Review Article

Zinc Use and Management of Oilseed Crops: An Overall Review

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Abstract

Zinc deficiency in soil is leading to low productivity in oilseed crops. Low productivity mainly due to sub-optimal or imbalance application of fertilizers, cultivation on marginal lands. As Zinc plays a key role in regulatory cofactors of different enzymes and protein in many biochemical pathways it can help in high productivity in oilseed crops. Zn deficiency is expected to increase from 42 % in 1970 to 63 % by 2025 due to continuous depletion of soil fertility (Singh, 2011). So, zinc supplying capacity through foliar or soil application to oilseed crops needs to be strengthened. And also need to long term studies on residual zinc in oilseed crop production.

Keywords: Zinc deficiency, Oilseed crop, High productivity

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Introduction

Oilseed crops are mainly cultivated under rainfed condition in India. Low average productivity of oilseed crops because of it cultivated in marginal to low fertility soils. More than 30 percent of agricultural soils globally are low in available Zn leading to deficiency in crops and productivity (Alloway, 2000). Therefore causing malnutrition among the resource poor people (Singh, 2011). So need to increase average productivity levels from the present 968 kgha^{-1} to 1450 kgha^{-1} by 2025 to meet the increasing demand for oilseeds.

In Indian soils, Zn deficiency is expected to increased from 42 percent in 1970 to 63 percent by 2025 due to continuous depletion of soil fertility (Singh, 2011). In Odisha, Jena *et al*. (2008) reported that the soils of Odisha mainly deficient in Zn and B. Zinc content in soils of Odisha ranged from 0.24 to 2.08 mg kg^{-1} with a mean of 1.10 mg kg^{-1}. Zinc deficiency ranged from 0 to 76 percent with a mean value of 19 percent. The deficiency of zinc ranged from7.0 to 76.0 percent in alluvial, 2 to 12 percent in laterite and 42 percent in black soils. Sahu and Mitra (1992) reported that black, mixed black and red and alluvial soils appear to be more deficient in zinc than others. Zn deficiency attributed to the precipitation of Zn as hydroxide, Carbonate and sulphide and its adsorption on the surface of freshly formed oxides of Fe having largest surface area. Zn supplying capacity of rice soils decreased with increased in clay and silt content (Pal *et al* 1997; 2002). Further Pal *et al*. (1997) reported that the solubility of Zn in soils from different Zn bearing minerals namely, Sphalerite (ZnS), Smithsonite ($ZnCO_3$) and Hemimorphite [Zn_4 (OH_2) SiO7.H2O] affect the availability of Zn to plants. Total Zn content in Laterite soils (Haplustalfs) ranged from 157 -231 mg kg^{-1} and fractionate into water soluble plus exchangeable (WSEX-Zn) contribute only 0.19 percent of total Zn, organic complex (OC-Zn) contribute 2 percent, amorphous sesquioxide (AMOX-Zn) contribute 1.6 percent, crystalline sesquioxide (CRYOX-Zn) contribute 3.2 percent and rest are residual zinc.

Oilseed crops account nearly 3 percent of gross domestic product and 5.98 percent of value of all agricultural products in India. India occupies 12 -15 percent of oilseed area globally and 6-7 percent of vegetable oil production, 9-10 percent of total edible oils consumption and 13.6 percent of vegetable oil imports (Varaprasad *et al*. 2011). Generally seven edible oilseed crops, viz. Groundnut (Arachishypogaea), mustard (Brassica Juncea L), Soyabean (Glycine), Sunflower (Helianthus annus), Safflower (CarthamusTinctorius), Sesame (Seasamum indicum) and niger (Guizotiaabyssinica) and two non-edible oilseed crops, Viz. Castor (Ricinuscommunis) and linseed (Linumusitatissimum) are grown. In India oilseed crops are cultivated on 26.7 million ha with productivity of 1087 kgha^{-1} for ending 2012-13. In Odisha, oilseed crops covered 7.524 lakh ha and the productivity is 928 kgha^{-1}. Among the oilseed crops, mustard occupied 19 percent of total oilseed area and 45.6 percent of total oilseed productivity (Odisha Agriculture Statistics, 2013-14).

The productivity of oilseed is far below that of developing countries (2.5 – 3.0 t ha^{-1}) and world average (1.9 t ha^{-1}). Low productivity mainly due to sub-optimal or imbalance application of fertilizers, cultivation on marginal lands and under rainfed condition (Tripathi *et al*. 2010). So there is a big gap between requirement and production of mustard in our country or low productivity may be due to continuous mining of nutrients from the soil by oilseed crops (SudhakaraBabu and Hegde, 2011). Hence there is an urgent need of enhancing the zinc use and soil-crop-zinc fertilization management for increasing the oilseed crop productivity.

Role of zinc in crop production

Zinc plays a key role in structural or regulatory cofactors of different enzymes and protein in many biochemical pathways like carbohydrate metabolism, photosynthesis, conversion of sugar to starch, protein metabolism, auxin (growth regulator)metabolism, Pollen formation, integrity of biological membranes and resistance to infection by certain pathogens (Alloway,2000). Micronutrients are involved in the key physiological process of photosynthesis and respiration (Marschner, 2002). However, micronutrient deficiency can result in great deal of limitation in the physiological and metabolic processes even if plants need only small amount of micronutrient for satisfactory crop growth and production (Nasiri *et al*. 2010). Zinc deficiency leads to delay in flowering and fruit development, prolonged growth period causes low quality of yield and nutrient use efficiency. Zinc is not readily translocated from old to new tissues. During Zinc shortage, the deficiency symptoms usually appear on the recent new growth. Erenogin *et al*. (2002) reported that the deficiency symptom mostly appear on the second or third fully matured leaves from the top of the plant.

Zinc deficiency symptom in oilseed crops in India

Zinc deficiency symptom in many plants appears in four week old plant on older and emerging leaves. These are light green yellow or bleached spots in interveinal area of older leaves. The emerging leaves become smaller in size and often termed as ‘little leaf’ During severe deficiency intermodal distance become too short so it appears that it come out from the same point, which is termed as ‘rosetting’. The interveinal area of sub terminal leaves develop light brown necrotic patches in Indian mustard whereas in sunflower and sesame, the deficiency symptoms first appear on middle leaves as it losses green color, followed by development of brown spots in between veins. Plants are stunted and produce small thin grains. Zn deficiency aggravated in increasing drought spell or salinity (Bagci *et al*. 2007). These abiotic stresses/adverse soil conditions lead to impeded growth of plants and slow root activity, resulting in an inhibited spatial availability of Zn. In Semi-arid zone soils of India, low available Zn besides the other essential nutrients for oilseed crops reported. Extractable DTPA- Zn was most revealing and showed that 62-94% of the farmer’s field were deficient in Zinc (Rego *et al*. 2007; Srinivas Rao ch. *et al*. 2009). In Jhunjhunu tehsil of Rajasthan, 70% soils were found deficient in Zn and their value ranged from 0.12 to 1.30 mg kg^{-1} (Kumar and Babel, 2011). zinc deficiency is widespread in most oilseed growing states in India like MP, Rajasthan, Maharastra, Gujrat, AP, Karnataka and UP. The percentage of farmers’ field testing low in zinc ranged from 46% in Rajasthan to 85% in Gujrat (**Table 1**). Soil maps were prepared showing soil nutrients status including Zn for 15 dryland districts of Karnataka (Sahrawat *et al*., 2011).

Table 1 Soil Test results of Farmers field in different states of India (Kumar and Babel, 2011; Sahrawat *et al*., 2011)

States	**District**	**No. of Farmers field**	**% classes as low**	
			Oc	**Av.Zn**
Karnataka	16	33200	66	57
Andra Pradesh	11	3650	76	69
Rajasthan	9	421	38	46
Madhya Pradesh	12	341	22	66
Tamilnadu	5	119	57	61
Gujrat	1	82	12	85

Pal and Jena (2012) developed nutrient maps of micronutrients by using GIS and GPS, based on Farmers field data and delineate the deficient areas of Odisha. They found that the zinc status varied from 0.01 to 32.77 mg kg^{-1} and the deficiency is increased to 32 percent. Considering the different Agro-climatic region of Odisha, the deficiency is in the following orders: South Eastern Ghat> Eastern Ghat highland > North Eastern Coastal Plain> North Eastern Plain = North Central Plateau > Mid Central Table land > North Eastern Ghat> West Central Table land > East and South Eastern Coastal Plain > Western undulating zone.

Critical levels of zinc in soil and plant

To delineate the zinc responsive soils for oilseed crops, 0.75gkg^{-1} was considered critical DTPA-Zn level for semi-arid tropical soils (Rego*et al*. 2007). Critical level of DTPA –extractable zinc. In most of the Indian soils was taken 0.6 mgkg^{-1} in general (Murthy, 2011). Genotypic difference, Crop age and plant part have a significant role in establishing critical limit for crops. The sufficiency levels of Zn in oilseed crops, viz. Ground nut, mustard and soyabean was found to be > 22 mgkg^{-1}, 34-200 mgkg^{-1} and 21-50mgkg^{-1}, respectively (Jones *et al*. 1991). The common recommendation of Zn as ZnSO4 alongwith recommended N,P,K and organic manure for different oilseed crops in different states used the critical limit(mgkg^{-1}) as stated in **Table 2** (Shukla *et al*. 2012).

Table 2 Statewise recommendation of Zinc in oilseed crops (Shukla *et al*. 2012)

State	**Crops**	**Critical limit (mgkg^{-1})**	**Dose and method of application**
Andra Pradesh	Groundnut, Cotton, sunflower, Castor	0.6	Basal application Zn@5 kgha^{-1}
Bihar & Jharkhand	Oilseed crops	0.78	Basal application or foliar spray of $ZnSO_4$alongwith 0.25% lime 2-3 times at weekly interval is sufficient if symptoms appears in standing crop
Gujrat	Ground nut-wheat	0.5	Apply 5 kg Znha^{-1}in G nut on light textured soils of middle & north Gujrat
Odisha	Groundnut, mustard, sesame	0.6	Soil application of Zn@2.5 kgha^{-1} + 200kg FYM for medium land lateritic and upland alluvial soils
Punjab & Haryana	Groundnut	0.6	Basal application of 2.5 kg Znha^{-1} to each crop
Tamilnadu	Groundnut, sunflower, Rice-Groundnut-gingelly	1.2	Basal application of 5kgZnha^{-1} in Zn deficient red sandy loam or clayey loam soil in alternate year
UP & Uttarkhand	Mustard, Toria, Ground nut	1.0	Apply 7.5kg Znha^{-1} once in three years, before planting in loamy sand, slightly alkaline & low OC content soils of UP region. In loamy texture, neutral soil reaction with high OC soils of Tarai region, apply 5kg Znha^{-1} before sowing in alternate year If missed, foliar spray of 0.5% ZnSO4(20-21%Zn)+1% urea solution on the standing crop at 30 and 45 DAS is useful to mitigate Zn deficiency in mustard and Toria. In alkaline sandy loam soils of western UP plain, apply 5kgZnha^{-1} as basal before sowing or seed treatment with 8ml Teprosyn –Znkg^{-1} groundnut seed. or foliar spray of 0.5% ZnSO4+0.25% lime at 30 and 45 d after emergence is recommended.

Zinc uptake by crops

Zinc is absorbed as Zn+2 from soil solution through roots. The amount of Zn absorbed depends on soil condition, Crop, variety and yield level. Intensive cropping system depletes soil zinc more due to higher production. The amount of Zn absorbed varies with the oilseed based cropping systems and ranged from 242 to 504 g ha^{-1} year-1 (Sakal*et al*. 1996). The utilization of applied Zn by crops was found to be <0.5 % (Prasad, 2006). Based on on-farm trials in A. P. Rego*et al*. (2007) reported that the average zinc uptake /ton grain production in case of ground nut is 102 g. Shukla and Behera (2011) reported that on an average, one ton of oilseed yield leads to 45- 150 g. uptake of Zn (**Table 3**). Genotypic difference of oilseed crops had varied distribution pattern of Zn in seed and stover. Zn percent uptake by seed portion in various oilseed crops follows the order: Linseed >Soyabean> Mustard > Sunflower > groundnut.

Table 3 Average zinc (Zn) uptake by oilseed crops (Shukla and Behera, 2011)

Crops	**No. of Experiments**	**Average uptake (g/ton produce)**
Soyabean	25	77
Groundnut	20	120

Mustard	12	95
Sunflower	15	50
Sesame	10	150
Linseed	8	45

Oilseed crops tolerant and sensitive to Zn stress

Genotypes of oilseed crops vary in their magnitude of response to Zn. This variability among genotypes in Zn can be explained for optimizing crop production under fertilizer/ resource constraint. Yield may vary due to different genotypes in the same soil. Fitting of soil environment for different oilseed crops are difficult and not practicable than tailoring the crop and their cultivars to suit the adverse soil conditions. Tolerance to Zn deficient soils, as a genetic trait, is usually called Zn efficiency and defined as the ability of a genotype to grow and yield well and soils deficient in Zn for a standard genotypes. Grewal *et al*. (1997) conducted a pot culture experiment and revealed that considerable genotypic variation exist in oilseed rape for Zn efficiency, and therefore, to tolerance in Zn deficient soil. Root dry matter accumulation and retranslocation from root to shoot were higher in efficient genotypes which may be either the cause or result of Zn efficiency and seems to be genetic control over Zn concentration in tissue: Efficient genotypes had low Zn concentration in roots but higher Zn concentration in youngest fully opened leaf blades; Zn uptake by shoot was also higher in efficient genotypes and appear to be related to expression of the zinc deficiency trait. Similarly, promising and recommended genotypes of groundnut, soybean and brown mustard were screened in pot culture experiment for their relative tolerance to Zn stress (Tandon, 1995) and most Zn efficient and susceptible genotypes were identified. The susceptibility or tolerance of a genotype may be related to the exploring capacity of roots for nutrients. The tolerance cultivar of groundnut MH- 2 had higher Zn content than susceptible cultivars. Thus genetic potential of crop varieties to withstand Zn stress can be used for breeding crop cultivars, which may perform well without Zinc application.

Response of zinc on oilseed crop yield,quality and economics

Spectacular response in Zn application has been reported in oilseed crops viz. groundnut, mustard, Raya, gobisarson, toria, soybean, sunflower, sesame, sunflower, castor and linseed crops across the country. Critical analysis are made by compiling data of AICRP-MNS and Shukla *et al*. (2012) reported that the average response of oilseed crops to Zn was 0.11 to 0.36 t ha^{-1} (**Table 4**) which signifies the necessity of Zn application for obtaining higher yield.

Table 4 Response of oilseed crops to Zn fertilization in India (Shukla *et al*. 2012)

Crops	**No. of experiments**	**Range of response (t ha^{-1})**	**Average response (t ha^{-1})**
Ground nut	83	0.21- 0.47	0.32
Soybean	12	0.16- 0.39	0.36
Mustard	11	0.14- 0.26	0.27
Linseed	5	0.15- 0.20	0.16
Sunflower	8	0.15- 0.20	0.24
Sesame	6	0.08- 0.15	0.11

In Odisha, several field experiments were conducted on oilseed crops in AICRP on Micro and secondary nutrient and Pollutants, Bhubaneswar. Pal *et al* (2012) reported that the oilseed crops like ground nut, mustard and sesame responded to Zn application by producing an average yield response of 3.25, 2.57 and 1.31q ha^{-1} with a benefit: cost ratio of Rs.5.6 to 15.3:1 (**Table 5**). Further study under frontline demonstration (FLD), it was observed that the yield of groundnut increased with level of Zn applied upto5 $kgha^{-1}$ through $ZnSO_4$ in red and alluvial soil whereas mustard and sesame responded up to 2.5kg $Znha^{-1}$. The combined application of 2.5 $kgZnha^{-1}$ with FYM @ 200 kg oilseed crops ha^{-1} the response over control was in the order of Mustard> Groundnut > Sesame ie. 2.57, 1.98 and 0.57 qha^{-1} (**Table 5**).

Aulakha *et al*. (1985) found that the yield of various oilseed crops and their uptake of zinc (**Table 6**). The yield of different oilseed crops varied from 600 to 2500 $kgha^{-1}$ and the total uptake of Zn varied from 28 to 208 g ha^{-1}, respectively.

Table 5 Response of crops to Zn application under field condition (Pal *et al.* 2012)

Crops	**Range of response (qha^{-1})**	**Average response (qha^{-1})**	**Response over control(qha^{-1})**	**B:C**

Groundnut	1.98- 5.0	3.25	1.98	15.3:1
Mustard	2.57	2.57	2.57	14.4:1
Sesame	1.05- 1.57	1.31	0.57	5.6:1

Table 6 Yield (kgha^{-1}) and uptake (g ha^{-1}) of zinc in different oilseed crops (Aulakha *et al*. 1985)

Crops	Yield (kgha^{-1})	Zn uptake (g ha^{-1})
Soybean	2500	196
Grounnut	1900	208
Mustard	1500	154
Sunflower	600	28
Linseed	1600	73
Sesame	1200	201

Suresh *et al*. (2013) studies on zinc use and its management in oilseed crops and found that the application of customized fertilizer (CF) and S-B-Zn sources to oilseed crops showed promising. Adopting suitable integrated nutrient management (INM) practices with balance application of all the necessary nutrients including Zn resulted higher oilseed productivity.

Groundnut

In Zn deficient soils, application of Zn increased the nodulation, chlorophyll content and pod yield. After sowing if irrigation is ceased for 30 days, there is drastic reduction in Zn level ie. 13.5 to 10.1 kgha^{-1} in ground nut pod yield in upper Krisha Project area (Halepyati and Karnataka, 2001).

Chaube *et al*. (2002) reported that soil application of ZnSO4 @ 25 kgha^{-1} recorded significantly higher pod Yield (3888 kgha^{-1}), haulm yield (5218 kgha^{-1}) and seed yield (2512 kgha^{-1}) of ground nut as compared to control. Application of Zn and B through foliar spray resulted higher pod and haulm yield, seed weight and shelling percentage compared to soil application. Soil application of ZnSO4 at 20kgha^{-1} + borax 0.5 kgha^{-1} recorded 28 % increase in yield over NPK alone (Shankar *et al*. 2003). Jadhao *et al*. (2004) found that combined application of 30 kg Sha^{-1} +7.5 kg Znha^{-1} showed a significant higher oil content (48.3%) ground nut kernel cv. JL-27. Application of ZnSO4 @ 5 kgha^{-1} + $FeSO_4$ @ 10 kgha^{-1} + boron @ 1 kgha^{-1} along-with recommended dose of NPK showed significant higher pod yield, oil content and seed quality (Janakiraman *et al*., 2005). Field experiments were conducted at Chiplima, Odisha from 2003 to 2005 under AICRP - MNS, Bhubaneswar. The pool data revealed that due to absence of Zn, the pod yield was decreased by 9.8% over Zn+ B+ Mo+ Cu along with NPK. Farmer's field trials were also conducted at two location of Odisha on oilseed crops, the integrated effect of Zn on different oilseed crops were shown in **Table 7**. The results showed that the application of Zn @ 2.5 kgha^{-1} yielded 7.8% over control whereas with combination of FYM @ 200 kgha^{-1} gave better groundnut pod yield i.e. 17.3% over control.

Table 7 Integrated effect of Zn on yield (qha^{-1}) of different oilseed crops (AICRP- MNS, 2005)

Treatment	Groundnut	% Increase	Mustard	% Increase	Sesame	% Increase
Control	11.42	-	9.41	-	6.60	-
Zn 2.5kg/ha	12.31	7.8	11.61	23.4	6.70	1.5
Zn 5kg/ha	12.58	10.1	10.36	10.1	6.80	3.0
FYM100kg/ha+2.5kgZn/ha	13.05	14.3	11.50	22.2	6.80	3.0
FYM100kg/ha+5kgZn/ha	12.70	11.2	10.98	16.7	6.97	5.6
FYM200kg/ ha+2.5kgZn/ha	13.40	17.3	11.98	27.3	7.17	8.6
FYM100kg/ha+5kgZn/ha	12.82	12.3	11.36	20.7	6.9	4.5

Tathe *et al*. (2008) conducted a pot culture experiment In Vertisols and found that the application of 40kg Znha^{-1} recorded significantly higher pod yield, oil content, protein content and Zn uptake by ground nut. Application of Fe and Zn to groundnut with recommended dose of fertilizer (RDF) at 25.5 kg N and P ha^{-1} significantly higher dry pod yield (1992 kgha^{-1}), seed yield (1418 kgha^{-1}), haulm Yield (4765 kgha^{-1}) and maximum oil yield (663 kgha^{-1}) was obtained. (Thakur *et al*. 2010). Mean response of groundnut to Zn application varied from 210 to 470 kgha^{-1} in different agro-climatic regions of the country. So to enhance the productivity in Zn deficient crops, optimum Zn application is necessary. Application of 5 kg Znha^{-1} was significantly increase N uptake (41.52 kgha^{-1}) but not P and K uptake at all the stage of groundnut growth (Jadhao *et al*. 2004).

Mustard

Generally, mustard is sensitive to Zn and B deficiency. Grewal *et al*. (1997) observed that when low Zn seed type and high Zn seed types were sown in Zn deficient soil, the high types had better vigor, increase root and shoot growth, more leaf area and chlorophyll concentration in fresh leaf, and higher Zn uptake in shoot compared to those of low Zn seed types in rape genotypes. Maximum mustard seed yield was recorded in ZnSO4 @ 40 kgha^{-1} with three irrigation (Upadhyay *et al*. 2000). Application of Zn @ 5 and 10 kgha^{-1} on Cv. Varuna, the seed yield response was 300 to 500 kgha^{-1} and 450 to 700 kgha^{-1}, respectively. Zn uptake was found to be increased with increasing levels of Zn in calcareous, alkaline sandy loam to silty clay loam textured soils. The Zn uptake was 63 and 103 percent over no Zn (Sakal *et al*., 1996).

Meena *et al*. (2006) reported that the combined application of S, Zn and Fe in loamy sand soil increased the seed and stover yield of mustard. further observed the positive and significant relationship of S and Zn on S availability in soil. Subhash and Yadav (2007) found that combined application of S and Zn resulted in increase in growth, yield and quality of mustard as well as net return of mustard. Application of 40 Kg S ha^{-1} combined with 5 kg Znha^{-1} significantly increased the seed yield, oil content and yield of mustard (verma *et al*., 2007). The response of Indian mustard varieties, viz. Pusa Bold and Vardan to applied Zn was higher as compared to Varuna, RH-30 and Aravali (AICRP-RM,2000). Farmers field trials at two location of agro climatic zone of Odisha on mustard (**Table 7**), found that the application of Zn @ 2.5 kgha^{-1} yielded 23.4% seed yield increase over control whereas further addition of FYM @ 200 kgha^{-1}, the yield was increased 27.3% over control (AICRP- MNS,2005). Bell *et al*. (2007) studies on response of transplanted oilseed rape to Zn placement and root pruning and found that in post-transplanting, the Zn uptake in oilseed rape seedlings was reduced either by placement of Zn fertilizer close to root or minimizing root damage during transplanting. The effect of B, Mo and Zn on seed yield of rape seed and their interaction was studied by Yang *et al*. (2009) and found that the combined application of Zn and B resulted higher seed yield than application alone and also influenced the quality. Patel *et al*. (2010) conducted a experiment on multi micro nutrient mixture on mustard in sandy loam soils of north Gujrat and found that a significant increase in yield attributes, uptake and seed yield (1982 kgha^{-1}) with the application of 1.5 kg FeSO4 + 8 kg ZnSO4 based on soil test value. The zinc application in mustard may be attributed to various enzymatic reactions, growth processes, hormone production and protein synthesis and also the translocation of photosynthate to seed leading to higher yield of mustard (Bhadauria *et al*., 2012). Singh *et al*. (2012) found that the application of S @40 kgha^{-1} with Zn @6 kgha^{-1} increase the number of silique/plant, seed/silique, seed and stover yield and oil content of mustard. The application of 10 kg Znha^{-1} and 1 kg B ha^{-1} significantly increased seed yield, oil yield, protein content and nutrient content of mustard (Verma *et al*., 2012). Baudh and Prasad (2012) reported that combined application of S and Zn along with organic manures highly influenced the root length, no. of leaf /plant, no. of branches/plant, no. of capsule, seed output of the mustard. The productivity capacity and grain biological yield of mustard was also increased with increasing levels of nutrients. The highest benefit cost ratio (1.68:1) was obtained when 40 kg Sha^{-1} and 7.5 kg Znha^{-1} was applied on mustard (Dubey *et al*., 2013). Kumar *et al*. (2014) reported that the application of Fe and Zn resulted greater accumulation of carbohydrate, protein and their translocation to the productive organs, growth and yield attributing characters, resulting more grain, stover and biomass yield of mustard as well as nutrient uptake. The effect of N and Zn on the growth, yield and quality of oil in Indian mustard was studied by Vineet *et al*. (2016) and found that the application of 100 kg N along with 5 kg Znha^{-1} appeared to be more promising to boost the productivity of mustard (Brassica Juncea L.) and its oil quality. The higher seed yield of mustard was obtained under rainfed condition of Chitrakoot when combined application of 25 kg S ha^{-1} and 5 kg Znha^{-1} was applied to mustard (Misra *et al*., 2016). Sipai *et al*.(2017) found that the application of S @ 40 kgha^{-1} in conjunction with Zn @ 5 kgha^{-1} in presence of FYM @ 10 t ha^{-1} increased the yield, content and uptake of mustard (Brassica Juncea L.) grown in light textured soils of Kachchh. The maximum economic benefit was obtained along with highest B: C ratio of 4.84:1. Kour *et al*. (2017) conducted a field experiment on mustard in subtropical Inceptisols of Jammu region and found that highest grain and stover yield of mustard was recorded with combined application of 10 kg Zn + 2 kg B ha^{-1} along with RDF of NPK. The oil content was also increased. Shoja *et al*. (2018) found that the application of Zn, B and S along with NPK increased the yield and yield component of rape seed. The fatty acid components of rapeseed are influenced by these nutrients and the quality of edible oil depends on unsaturated fatty acid eg. Especially linoleic and linolenicacids which is supplied through diet. The highest B: C ratio of 2.6:1 was obtained in mustard by the application of 40 kg S ha^{-1} + Zn 5 kgha^{-1} + FYM 5 tha^{-1}along with recommended dose of NPK (Kumar *et al*.,2018). Rana *et al*. (2018) conducted an experiment under rainfed condition on mustard and found that seed and stover yield as well as uptake of nutrients increased significantly up to application of 45 kg S ha^{-1} and 5 kg Znha^{-1}. Nayak *et al*. (2020) conducted a pot culture experiment in Inceptisols of Bhubaneswar and found that the application of 60 kg S ha^{-1} + 2.5 kg $Znha^{-1}$ along-with FYM 10 t ha^{-1} increased the seed and stover yield as well as uptake of nutrients by mustard.

Soybean

Soybean (Glycine max L.) belongs to family Fabaceae. India ranks fifth after USA, Brasil, Argentina and China in production (FAO STAT). Rathore *et al*. (1995) reported that the application of Zn @ 5.5 $kgha^{-1}$ to soybean gave a significant higher yield of 390 $kgha^{-1}$ in black soil. In highly Zn deficient soils of Pantnagar, application of Zn @ 10 $kgha^{-1}$ increased soybean yield by more than 50% (Saxena and Chandel, 1997). Soybean (cv. JS 335) seed yield was significantly higher (25.9 qha^{-1}) at highest level of Zn than control (21.0 qha^{-1}). Further, significantly higher oil content (20.1 %) and test weight (11.3 g) was recorded at as high level of Zn application (Hubar and Kurdiken, 2000). Application of Zn (ZnO) and S as gypsum at increased levels on soybean (cv. PKV-1) significantly increased the protein and oil content of grain over control. High protein (37.25 %) and oil content (20.42%) were noted with application of 3 kg $Znha^{-1}$, while 40 kg S ha^{-1} gave the highest protein content (37.25%) and oil content (21.29%) in soybean seed (Sonuna *et al*., 2001).

The effect of P, phosphate solubilizing microbes (PSM) and Zn on yield of soybean invertisols of Chattisgarh revealed that the application of ZnSO4 improved the grain yield up to low P level (30 kg $P2O5ha^{-1}$) over no P but grain yield was decreased with 60 kg P2O5 ha^{-1} and PSM. Maximum percent Increase in grain yield of soybean over control was recorded under 60 kg P2O5 ha^{-1} + PSM (47.8%) followed by 30 kg P2O5+PSM+25 kg ZnSO4 ha^{-1}. Maximum impact of PSM and ZnSO4 (22.9%) was observed with no P. Highest levels of Zn application were not much effective at the lower levels either through ZnSO4 or ZnO. Decreased uptake of Fe by soybean could be ascribed to the antagonistic relation of Zn with Fe. On station experiments were conducted to evaluate the application strategy of Zn at International Crop Research institute for semi-Arid Tropics (ICRISAT), Patancheru, maximum productivity increase and net benefit were realized with 50% Zn+ B+S applied every year for soybean which was a more effective fertilizer management strategy than application full dose once in 2 or 3 years (Chander *et al*., 2011).

Pable *et al*. (2010) reported that the application of S and Zn increased the seed yield, seed oil and protein content of soybean, while Jyothi *et al*. (2013) found that the foliar spray of N and Zn improve seed yield, quality and uptake of nutrient in soybean. A field experiment conducted to study the influence of S and Zn level on growth, yield and quality of soybean (singh *et al*.,2017) and found that the combined application of 40 kg Sha^{-1} + 30 kg $Znha^{-1}$ increased the growth, yield attributes and significantly increase the uptake of S and Zn as well as quality of soybean.

Sesame

Micronutrient content in sesame seed in general followed the order: Fe > Cu > Zn >Mn. The sesame varieties Gowri and Madhavi have high requirement of macro and micronutrient. Based on field Experiment data under AICRP – MNS, Bhubaneswar (2005 to 2012), the range of response to sesame was 105 to 157 $kgha^{-1}$ and the average response was 131 $kgha^{-1}$ with B:C ratio of 5.6:1. Singarvel *et al*. (2001) Reported that soil application of 25 kg ZnSO4 ha^{-1} and 5 kg MnSO4 ha^{-1} recorded a significantly higher number of capsule(59 plant-1), number of seed per capsule (57), seed yield (794 $kgha^{-1}$) and stalk yield (2299 $kgha^{-1}$) of sesame as compared to other treatments. Shukla *et al*. (2012) reported that out of six experiments, the range of response was 0.080 to 0.15 t ha^{-1} with an average response of 0.11 t ha^{-1}.

Seed inoculation of with aspergillus, soil and foliar (5 kg and 0.5%) application of ZnSO4 and foliar spray of Planofix (30 mg kg^{-1}) was found useful in increasing growth characters, yield attributes and seed yield (1163 $kgha^{-1}$) in sesame over control (Murthy, 2011). Application of 100% RDF (60:30:30 $kgha^{-1}$ NPK) + FYM @ 2.5 t ha^{-1} + ZnSO4 @ 20 $kgha^{-1}$ recorded higher seed yield (840 $kgha^{-1}$) and was found more remunerative return (net return of Rs. 15,774 ha^{-1}). Effect of S and Zn on nutrient uptake and quality of sesame grown under semi arid condition showed that maximum uptake of S (9.68$kgha^{-1}$) and Zn(39.94 gha^{-1})was recorded with RDF of NPK + 20 kg Sha^{-1} +5 kg ZnSO4 ha^{-1}+ FYM 1 tha^{-1} which was significantly more than all other treatments.

Sunflower

Patil *et al*. (2006) reported that the application of B and Zn through soil as well as foliar application among them foliar application of borax @ 0.1% at 55 DAS had recorded significantly higher yield parameters of sunflower as compared to soil application. Zn and other micronutrient accumulation, uptake ratio and nutrient use efficiency showed that sunflower hybrids AS-471 and PAC- 6753 were rather more efficient in using bio-availabe micronutrient than other hybrids and check (KBSH-1, MSFH-17) Murthy(2001). ZnSO4 (Zn-130%, Teprosyn F-2498/Zn) application showed higher root length (22.5 cm) and Vigor index (3263). Phosphorus is essential for root development and F-3090 (Zn-P) formulation enhances root growth (Sankaran *et al*., 2002) resulting in utilization of applied Zn. Combination of $ZnSO_4$ at 25 $kgha^{-1}$ and borax at 60 $kgha^{-1}$ was found to improve the growth characters and yield (34.4 gplant-1) of sunflower, cv. Morden showing the advantage of combined application of Zn and B. Sunflower hybrids, MSFH-8 was Found to be most Zn efficient cultivar. The P-Zn uptake efficiency of the crop was positively related to the nutrient influxes. Despite the low root and shoot ratio, a higher uptake efficiency of sunflower was due to its higher Zn influx, compared to maize (Zea mays) and potato (Solanumtuberosum) crops (Trehan and Sharma,2000). In Zn deficient saline calcareous soil, the application of Zn 20 $kgha^{-1}$ had recorded higher grain yield of sunflower and helps in activation of many enzymes and utilization of available nitrogen (Mirzapour and Khoshgoftar, 2007). The foliar application of Zn @ 0.5% at 35 and 55 DAS of sunflower has recorded significantly higher plant height (65.66 cm), number of leaves (23.03 plant-1) and stem girth(4.13 cm) but it was statistically on par with boron application (Arvindkumar *et al*. 2010).

Choudhury *et al*. (2010) reported that foliar application of $ZnSO_4$ @ 0.5% at star bud stage +borax spray @ 0.20% at ray florateinition stage in sunflower has recorded significantly higher filled seeds per head (594.56),lower percent chaffiness (6.33) and seed yield (53.80 g plant-1) as compared to other treatments. Zinc spray at 0.25% at bottom stage of sunflower had a significant influence on plant height, 100-seed weight and oil content. Interaction (Stages x levels) effect was significant on plant height, 100-seed weight (4.3 g) and oil content (29.1%) (Murthy, 2011). Further reported that sunflower crops showed Zn deficiency symptoms, viz. decrease in seed size, seed weight and concentration of chlorophyll a and b under Zn stress condition. When sufficient Zn supply was made, the plants showed a significant increase in seed size, seed weight and chlorophyll a and b concentration as a result of increased carbonic anhydrase and reduce acid phosphatase activities in sunflower leaves. Singh and Arvindkumar (2017) studies the performance of sunflower to different concentration of nano zinc sulphide and nutrient dynamics in soil. They found that nano ZnS (500 ppm) sprayed at 55 DAS recorded significantly higher seed yield (5.27 g plant-1) and yield attributes at par with 400 ppm of nano ZnS sprayed at 35 DAS (4.87 g plant-1).

Safflower

Application of 45 kg elemental S and 30 kg Zn ha^{-1} increased safflower seed yield (29.34 $kgha^{-1}$), giving 92.1% increase over control. Further S X Zn interaction was synergetic and better in improving oil and protein contents and nutrient uptake by safflower (Dinesh kar and Babhulkar 1998). Safflower seed yield was significantly high (2.37 t ha^{-1}) with application of Zn @ 15 $kgha^{-1}$. With the application of 30 kg Zn ha^{-1}, straw yield (7.62 t ha^{-1}) and nutrient concentration in the seed and dry matter were significantly high. Increase level of S and Zn significantly increased oil and protein content in seed. The interaction of S and Zn was significant, and the highest seed (2.93 tha^{-1}) and straw (9.42 tha^{-1})yields were obtained with combined application of 45 kg S and 15 kg Zn ha^{-1} (Babhulkar *et al*.,2000). Further reported that a significant higher nutrient uptake of major and micronutrients as compared to control, may be due to synergistic effect of combined application of micronutrient. Ravi *et al*. (2008) found that the foliar application of Zn and Fe both @ 0.5% each at 30 and 65 DAS of safflower had recorded significantly higher growth parameters like plant height (97.5 cm), no. of leaves (81.5 plant-1), primary (10.8 plant-1), secondary (17.3 plant-1) and dry matter production (2440.7 $kgha^{-1}$) as compared to control (80.4 cm, 65.4 plant-1, 7.6 plant-1,13.7 plant-1and 2029.6 $kgha^{-1}$, respectively). Further reported that higher number of capsule (28.8 plant-1), seed weight per head (0.78 g), 1000 seed weight (56.8 g) and seed yield (1445 $kgha^{-1}$) as compared to control (20.5 plant-1, 0.62 g., 44.7 g. and 1172 $kgha^{-1}$, respectively). In Zn deficient vertisols, the application of Zn @ 5 $kgha^{-1}$ yielded higher seed yield of safflower (2366 $kgha^{-1}$) and showed synergistic influence on uptake of other micronutrient cations at flowering stage of the crop. An antagonistic effect of Cu and Fe uptake by seed with increasing levels of Zn is enough to meet the crop Zn to obtain maximum seed yield. Zn use efficiency by seed decreased with increasing levels of Zinc (Murthy and Padmavathi, 2008). Application of FYM @ 2.5 tha^{-1} with RDF (N:P:K :: 50:25:0 $kgha^{-1}$), soil application of elemental S at 5.1 $kgha^{-1}$ and $ZnSO_4$ at 30 $kgha^{-1}$ resulted significantly higher seed yield and better economic returns of safflower under dryland condition of Maharastra (Khadtare *et al*., 2009). Available Zn status improved from initial 0.49 to 0.68 $mgkg^{-1}$ because of continuous application of $ZnSO_4$ @ 30 $kgha^{-1}$ for 7 years in black soil of Parbhani. Pooled data revealed that application of 30 kg $Znha^{-1}$ increased the seed yield of safflower (2108 $kgha^{-1}$). In black soils of Indore Zn application also improved the seed yield of safflower (AICRP-safflower, 2011).

Castor

Zinc application as foliar spray @ 0.5% at flowering stage of first raceme + at flowering stage of secondary raceme had recorded significant higher yield as compared to spraying at flowering stage of first raceme (Mahesh *et al*.,2003). Zn application at 5 $kgZnha^{-1}$ in Zn deficient red soil for castor hybrids DCH-32 and GCH-4 and varieties Kranti and 48-1 was found to be adequate (Murthy and Muralidharudu, 2003). A significant increase in seed yield of the hybrid

GCH-9 was due to Zn fertilization. Zn fertilization at 10 and 5 kgha^{-1} increased seed yield by 12.8 and 11.5%, respectively over control (Mathukia and Khanpara, 2008). Application of Zn @ 5 kgha^{-1} significantly increased the dry matter yield of Hybrid DCS-9 and rated as most optimum and economic level. Dry matter yield of 90 days old crops in different red soils ranged between 6.9 and 13.4 g plant-1 in control plot whereas it varied from 8.5 to 18.8 g plant-1 in Zn treated plots. On farm trial was conducted during 2002 -2004 in semi arid zone of India showed significant yield response of castor and groundnut, to the application of S, B and Zn (Rego *et al*., 2007) along with N and P. It also significantly increased the uptake of Zn and other nutrients in the crop biomass. Zinc use efficiency in castor at optimum dose (5 kgha^{-1}) decreased with an increase in DTPA-Zn (Murthy *et al*., 2009). Field studies under integrated nutrient management (INM) practices on castor under irrigated conditions revealed that the maximum length of primary spike, more no. of spikes plant-1, capsule spike-1, seed and oil yield and nutrient uptake of castor were recorded with the application of 75% RDF(NPK) + ZnSO4 at 12.5 kgha^{-1} as basal and 0.25% ZnSO4 foliar spray twice at 30 and 45 DAS compared to inorganic nutrients. Performance of castor under irrigated/ rainfed condition differed. Soil application of ZnSO4 at 15 kgha^{-1} resulted in higher seed and economic return under irrigated condition of Mandor (Rajasthan) whereas foliar spray of ZnSO4 at 0.5% twice was found to be better than soil application of ZnSO4 at 15 or 25 kgha^{-1}at Palem and Hiriyur under rainfed conditions (AICRP-Castor, 2013).

Conclusion and Future strategy

Based on review papers, suggested that zinc supplying capacity through foliar or soil application to oilseed crops needs to be strengthened. Data should be generated to monitor zinc status in oilseed based cropping system. Soil test results can be used for preparing zinc nutrient maps for balancing management in farmer's field. Screening of oilseed crop cultivars for zinc deficiency tolerance should be intensified and morphological, physiological and biochemical traits of varieties and hybrids associated with mining power of zinc need to be determined. Need to verify the agronomic advantages or role of zinc in rainfed oilseed crops. Long term studies on residual zinc in oilseed crop production are important. Study on customized fertilizers or coated, fortified fertilizers with micronutrients need to study for sustainable crop production.

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