat zinc malnutrition especially developing country like India. To reduce zinc malnutrition, the crop fortification is important aspect which not only enhances the zinc content in kernel and also increases the productivity of peanut. The future strategies to be adopted for enhancing the zinc in peanut kernels are narrated below:

i) Screening programme to explore the inherent genetic variability in peanut for zinc both in kernel and foliage, since the fodder is also very much desired. This would enable peanut genotypes to be matched to soils and reduce the requirement for zinc fertilizers. List of peanut varieties which are highly susceptible to zinc deficiency would also be useful for farmers and extension workers so that they can be extra vigilant with those most at risk of deficiency. Zinc efficient confectionary type peanut strains could be used in breeding programmes to develop high dense zinc varieties to grow in areas where people are affected by zinc deficiency,

ii) Studying the solublization and mobilization of zinc in soil and interaction with other nutrients in various types of soils are essential for the precise recommendation and use of zinc. The majority of peanut crop is grown under rain-fed conditions. Hence, there is a need to develop the comprehensive nutrient management practices to be developed by taking into account of macro, micro and soil amendment (gypsum) requirement of peanut. Development of easy and economic, field-based biochemical test kits for assessing the zinc status of crops without relying on analytical laboratories is a key in the efficient use of zinc in agriculture near future,

iii) The peanut is a zinc responsive crop, but most of the peanut growing soils are deficient in zinc that fails to support the zinc dense cultivars. Hence, GIS/remote sensing strategy may be used to delineate the zinc deficient peanut area for site specific recommendation,

iv) Better understanding of molecular and physiological mechanisms of zinc uptake, mobility and partitioning in peanut is required to design the suitable source, method of application and the stage of application. Investigation is needed on plant anatomical and rhizosphere changes responsible for the variability in absorption, translocation and uptake of zinc in peanut,

v) Creating mass awareness about zinc nutrient application in peanut or food crops, prioritization of government policy for emphasizing micro-nutrient usage in agriculture is very much desired.

At last to enrich micronutrient in food crops, the collaborative multidisciplinary research involving soil scientists, agronomists, plant breeders, human nutritionists and food technologists on the bio-fortification with zinc in a form which is bio-available to consumers is need of the hour. Further, the positive approach of government in their policies to enhance the micro-nutrients in stable food crops and their use in regular foods are very much desired to address the hidden hunger problem.

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