J. Soils and Crops 28 (2) 249-258, December 2018

ISSN 0971-2836
NAAS Rating - 4.46
Scientific Journal Impact Factor - 6.736

Review article

RESPONSE OF PULSE CROPS TO SOLE AND COMBINED MODE OF ZINC APPLICATION : A REVIEW

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Zinc has been the micronutrient needed by crops especially pulses in sufficiently large quantity. Unfortunately, in India, about 50% of soils are deficient in zinc inducing Zn deficiency in human and animal due to reduction in concentration of zinc in edible plant parts. Recent research revealed that one third of the world population under the risk of zinc malnutrition. Zinc plays an important role in metabolism both in plants as well as in animals by acting as essential component of enzyme, RNA, electron carrier etc. Soil is the only source for availability of zinc to plants and animals naturally but the intensive cropping system involving high yielding varieties have led to depletion of soil zinc. Soil zinc deficiency can be overcome by the application of zinc salts and organic manures. But the use efficiency of the soil zinc application is poor. Hence, application of zinc through different and combined modes has been widely studied and adopted. Present review discuss the findings of the effects of different and combined modes of zinc application on growth, yield, produce quality, zinc concentration in plant tissue and zinc uptake by crop in pulses under diverse soils. The comprehensive review on the effects of different modes of zinc application on performance of crops especially pulses revealed that, the combined mode of zinc application involving soil zinc along with organic manures and foliar applications proved more beneficial among any sole mode of application with respect to increment in plant growth, yield and produce quality.

Zinc is a chemical element exhibit only one normal oxidation state (Zn^{2+}) and has five stable isotopes. The element was discovered by German chemist Andreas Sigismund Marggraf in 1746. Zinc plays an important role in successful completion of life cycle hence, it has been placed among 17 essential elements required by the plants. Unlike plants, zinc is essential for living organisms too. Zinc is directly and indirectly involved in the synthesis and metabolism in living organisms and plants. Zinc serves as an essential component of enzymes and acts as a functional, structural and/or regulatory cofactor of a large number of enzymes. The proteinases, peptidases, carbonic, dehydrogenase, anhydrase etc. are the examples metalloenzymes in which zinc is the integral part. Besides enzymes, zinc also associated with the proteins and plays an important role. The plants exhibited lower rate of protein synthesis and protein accumulation under zinc deficiency. Zinc also plays important role in physiological process of plants through synthesis of hormones essential for growth and reproduction. Zinc is an essential component of RNA polymeras and provides structural integrity to ribosomes. Soil is the principal source of zinc for plants.

The accumulation of zinc in edible parts of plant serves as zinc source for primary consumers. Unfortunately, about 50% of Indian soils are deficient in zinc and expected to further increase up to 63% by 2025 which imparting zinc malnutrition in population especially in children (Singh, 2006; Shukla *et al.,* 2014). One third of the world population is reported at the risk of zinc malnutrition due to inadequate dietary intake of zinc (Cakmak, 2009) resulting from wide spread hidden hunger of zinc in seeds and feeds (Singh, 2010). Also, the intensive cropping systems of high yielding varieties have led to depletion of micronutrients, especially zinc. The application of higher levels of phosphorus fertilizers also known for inducing zinc deficiency in plants as P has a negative interaction with Zn. Similarly, enhanced zinc adsorption to hydroxides and oxides of iron and aluminum and to $CaCO_3$, 'Physiological inactivation' of zinc within the shoots due to zinc translocation and high concentrations of divalent cations (e.g. Ca^{++}) are the other reasons for zinc deficiency in plants. The zinc deficiency significantly lowers the crop yield causing economic burden among the resource poor people (Hegazy *et al.,* 1990; Takkar *et al.,* 1990; Singh *et al.,* 2011). In order to overcome the soil zinc deficiency, application of zinc salts, manures, foliar applications etc. has been practiced. Considering the above mentioned facts, modes of application of zinc and subsequent effects on crop performance has been reviewed.

ZINC APPLICATION AND CROP PERFORMANCE

The application of graded level of soil zinc application on performance of different pulse crops has been widely studied since long. The response of different

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crops to the applied zinc through different modes alone or in combination has been reviewed with respect to growth parameters, yield attributes, yield and nutritional quality. Performance of the crop is measured in terms of plant height, leaf area, primary and secondary branches, biomass accumulation, chlorophyll content, yield etc.

Plant height

Plant height is one of the important morphological growth parameter influenced by the applied nutrients and growth regulators. Sangwan and Raj (2004) and Khrogamy and Farnia (2009) observed significantly higher plant height of chickpea under the application of 15 kg Zn and 20 kg $ZnSO_4$ ha^{-1}, respectively as compared to no zinc application. Kuniya *et al.* (2018) investigated the effect of zinc application on yield and quality of summer clusterbean in light textured soil and found that the application 5.0 kg Zn ha^{-1} resulted in significantly higher plant height. The application of 10 kg Zn ha^{-1} significantly influenced the plant height (47.76 cm and 47.88 cm in summer mungbean (Ram and Kattiyar, 2013). Tayyeba *et al.* (2017) tested performance of mungbeans with various concentrations of Zn and found that the application of Zn @ 2 μM significantly improved the plant height of mungbean. As far as the performance of pigeonpea is concerned, Puste and Jana (1988) studied the effect of different levels of zinc (0, 10 and 20 kg $ZnSO_4$ ha^{-1}) on the crop growth pattern in pigeonpea and found that application of $ZnSO_4$ @ 20 kg ha^{-1} greatly influenced the plant height. The application of 5 mg kg^{-1} Zn added to soil improved the plant height of pigeonpea crop (Dube *et al.,* 2001). The similar kind of increment in plant height of pigeonpea was also reported by Shah *et al.* (2016) and Thamke (2017) with the soil application of $ZnSO_4$ applied at the magnitude of 20 kg ha^{-1} and 15 kg ha^{-1}, respectively.

The application of zinc in combination with FYM is known for imparting favorable changes in the plant height of the crop. Sharma *et al.* (2009) observed significantly higher plant height (184.09 cm) of pigeonpea under combined application of zinc ($ZnSO_4$ @ 15 kg ha^{-1}) and FYM @ 5t ha^{-1} in a Vertisol of Karnataka.

The foliar application of nutrients in standing crops in order to avoid the deficiency had been introduced. The application of zinc through foliar application of zinc salts proved beneficial in eliminating the Zn deficiency in many crops especially pulses. The increment in plant height of cowpea with zinc spray (1 g L^{-1}) has been documented by Salehin and Rahman (2012). Habbasha *et al.* (2013) observed 0.2 % $ZnSO_4$ application to chickpea at seed filling stage result in significantly higher plant height (81.43 cm). The foliar Zn application at flowering and podding stages has been effective in prevention of flower and premature abscission and acceleration of assimilate translocation in pulses (Tekale *et al.,* 2009). The importance of appropriate time of application (*i.e.* flowering and panicle initiation) of Zn could alter the physiological events of crop. Increase in plant height was mainly attributed due to higher shoot growth through cell elongation, cell differentiation and apical dominance promoted by zinc. Zinc were also supposed to be involved in the hormone synthesis, hence indirectly related to translocation and metabolism of carbohydrate finally contributing to additional growth compared to control (Padma *et al.,* 1989 and Deotale *et al.,* 1998).

Branching

Number of main branch and number of sub branch plays an important role in determining the yield of the crop. The positive effect of soil zinc application ($ZnSO_4$ @ 20 kg ha^{-1}) on branching in chickpea was reported by Khorgamy and Farmia (2009). Similar kind of findings with respect to branching in chickpea, culasterbean, mungbean and pigeonpea with the application of zinc at a magnitude of 15 kg Zn ha^{-1}, 5 kg Zn ha^{-1}, 10 kg Zn ha^{-1} and 5 mg kg^{-1} were reported by Sangwan and Raj (2004), Kuniya *et al.* (2018), Ram and Katiyar (2013) and Dube *et al.* (2001), respectively. These studies showed that Zn had significant effects on branching in the studied crops. The effect of application of soil zinc in combination with FYM also found beneficial with respect to branching in the different crops. Singh *et al.* (2012) found that, the application of soil zinc (25 kg $ZnSO_4$) along with FYM @ 5 t ha^{-1} resulted in 9-11% higher branches in chickpea. Sharma *et al.* (2009) also reported that the application of FYM @ 5 t ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} to pigeonpea showed significantly higher primary branches (12.34) and secondary branches (7.86) $plant^{-1}$ as compared to the treatment without FYM. The reported positive effect of foliar application of Zn on an enhanced branching in pulses mainly attributed to promotion of bud and branch development by the auxins whereas Zn application ultimately increased the availability of other nutrients and accelerated the translocation of photo assimilates (Guhey, 1999; Barclay and Mcdavid, 1980).

Leaf area and chlorophyll content

Puste and Jana (1988) found that application of zinc at 20 kg $ZnSO_4$ ha^{-1} greatly influenced the leaf area index and crop growth rate of pigeonpea. Thamke (2017) also studied the effect of graded levels of zinc on leaf area and growth parameters of pigeonpea and indicated significantly higher leaf area under application of 15 kg $ZnSO_4$ along with RDF. Mondal *et al.* (2011) studied the effect of foliar zinc application (0.1%) on leaf area of mungbean and reported significantly higher leaf area $plant^{-1}$ (497 cm^2) over control.

Akay (2011) studied the effect of zinc (0, 0.5, 1.0 and 1.5 kg ha^{-1}) fertilizer applications on chickpea under irrigated conditions. The results showed significant increase in phosphorus, phytic acid and zinc content in the seed and the chlorophyll concentration in leaf under zinc fertilizer application at a dose of 1.0 kg ha^{-1} ($P < 0.01$). Similar result with respects to leaf chlorophyll content in mungbean was recorded at 2 μM concentration of zinc (Tayyeba *et al.,* 2017). The effects of zinc application on chlorophyll and leaf area mainly attributed to more availability of zinc both during seedling and subsequent stages of plant growth which has been known to increase photosynthates and 'N' fixation (Hegazy *et al.,* 1990; Nayak, 1989). The zinc have important role in chlorophyll formation which enhanced chlorophyll content in leaf of the plants (Sharma *et al.,* 2010). Purushottam *et al.* (2018) observed 3-8% increment in leaf chlorophyll of pigeonpea with foliar application of 0.5% $ZnSO_4$.

Nodulation

Chickpea, clusterbean, mungbean, soybean and pigeonpea showed positive response to applied zinc in terms of nodulation. Chauhan *et al.* (2013) reported 91% higher nodulation in soybean under the application of Zn @ 5 kg ha^{-1} in consecutive years of study. The positive response towards root nodulation in chickpea with the application of $ZnSO_4$ @ 20 kg ha^{-1} was observed by Khorgamy and farina (2009). Ram and Kattiyar (2013) found that the application of Zn @ 10 kg ha^{-1} to mungbean significantly improved the nodulation. Recently, Kuniya *et al.* (2018) found that the application of 5.0 kg Zn ha^{-1} resulted in significantly higher number of root nodules and fresh weight of root nodules $plant^{-1}$ in clusterbean.

Seed and pod

Zinc application either alone or in combination with FYM through soil and/or foliar application improves the number of seeds pod^{-1}, number of pods $plant^{-1}$ and test weight in many crops. Studies on chickpea suggested application of Zn at 15 kg ha^{-1} resulted in significant response over control in terms of number of pods $plant^{-1}$ and 1000 grain weight (Sangwan and Raj, 2004). Besides chickpea, culasterbean also responded to the application of Zn @ 5 kg ha^{-1} in terms of significantly higher seeds pod^{-1} and pods $plant^{-1}$ (Kuniya *et al.,* 2018). The similar results in mungbean crop were obtained by Malik *et al.* (2015) with 20 ppm zinc application. Ram and Katiyar (2013) found that the application of 10 kg Zn ha^{-1} to mungbean resulted in significant improvement in the pod and seed number. Dube *et al.* (2001) showed positive responses to graded (1 to 25 mg kg^{-1} soil) Zn amendment. The enhancement in production of pods and seeds pod^{-1} in pigeonpea was highest at 5 mg kg^{-1} Zn added to soil. Earlier, Puste and Jana (1988) also reported that the application of zinc at 20 kg $ZnSO_4$ ha^{-1} greatly influenced the pod and crop growth rate of pigeonpea. Shah *et al.* (2016) concluded that the number of seeds pod^{-1} and number of pods $plant^{-1}$ in pigeonpea significantly enhanced under the application of Zn @ 20 kg ha^{-1}. The seed treatment of $ZnSO_4$ @ 4 g kg^{-1} of seeds increased the seeds pod^{-1} and number of pods $plant^{-1}$ in a shallow black soil of Karnataka in south India (Sharma *et al.,* 2010). Srikanth Babu *et al.* (2012) studied the effect of organic manures and graded levels of zinc sulphate on yield and yield components of pigeonpea and concluded that significantly higher seeds pod^{-1} and number of pods $plant^{-1}$ was obtained with $ZnSO_4$ @ 20 kg ha^{-1} when compared to no zinc application. The increase in number of pods $plant^{-1}$, test weight and grain yield $plant^{-1}$ in pigeonpea in Alfisol with the application of $ZnSO_4$ @ 12.5 kg ha^{-1} has been reported by Umesh and Shankar (2013). Recently, Thamke (2017) studied the effect of graded levels of zinc on performance of pigeonpea. The results clearly indicated that various growth and yield parameters like plant height, leaf area, number of pods, seed yield and dry matter yield was increased due to application of zinc. These results were obtained under the application of 15 kg $ZnSO_4$ ha^{-1} with RDF.

The combined application of 25 kg $ZnSO_4$ along with FYM @ 5t ha^{-1} increased pods $plant^{-1}$ in chickpea by 17% as compared to no zinc application (Singh *et al.,* 2012). Habbasha *et al.* (2013) observed that the application of 0.2 % $ZnSO_4$ at seed filling stage in chickpea showed significantly higher number of seeds $plant^{-1}$ (83.92) in chickpea as compared to no foliar application. Similarly, foliar application of $ZnSO_4$ @ 0.5% to mothbean (Ramesh, 2002); foliar application of 500 mg l^{-1} Zn to mungbean (Ali and Mahmoud, 2013), foliar N + Zn (1.5% urea; 0.1% Zn) to mungbean (Mondal *et al.,* 2011) and foliar Zn+Fe (116 ppm each) to soybean (Heidarian *et al.,* 2011) resulted in significantly enhanced ($p=0.05$) number of pods $plant^{-1}$ and number of seeds pod^{-1} over control. The interactive effect of zinc spray (1 g l^{-1}) and nitrogen fertilizer on number of seeds pod^{-1} in cowpea was positive even at 1% significance level (Salehin and Rahman, 2012) indicating the significance of zinc in plant growth. The enhancement effect on seeds pod^{-1} and pods $plant^{-1}$ attributed to the favorable influence of the Zn application to crops on nutrient metabolism, biological activity and growth parameters and hence, applied zinc resulted in taller and higher enzyme activity which in turn encourage vegetative branches and pods $plant^{-1}$ (Michail *et al.,* 2004).

Test weight

Hundred grain weight/seed index is one of the most important yield components in crop. The application of zinc showed significant effect on the size and weight of the seeds. Khrogamy and Farnia (2009) observed that application of $ZnSO_4$ @ 20 kg ha^{-1} had a significant effect on hundred grain weight (59.64 g) in chickpea cultivars. A similar observation in chickpea (1000 seed weight) with Zn at 15 kg ha^{-1} has been recorded by Sangwan and Raj (2004). Recently, the lower application (5.0 kg Zn ha^{-1}) in culasterbean has been found to alter test weight significantly (Kuniya *et al.,* 2018). Ram and Katiyar (2013) found that the application of 10 kg Zn ha^{-1} to mungbean resulted in significant improvement in test weight.

Shah *et al.* (2016) concluded that the test weight in pigeonpea significantly enhanced under the application of Zn @ 20 kg ha^{-1}. The seed treatment of $ZnSO_4$ @ 4 g kg^{-1} of seeds increased the test weight in a shallow black soil of Karnataka in south India (Sharma *et al.,* 2010). Srikanth Babu *et al.,* (2012) studied the effect of organic manures and graded levels of zinc sulphate on yield and yield components of pigeonpea and concluded that significantly higher test weight was obtained with $ZnSO_4$ @ 20 kg ha^{-1} when compared to no zinc application. The increase in number of pods $plant^{-1}$, test weight and grain yield $plant^{-1}$ in pigeonpea in Alfisol with application of $ZnSO_4$ @ 12.5 kg ha^{-1} has been reported by Umesh and Shankar (2013). Recently, Thamke (2017) indicated that the test weight of pigeonpea was increased due to application of zinc. These results were obtained under the application of 15 kg $ZnSO_4$ ha^{-1} with RDF.

However, contradictory results with respect to the test weight of chickpea upon application of $ZnSO_4$ @ 25 kg ha^{-1} in combination with FYM @ 5 t ha^{-1} were observed by Singh *et al.* (2012). Besides sole inorganic and combined with FYM application, the foliar application with different magnitudes and at different growth stages significantly altered the test weight in various crops. Pandey *et al.* (2010) and Ali and Mahmoud (2013) studied the effect of zinc foliar application on 1000 seeds weight of mungbean and found its superiority at 400 and 500 mg l^{-1} Zn as compared with control (untreated plants), respectively. In another study, Heidarian *et al.* (2011) found that combination of Zn + Fe (116 mg l^{-1} each) treatment produced maximum 1000 grain weight in soybean.

Yield and biomass

Grain yield is the ultimate economic produce of the crop which is determined by grain weight, number of grains $unit^{-1}$ land area as governed by the management practices and its native genetic potential. Studies on response of Zn fertilization to crop yield showed positive effect (Table 1). Zn at 5 kg ha^{-1} and S at 60 kg ha^{-1} resulted in the highest grain yield, which was 66.98% higher than that in the control (Mali *et al.,* 2003). Khrogamy and Farnia (2009) observed that application of $ZnSO_4$ @ 20 kg ha^{-1} had a significant effect on seed yield and total biomass in chickpea cultivars. Singh and Singh (2012) conducted an experiment to study the effect of zinc on yield of chickpea. The results showed that grain and straw yield increased significantly by 9.8 and 11.4 % respectively with the application of 5 kg Zn ha^{-1}. Valenciano *et al.* (2010) reported that chickpea responded to Zn (0, 1, 2, 4 and 8 mg Zn pot^{-1}) applications. At maturity, plants fertilized with Zn had a greater total dry matter production and seed yield, mainly due to an increment in pod dry matter. The positive response of chickpea to soil zinc application has also been documented by Sangwan and Raj (2004) and Purushottam *et al.* (2018). Recently, Kuniya *et al.* (2018) found that the application of 5.0 kg Zn ha^{-1} resulted in significantly higher seed and stover yield of clusterbean. Greengram showed positive response to SSNM of and yield increases from 0.54t ha^{-1} to 0.75t ha^{-1} (Srinivasarao, 2012) (Table 1).

Ramakrishna *et al.* (2005) studied the effects of improved production technologies involving application of 10 kg Zn ha^{-1} and found increased pigeonpea yield. T_1 consisted of a medium-duration high-yielding cultivar (ICPL 87119), sowing rate of 12 kg ha^{-1}, seed treatment with thiram (3 g kg^{-1}), inoculation with *Rhizobium*, 20 kg N, 50 kg P_2O_5 ha^{-1}, basal application of micronutrient mixture (5 kg borax, 0.5 kg B ha^{-1}; 50 kg zinc sulfate, 10 kg Zn ha^{-1}; and 200 kg gypsum, 30 kg S ha^{-1}), and need-based pest and disease control measures. Inter-cultivation was conducted at 25 and 50 days after sowing to control weeds. One insecticide spray was given at the pod formation stage to control pod borers. T2 included a sowing rate of 10 kg ha^{-1}, 12 kg N ha^{-1}, and 30 kg P_2O_5 ha^{-1}. 204% higher yield of pigeonpea than that obtained byformer practice. Patil *et al.* (2006) studied the effect of four different levels zinc (*viz.,* 0,10, 20 kg ha^{-1}) on growth and yield of pigeonpea and reported that the application of $ZnSO_4$ @ 10 kg ha^{-1} produced significantly higher grain (29.55 q ha^{-1}), stalk (95.81 t ha^{-1}) and bhusa yields (20.58 q ha^{-1}). Goud *et al.* (2012) conducted field experiment to a study the effect of spacing and fertilizer on growth, yield and soil health in hybrid pigeonpea. The results showed that the application of 20:45:20:20:15 kg $NPKSZnSO_4$ ha^{-1} was found economical. The results showed that these applications are essential for obtaining high grain yield of hybrid pigeonpea. Srikanth babu *et al.* (2012) studied the response of graded levels of zinc sulphate to pigeonpea and revealed that, significantly higher yield (1324 kg ha^{-1}) was obtained with the application of $ZnSO_4$ @ 20 kg ha^{-1} as compared to no application of zinc sulphate. Umesh and Shankar (2013) conducted a field experiment in Alfisol at Dryland Agriculture Project, Bangalore to study the impact of graded levels of zinc on growth and yield of pigeonpea varieties. The results revealed significant increase in grain (1759 kg ha^{-1}) and stalk yield (6004 kg ha^{-1}) of pigeonpea with the application of 50, 100 and 75 kg N, P_2O_5 and K_2O ha^{-1} along with common dose of $ZnSO_4$ @ 12.5 kg ha^{-1}. Malik *et al.* (2015) evaluated the effect of zinc on growth and yield of mungbean and found that maximum seed yield $plant^{-1}$ (78.20 g) was recorded with the application of 20 ppm zinc as compared to control. Shah *et al.* (2016) revealed that the yield of pigeonpea was found highest under the treatment receiving Zn @ 20 kg ha^{-1}. Recently, Thamke (2017) studied the effect of graded levels of zinc on growth and yield of pigeonpea. The results clearly indicated that various growth and yield parameters were significantly influenced by the application of 15 kg $ZnSO_4$ ha^{-1} along with RDF. Besides these crops, mungbean (Ram and Katiyar, 2013), pigeonpea (Mali *et al.,* 2003; Sharma *et al.,* 2010) and soybean (Chauhan *et al.,* 2013) also responded to soil application of inorganic zinc (Table1).

Table 1. Yield response to mode of zinc application

Crop	Mode of Zn application	Rate of Zn application	Yield response	Reference
Chickpea	Soil	Zn @15 kg ha^{-1}	35% higher yield	Sangwan and Raj (2004)
Greengram	Soil	Zn @5 kg ha^{-1}	18-44% higher yield	Srinivasarao (2012)
Pigeonpea	Soil	Zn @5 kg ha^{-1}	67% higher yield	Mali *et al.* (2003)
Soybean	Soil	Zn @5 kg ha^{-1}	33-43% higher yield	Chauhan *et al.* (2013)
Culasterbean	Soil	Zn @5 kg ha^{-1}	40% higher yield	Kuniya *et al.* (2018)
Mungbean	Soil	Zn @10 kg ha^{-1}	31% higher yield	Ram and Kattiyar (2013)
Clusterbean	Soil+foliar	$ZnSO_4$ @ 20kg ha^{-1} and 0.5 % $ZnSO_4$	54% higher yield	Selvaraj and Prasanna (2012)
Cowpea	Foilar	0.1% Zn	15% higher yield	Salehin and Rahman (2012)
Pigeonpea	Soil+FYM	$ZnSO_4$ @ 15 kg ha^{-1} + FYM @ 5t ha^{-1}	25% higher yield	Sharma *et al.*(2009)
Black gram	Foliar	0.5% $ZnSO_4$	18% higher yield	Pandey and Gupta (2012)
Chickpea	Foliar	0.2 % $ZnSO_4$	37% higher yield	Habbasha *et al* (2013)
Cowpea	Foliar	0.5% $ZnSO_4$	43% higher yield	Anitha *et al.* (2005)
Greengram	Soil + foliar	5.5 kg Zn ha^{-1} + 0.1% Zn	57% higher yield	Roy *et al.* (2014)
Mungbean	Foliar	500 mg L^{-1} Zn	23% higher yield	Ali and Mahmoud (2013)
Soybean	Foliar	1.0 % $ZnSO_4$	29% higher yield	Gowthami and Rao (2014)
Chickpea	Soil + foliar	(25 kg+0.5 %) $ZnSO_4$	24% higher yield	Sharafi (2015)
Pigeonpea	Foliar	0.5% $ZnSO_4$	23-41% higher yield	Purushottam *et al.* (2018)

The combined application of Zn with FYM or foliar spray with different magnitude and time to various crops showed significant increment in yield (Table 1). Selvaraj and Prasanna (2012) carried out a study on effect of nitrogen and zinc on yield of cluster bean and reported that application of 0.5 % $ZnSO_4$ at 25 and 45 DAS resulted highest seed (819 kg ha^{-1}) and stalk yield (1045 kg ha^{-1}). In another experiment by Salehin and Rahman (2012) reported highly significant (p=0.01) effect of zinc spray and nitrogen fertilizer on seed yield of cowpea. The application of farm yard manure @ 5t ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1} to chickpea increased the yield by 5% over control (Singh *et al.,* 2012). Mungbean crop supplied with zinc enriched FYM (5 kg Zn with 500 kg FYM ha^{-1}) 23-45% higher grain yield over control (Meena *et al.,* 2017). Sharma *et al.* (2009) conducted a field experiment studied the response of pigeonpea to conjunctive use of organic and inorganic fertilizers at Agricultural Research Station, Gulbarga on Vertisols during *kharif* season of 2000, 2001 and 2002 revealed that application of FYM @ 5t ha^{-1} + Seed inoculation with *Rhizobium* + Micronutrient ($ZnSO_4$ @ 15 kg ha^{-1}) + crop residue @ 5t ha^{-1} recorded significantly higher seed yield (15.81 q ha^{-1}). Vyas *et al.* (2006) obtained the maximum soybean and pigeonpea yield under intercropping system with 75% RDF + FYM @ 5t ha^{-1} + 5 kg Zn ha^{-1}. The maximum soybean equivalent yield and land equivalent ratio were also recorded with the same during both the years. The cereal crops such as rice and wheat also showed positive effect on yield upon combined application of Zn (2.5 and 5.0 kg Zn ha^{-1}) with FYM and/or other organic manures such as poultry manure and pig manure (Kulhare *et al.,* 2014).

The foliar application of zinc helps standing crop to eliminate the zinc deficiency. The crop response is more prompt in case of foliar application than any other mode as the zinc is readily assimilated by the crop through leaves. The foliar application of 0.5% zinc sulfate ($ZnSO_4$) to black gram showed favorable results in yield (Pandey and Gupta, 2012). Habbasha *et al.* (2013) observed that application of 0.2 % $ZnSO_4$ at seed filling resulted significant effect on seed yield $plant^{-1}$ (16.32 g), seed yield (1.51 t ha^{-1}) and straw yield (2.57 t ha^{-1}) in chickpea. The spraying of 0.5% $ZnSO_4$ at 45 DAS proved most effective in cowpea which increased the seed yield by 43% per cent when compared with control (Anitha *et al.,* 2005). Combined application of inorganic soil zinc and foliar spray (0.1%) in greengram was studied by Roy *et al.* (2014) and reported an increase in the yield with 5.5 kg Zn ha^{-1} + 0.1% Zn spray. The increased in straw and seed yield was 56% and 57%, respectively. The application of 500 mg l^{-1} Zn to mungbean proved superior with respect to the yield and yield components (Ali and Mahmoud, 2013). Similar to mungbean, a considerable increase in yield (400 kg ha^{-1}) in pigeonpea was observed under the foliar spray of 0.5% Zinc sulphate at flower initiation stage. Positive effects of foliar Zn (0.5% $ZnSO_4$) application on pigeonpea have also been observed by Sharafi (2015). Osman *et al.* (2000) reported that foliar application of zinc @ 0.4% in soybean significantly increased the seed yield. Gowthami and Rao (2014) conducted a field experiment to study the effect of foliar application of zinc on growth and yield of soybean. Foliar sprays of Zn increased the seed yield considerably over control. Significant differences were observed among different treatments with regards to seed yield and revealed that the treatment involving application of zinc sulphate @ 1 % at 30 DAS and 60 DAS recorded significant increase in seed yield (2996 kg ha^{-1}) which was 28.59 % higher over control (2330 kg ha^{-1}). Heidarian *et al.* (2011) conducted a field experiment in order to investigate Zn, Fe and Zn + Fe foliar application effects on soybean. The combination of Zn + Fe (116 mg l^{-1} each) treatment produced maximum yield which was 1.575 ton ha^{-1}. Purushottam *et al.* (2018) observed 23-41% higher yield of pigeonpea under the foliar application of 0.5% $ZnSO_4$.

Among these studies, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in growth and yield of crops. Zn is required for the biosynthesis of plant growth regulator (IAA) and for carbohydrate and N metabolism which leads to high yield and yield components (Taliee and Sayadian, 2000). Overcoming limitations to plant nutrient through the application of appropriate fertilisers increased assimilate production and photosynthesis efficiency at the seed filling stage (Yilmaz *et al.,* 1997; Ali *et al.,* 2004; Calhor, 2006). High harvest index indicates a high seed yield (economic yield) relative to total biomass production. Zn fertiliser ($ZnSO_4$) decreases pH of soil in dry lands and increases root absorption of minerals (Taliee and Sayadian, 2000). The positive crop response to zinc fertilization either through soil or foliar with and without FYM might be due to the Zn fertilizer (as $ZnSO_4$) decreases pH of soil and increases root absorption of minerals and improved Zn nutrition of plants improves biosynthesis of the plant growth regulator IAA, carbohydrate and N metabolism which lead to high yield and yield components. The enhanced plant nutrition increases photosynthesis efficiency, assimilation and production (Taliee and Sayadian, 2000; Jakson *et al.,* 2003; Calhor, 2006; Amjad *et al.,* 2004 and Ali *et al.,* 2004). Dry matter accumulation in the plant at progressive stages is a justified assessment of growth as a cumulative expression of different growth parameters. Further, it was observed that crop productivity is not only dependent on accumulation of total amount of dry matter but its effective partitioning into economic sink seems to be key to increase the yield. Auxin is known to maintain the higher rate of photosynthesis which contributed to higher dry matter which was an indicator of current photosynthesis (Bangla *et al.,* 1983; Puste and Jana, 1988; Shinde *et al.,* 1991 and Upadhyay, 2002).

Harvest index

Harvest index (HI) is the genetic character of the crop and varies with cultivar. The harvest index of the crop generally remains unchanged but some crucial management practices make some changes in HI. Following studies on the application of the zinc showed favorable results with respect to the harvest index of crop. Dube *et al.* (2001) showed positive response of harvest index of pigeonpea with the application of Zn @ 5 mg kg^{-1}. Kumawat *et al.* (2015) also studied the effect of integrated nutrition on productivity and nutrient uptake of rainfed pigeonpea. The results showed that the treatment involving application of 100% recommended dose of fertilizers + 50% recommended dose of nitrogen through vermicompost + 5 kg Zn ha^{-1} recorded significantly higher harvest index (20.23 %) of pigeonpea. Similarly, the foliar application of N+Zn (urea 1.5%; Zn 0.1%) also reported to enhance harvest index of mungbean (Mondal *et al.,* 2011). A recent study conducted by Purushottam *et al.* (2018) observed 15-20% higher harvest index of pigeonpea under the foliar application of zinc. The harvest index was observed 28.2% in control whereas, it was found 32.3% and 33.8% in the treatment with 0.25% $ZnSO_4$ and 0.50% $ZnSO_4$, respectively.

Zn accumulation in plant tissue and grain

The soil available nutrients, applied nutrients and their accumulation in the plant have significant positive relationships. Akay (2011) studied the effect of graded zinc fertilizer applications on chickpea under irrigated conditions and showed significant increase in phosphorus, phytic acid and zinc content in the seed and the chlorophyll concentration in leaf under zinc fertilizer application at a dose of 1.0 kg Zn ha^{-1} ($P < 0.01$). Khorgamy and Farnia (2009) also reported higher zinc concentration in grain of chickpea. The soil zinc application and enhancement in the zinc concentration in zinc leaf and grain also observed in other pulse crops like mungbean with 2 µM Zn (Tayyeba *et al.,* 2017) and pigeonpea under soil application of Zn @ 5 mg kg^{-1} (Dube *et al.,* 2001).

The combined application of zinc with FYM or other organic manures has been proved beneficial in improving the zinc concentration in plant tissue and grain/seed. Ranpariya *et al.* (2017) studied the effect of combined application of zinc and FYM on nutrient content in green gram (*Vigna radiata* L.) under south Saurashtra region of Gujarat. The results revealed that the zinc content in seed was significantly influenced by the application of 10 kg $ZnSO_4$ ha^{-1} with FYM.

The foliar application proved very effective in eliminating the nutrients deficiencies in standing crops and the researchers obtained very encouraging results. Pandey and Gupta (2012) revealed that the foliar spray of Zn [0.5% zinc sulfate ($ZnSO_4$)] improved seed Zn content in black gram. Roy *et al.* (2014) reported that the combined application of 5.5 kg Zn ha^{-1} + 0.1% Zn as foliar spray increased the seed and straw Zn content in greengram. Salih (2013) carried out an experiment to investigate the effect of foliar application of Zn on nutrient concentration of seed in cowpea. The results showed a significant increase of Zn concentration in cowpea seed with 2 ppm Zn foliar application as compared to control.

These studies showed positive response towards accumulation of Zn^{+} in plant tissues at different developmental stages. The relationship between the bio-accumulation of zinc and the zinc concentration in the nutrient solution has been noted earlier by Cui and Wang (2005) and Sharma and Agrawal (2006). Purushottam *et al.* (2018) reported 14-37% higher zinc content in pigeonpea stalk under the foliar application of $ZnSO_4$ (0.5%). Recently, a field study was conducted by Hanumanthappa *et al.* (2018) to evaluate the effect of zinc fertilization on zinc content of pigeonpea genotypes. Results revealed that, foliar application of $ZnSO_4$ @ 0.5% increased Zn content in pigeonpea seed by 11-96% among different genotypes as compared to control which proved foliar application of zinc offer a practical and useful option towards eliminating the Zn deficiency through biofortification.

Protein

Plant nutrient increases assimilation, production and photosynthesis efficiency at seed formation stage (Taliee and Sayadian, 2000). The micronutrients especially Zinc have important role in chlorophyll formation, carbohydrate metabolism, synthesis of proteins and activation of oxidation process and enzymes. Zn is required for the biosynthesis of plant growth regulator (IAA) and for carbohydrate and N metabolism which leads to improvement in seed quality components (Taliee and Sayadian, 2000). The work of Khrogamy and Farnia (2009) on zinc application in chickpea revealed the fact that, the application of $ZnSO_4$ @ 20 kg ha^{-1} improved the protein content (24.02 %) in chickpea cultivars. Singh and Singh (2012) also reported 20.2% higher protein content in chickpea grain under the application of 10 kg Zn ha^{-1}. Recently, Kuniya *et al.* (2018) found that application of 5.0 kg Zn ha^{-1} resulted in significantly higher protein content, protein yield and gum content in seed of culasterbean. A two years experiment during 2008-10 was conducted to study the effect of zinc on seed protein content of summer mungbean revealed that the application of 10 kg Zn ha^{-1} gave maximum protein content (24.17 % and 24.32 %) in both years of study (Ram and Kattiyar, 2013) whereas, Tayyeba *et al.* (2017) found significantly higher protein content with 2 µM Zn. Shah *et al.* (2016) conducted a field experiment in sandy loam soil at Pulse Research Station in Gujarat to study the effect of zinc application on seed quality of pigeonpea. The study revealed that the protein was increased significantly with the application of Zn @ 20 kg ha^{-1}. Further, a study in shallow black soil of Gulbarga (Karnataka) by Sharma *et al.* (2010) reported that seed treatment of pigeonpea with $ZnSO_4$ @ 4 g ha^{-1} seeds impart a positive effect on protein content. Similarly, Thamke (2017) studied the effect of graded levels of zinc on seed quality of pigeonpea and obtained highest protein content with the application of 15 kg $ZnSO_4$ ha^{-1} along with RDF. The foliar application of 0.5 % $ZnSO_4$ in clusterbean at 25 and 45 DAS resulted in highest protein content (28.9%) (Selvaraj and Prasanna, 2012). Habbasha *et al.* (2013) conducted a field experiment for two years and observed that application of 0.2 % $ZnSO_4$ at seed filling stage resulted significant effect on seed protein content (21.05 %) in chickpea during both the years. Roy *et al.* (2014) reported that the combined application of 5.5 kg Zn ha^{-1} + 0.1% Zn as foliar spray increased the seed crude protein by 26.9% over control. Seed and straw Zn content also showed a significant and positive correlation with all yield attributes.

Zn fertilizer ($ZnSO_4$) decreases pH of soil in dry lands and increases root absorption of minerals (Taliee and Sayadian, 2000).Thus, good and correct management of macronutrients and zinc (both rate and type of application) improves soil fertility which can lead to high protein content in seed. Calhor (2006) and Yilmaz (1997) reported that Zn deficiency caused low protein content in seed of pulse and cereal. Ved *et al.* (2002) stated that foliar applied zinc enhances photosynthesis, early growth of plants, improves nitrogen fixation, grain protein and yields.

Zn uptake

The nutrient uptake in any crop is the resultant of crop yield and nutrient concentration in plant tissue/grain. Umesh and Shankar (2013) revealed significantly higher zinc uptake by pigeonpea with the application of $ZnSO_4$ @ 12.5 kg ha^{-1}. The combined application of Zn with FYM in greengram also showed significant increment in zinc uptake by greengram (Ranpariya *et al.,* 2017). Similarly, Kumawat *et al.* (2015) studied the effect of integrated nutrition on productivity and nutrient uptake of rainfed pigeonpea. The results showed that the application of 100% recommended dose of fertilizers + 50% recommended dose of nitrogen through vermicompost + 5 kg Zn ha^{-1} recorded significantly higher total uptake of N, P, K, S and Zn. Roy *et al.* (2014) studied the response of greengram to application of Zn @ 0,5.5 kg, 22 kg Zn ha^{-1}, 0.1% Zn foliar application, 5.5 kg Zn ha^{-1} + 0.1% Zn spray and reported that the combined application of 5.5 kg Zn ha^{-1} + 0.1% Zn as foliar spray significantly increased the Zn concentration in straw and seed and total zinc uptake. The relationship between the bio-accumulation of zinc and the zinc concentration in the nutrient solution has been noted earlier by Cui and Wang (2005); Sharma and Agrawal (2006). Recently, an increment of 18-37% in total zinc uptake by pigeonpea under 0.5% foliar application of zinc sulphate was reported by Purushottam *et al.* (2018). In the present review, the zinc concentration in plant tissues increased with the increase in time and in the intensity of treatment. Leaf showed greater accumulation of zinc in the treatments receiving foliar application of zinc. The higher accumulation of the zinc in the plant tissues *viz*., leaf, stalk and grain resulted in the higher total zinc uptake. It is the compound effect of grain and stalk yield of their content.

The comprehensive review on the effects of different modes of zinc application on performance of crops especially pulses revealed that, the combined mode of zinc application involving soil zinc along with organic manures and foliar applications proved more beneficial among any sole mode of application with respect to increment in plant growth, yield and produce quality.

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Rec. on 05.05.2018 & Acc. on 25.05.2018