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Phosphorus build up in soil affecting zinc availability to plants in rice based cropping system

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ABSTRACT

Rice (Oryza sativa L.) is the most important food crops of India in terms of both area, production and consumer preference. India is the second largest producer and consumer of rice in the world. Long-term application of phosphorus fertilisers to agricultural fields and intensive cultivation can lead to P build up in soil which is a common practice generally followed by the farmers in rice based cropping system. Phosphorus is the most important element which interferes in zinc uptake by plants as it is assumed that zinc uptake by plants is reduced with increasing levels of phosphorus in soil. High levels of phosphorus may decrease the availability of zinc or the onset of zinc deficiency associated with phosphorus fertilisation may be due to plant physiological factors. In this short paper we briefly review this research, summarize some recent work and highlight some new data for the study of the effect of P build up in soil on the availability of Zn in plants in rice based cropping system.

Key words: *Biofortification, interaction, phosphorus build up, rice, zinc availability*

INTRODUCTION

The rice-wheat cropping system is the world's largest agricultural production system occupying 24 million ha throughout India and China alone and around 85% of this area falls in the Indo-Gangetic plain (IGP) (Shukla et al., 2005). Rice is the primary food source for more than one third of world's population (Prasad et al., 2010) and provides 21 % of energy and 15 % of protein requirements of human populations globally (Maclean et al., 2002; Depar et al., 2011). In Asia, India has the largest area under rice cultivation (44.3 million ha) accounting for 29.4 per cent of the global rice area (Mahata et al., 2012). West Bengal is one of the leading states for rice cultivation in India. But, due to continuous growing of high yielding varieties with the use of high analysis macronutrients in cropping system, the soils are poor in micronutrients. The deficiencies of micronutrients are of critical importance for sustaining high productivity of rice in India. Zinc (Zn) is one of the essential plant micronutrients and its importance for crop productivity is similar to that of major nutrients (Rattan et al., 2009). Zn deficiency is also quite widespread in the IGP (having calcareous soils with high pH) and other important states like Punjab, Uttar Pradesh, etc. which account for almost three-fourths of the country food grain production.

The increased use of phosphorus (P) fertilizers as well as fertilizers with less Zn-containing impurities can exacerbate Zn deficiency (Loneragan and Webb, 1993). Almost 50 per cent of the world soils used for cereal production is Zn deficient (Gibbson, 2006) which reduces not only grain yield but also nutritional quality (Graham and Welch, 1996). In West Bengal, about 30% of cultivated soils are deficient in plant available Zn (Singh, 2009).

As in the case with plants and soils, Zn deficiencies are also the most widespread micronutrient deficiencies in humans. Zn deficiency is the fifth most important risk factor of human disorders affecting one-third of the world's population (approximately two billion people), with prevalence rates ranging from 4 to 73% in various regions (WHO, 2002), causing serious health and productivity problems for various population groups, especially among resource-poor women, infants and children. These deficiencies are particularly widespread in developing countries where diets are rich in cereal-based foods (for calorie and protein intake) with low concentration of bio-available Zn (Biesalski, 2013). An estimated 30% of the world's population experiences inadequate dietary Zn intake (Brown and Wuehler, 2000).

Zinc in soil

Soil Zn occurs in three primary fractions: (i) water-soluble Zn (including Zn^{2+} and soluble organic fractions); (ii) adsorbed and exchangeable Zn in the colloidal fraction (associated with clay particles, humic compounds and Al and Fe hydroxides); and (iii) insoluble Zn complexes and minerals (reviewed by Lindsay, 1979; Barrow, 1993; Alloway, 1995; Barber, 1995). Zn^{2+} typically accounts for up to 50% of the soluble Zn fraction and is the dominant plant-available Zn fraction. Chattarjee and Khan (1997) reported that DTPA extractable zinc varied from 1.8 to 77.3 mg kg^{-1} soils in Alfisols of West Bengal. Saha et al. (1982) suggested that the mean value of available Zn content in the soils of West Bengal was 1.71 mg/kg. The critical soil levels that lead to Zn deficiency vary between 0.6 and 2.0 mg Zn/kg soil depending on the Zn extraction method (Singh et al., 2005). Based on greenhouse and field experiments, approximately 0.6 mg/kg DTPA-extractable Zn has been suggested as a critical concentration for wheat grown in calcareous soils of arid regions in India (Sadeghzadeh, 2013).

Factors affecting availability of soil zinc to plants

The term "availability" is commonly used to describe the ability of plants to take up nutrients from the soil. Zn availability to plants can be affected by various factors of which some of them are discussed here.

Soil reaction (pH)

Soil reaction may modify the uptake of zinc by influencing the activities of soil micro-organisms and changing the ability of the plant to absorb or transport to the top, the stability of soluble and insoluble organic complexes of Zn, the solubility of antagonistic ions, any rhizosphere effects etc. Zn deficiency has frequently been recorded on calcareous soils of the Indo-Gangetic plains with pH > 8.0 (Qadar, 2002; Srinivasara et al., 2008). The solubility of Zn decreases by a factor of 10^2 for each unit increase in soil pH (Lindsay, 1991). Precipitation of Zn in the form of $ZnCO_3$, $Zn(OH)_2$ and Zn_2SiO_4 in high pH soils also lowers Zn availability to plant roots (Ma and Lindsay, 1993).

Organic matter

Soil organic matter plays a critical role in solubility and transport of Zn to plant roots (Obrador et al., 2003; Cakmak, 2008). Soils low in organic matter such as subsoils demonstrate clearly the negative effects of Zn deficiency on plant growth in pot experiments (Özkutlu et al., 2006). The presence of organic matter in the soil very often promotes the availability of zinc by forming complexes with the substances that fix Zn. Fulvic acids mainly form chelates with Zn over a wide range of pH and increases the solubility and mobility of Zn (Kiekens, 1995). Simple organic compounds like amino acids, hydroxy acids and phosphoric acids are effective in forming complexes with Zn, thus increasing its mobility and solubility in soils (Pendias and Pendias, 1992). However, if the organic matter content in soil is too high, like in peat and muck soils, Zn deficiency is caused by binding Zn to solid state humic substances (Katyal and Randhawa, 1983).

Liming

Liming of acidic soils increases pH and also the Zn fixing capacity, particularly in soils with high P levels (Alloway, 2004). Limimg induces Zn deficiency by reducing the uptake of zinc by the crop due to lower movement of Zn in limed soil (Viets, 1966).

Soil texture

Heavier textured soils with larger CEC have higher capacities for Zn adsorption than light textured soils (Stahl and James, 1991). Consequently, Zn deficiency is more likely to occur in sandy than clayey soils.

Soil moisture

Sufficient soil moisture is necessary for an adequate Zn diffusion to plant roots (Cakmak, 2008). But in peat and coastal saline soils, submergence is the primary factor responsible for Zn deficiency (Quijano-Guerta et al., 2002). Decreased Zn solubility and low uptake of zinc in poorly drained soils is due to the co-precipitation of Zn with soluble iron and aluminium in the soil (Sadeghzadeh, 2013).

Soil temperature

A colder root zone temperature decreases root colonization with vesicular-arbuscular (VA) mycorrhizae, root growth, Zn uptake and Zn translocation into the shoots and thus increases the incidence and severity of Zn deficiency symptoms (Moraghan and Mascagni Jr, 1991).

Nutrient interactions

Reports are there that excess or prolonged use of phosphate fertilizers in Zn deficient soils reduces uptake of Zn and causes imposed deficiency of Zn in the plants (Alloway, 2008). This effect may be due to the physiological imbalances within the plant (Olsen, 1972). Zinc deficiency due to phosphorus application is termed "P-induced Zn deficiency" (Singh et al., 1986). Besides P negative interaction of soil Zn was also reported with N, Ca, Mg, S, Fe, Mn, Cu and Mo (Prasad, 2006).

P build-up in soil

Phosphorus is an important plant macronutrient, making up about 0.2% of a plant's dry weight. It is a component of key molecules such as nucleic acids, phospholipids and ATP and consequently, plants cannot grow without a reliable supply of this nutrient (Schachtman et al., 1998). In many agricultural systems in which the application of P to the soil is necessary to ensure plant productivity, the recovery of applied P by crop plants in a growing season is very low, because in the soil more than 80% of the P becomes immobile and unavailable for plant uptake because of adsorption, precipitation, or conversion to the organic form (Holford, 1997). Converting stable forms of soil P to labile or available forms usually occurs too slowly to meet crop P requirements. Therefore, continual long-term application of fertilizer or manure at levels exceeding crop needs lead to P build up and interactions in soils and/or plants affecting agricultural production (Barber, 1995).

When phosphatic fertilizers are added, part of them go to soil solution and is taken up by plants, while rest goes to exchange sites and is either adsorbed or precipitated and is a serious problem (Sharif et al., 2000). However, available phosphorus build-up was significant wherever farmers practiced higher doses of fertilizer application (intensive cropping and cultivation) and paddy cultivation (Kuligod et al., 2009). Rehman et al. (2007) found that the mean phosphorus fertility build-up factor (mg P required to build 1 mg P kg^{-1} soil) was 16.23 and the level of P build up (mg P kg^{-1} build-up in soil for each mg P kg^{-1} soil applied) was 0.062 in a Typic Camborthid (Sultanpur series) soil of rice tract of the Punjab, Pakistan. Ghosh et al. (2000) in a research experiment studied that there was a theoretical surplus of 22.45 kg P ha^{-1} under NPK treatment and this P build-up was more pronounced when it was supplemented with 10t FYM ha^{-1}. Similarly, Wani et al. (2007) noted that among nutrients, N and K were depleted from soil while P was build up under soybean based cropping system. Singh et al. (1998) in an experiment found that there was a theoretical surplus of 38 kg P/ha when a total of 70 kg P/ha was added annually through fertilizers under NPK treatment, and this P build up was more pronounced with higher NPK application. Reddy et al. (2006) showed a marked build-up with P application particularly at higher rates.

Phosphorus and Zinc interactions

Phosphorus is the most important element which interferes on zinc uptake by plants. High available P can emphasize visual Zn deficiency symptoms in plants (Das et al., 2005; Khorgamy and Farnis, 2009; Salimpour et al., 2010). This is called P-induced Zn deficiency. Zn-induced P deficiency is very rare because growers commonly apply the large amounts of P fertilizer as compared to Zn fertilizer (Cakmak and Marchner, 1987). The main reasons for effect of high levels of phosphorus on zinc deficiency can pointed to the following:

- Zinc transport from plant roots to shoot reduces due to high concentrations of phosphorus, so zinc accumulates in roots or its uptake decreases by roots.
- Zinc concentration in shoots of plants decreases by effect of induced growth response (dilution effect); *i.e.,* amount of zinc uptake in plant increases by increasing plant growth but its concentration decreases in plant tissues, in other words that element is diluted in plant tissues.
- Metabolism in plant cells is altered due to zinc and

phosphorus imbalance, so by increasing the phosphorus concentration, zinc uptake is impaired at specific positions in the cells (Mirvat et al., 2006; Mousavi, 2011).

In absence or low concentrations of zinc, phosphorus uptake and transport increased in the shoot and its concentration increased in the leaves, as a result can cause toxicity in the plant. This increase only occur zinc deficiency and was not observed in other micronutrient deficiencies; i.e., zinc deficiency increases the permeability of plasma membrane of the root compared to phosphorus (Bukvic et al., 2003; Mousavi, 2011).

Application of phosphorus has been reported in some cases to cause a decrease in the total uptake of zinc in plants (Loneragon, 1951; Stukenholtz et al., 1966), while in others it has shown either to have no effect or increased the uptake (Watanabe et al., 1965; Jackson et al., 1967).

Different crops such as beans, maize, potatoes, soybeans, sorghum, flax, citrus, rice, wheat, tomatoes, and hops have been reported to have experienced P-Zn interactions with a consequent detrimental effect on plant growth (Murphy et al., 1981). Although P interacts with many nutrients, the most commonly observed and studied antagonistic interaction is with Zn.

The results of a green house experiment by Haldar and Mandal (1981) shows that the concentration of Zn in shoots and roots decreased with the increase in P application. The results also shows that although the dry matter yield of both shoot and root increased due to P application, the uptake of Zn by the shoot declined while that in roots increased which suggests that the decrease in Zn concentration in shoots is not possible due to a dilution effect. It may, therefore, be attributed partly to retardation of its translocation from root to shoot and partly to the decrease in its absorption by plants owing to its decreased availability in soil resulting from P application.

Shivay and Kumar (2004) studied the effect of P and Zn fertilisation on the productivity and P uptake of aromatic rice under transplanted puddled conditions in a field experiment. It was found that the interaction effect of P and Zn on growth, yield attributes, grain yield, and P uptake of rice was not significant. The optimum proportion of both these nutrients is required to realise higher plant growth and yield. Shivay and Kumar (2005) studied that the moderate levels of P did not induce Zn deficiency in the crop and subsequently the interaction effect of Zn and P was not significant. But excess application of P fertiliser can induce Zn deficiency and increase plant requirements for Zn (Robson and Pitman, 1983).

Application of P caused a decrease in the water soluble plus exchangeable and organic complexes with a concomitant increase in the amorphous and crystalline sesquioxide bound forms of native soil Zn (Mandal and Mandal, 1990). Tagwira et al. (1992) in a research reported that increase in pH and P application decreased available and organic Zn and increased unavailable forms. Whereas, application of $ZnSO_4$ increased the amounts of Zn retained in the available and organically-found Zn forms. Again in 1993 he concluded that P application decreased Zn availability and increased cation exchange capacity of soil.

Rupa et al. (2003) reported that phosphorus additions up to 40 mg kg^{-1} soil increased the plant-available Zn in soils whereas at higher P levels plant-available forms decreased with a concominant increase in the inert forms. At 160 mg P kg^{-1} soil, the P effect was more pronounced in the shoot than in the root, suggesting that a higher P level inhibits Zn translocation from root to upper plant parts. Agbenin (1998) found that fertilizer-P placement around a growing crop plant which maximize fertilizer-P efficiency, can potentially limit Zn solubility and availability in a tropical semi-arid soil. It was also found that the P-treated soil retained 93±2 % of added Zn compared with 52±2 % of the control soil.

Tomar et al. (2003) reported that shoot Zn concentration and DTPA extractable Zn progressively decreased with increasing levels of DAP, while Zn uptake increased up to 40 mg P kg-1 and then decreased at 60 mg P kg^{-1}. Perez-Novo et al. (2011) stated that the proportion of Zn desorbed after adsorption in the presence of P in acid soil was significantly lower than in the absence of P which indicates that Zn binds more strongly to adsorbing surfaces in the presence of P than in its absence. Perez-Novo et al. (2011) again reported that the presence of P, especially at high concentrations, was found to boost Zn adsorption which is ascribed primarily to the formation of a P-Zn complex in colloid surfaces. Zou and Mo (1993) discussed the effect of P fertilizer on the various fractions and on Zn availability.

Site of P-Zn Interaction

Many researchers have reported that applied P accentuated Zn deficiency symptoms in plants (Sharma, 1968; Loneragan et al., 1979). The higher P levels in soil reduced the Zn concentrations in the plant tops and also reduced total Zn contents (Singh et al., 1986). They suggested that P-Zn antagonism existed in the roots of the plants. Khan and Zende (1977) also suggested that the plant roots are mainly involved in Zn-P interaction and the interaction originate in the plant roots, thereby retarding the translocation of each other to upper plant parts. Other studies suggested that although P decreased the Zn concentrations in the tops, the total Zn contents either increased or remained the same (Boawn and Brown, 1968a; Boawn and Leggett, 1968b).

Under conditions of high Zn application, P may circumvent Zn in roots by the formation of Zn-phytate (Rupa et al., 2003). Formation of sparingly soluble Zn phosphates in the apoplast of the root cortex might be a reason for uneven Zn distribution between roots and upper plant parts (Cakmak and Marschner, 1987).

According to Dwivedi et al. (1975), the P concentration reduced in the node and increased in the internodes. It was suggested that the P formed organic substances which accumulated at the internodes. This accumulation weakens the translocation of Zn and when the Zn status increases, it competes with synthesized organic complex and moves upwards. For this reason, Zn accumulated at the nodes when P is available at low concentration.

Interaction in rice based cropping system

The symptoms of Zn deficiency in rice were corrected by $ZnSO_4$ but increased by P applied without Zn (Yanni, 1992). According to Mandal and Mandal (1993), application of organic matter might be useful in overcoming the adverse effect of P application on availability of Zn in soils and its utilization by rice.

High P decreased Zn uptake by wheat plants and its upward translocation, but it promoted Zn fixation on the cell walls of the leaf cells of maize, resulting in the deactivation of Zn in the shoots (XiuLan et al., 1998). Singh and Choudhary (2002) in an experiment recorded highest straw and grain yields, number of grains per ear, and test weight of wheat with the application of 20 kg P and 10 kg Zn/ha on clay loam soil. High rates of P application decreased shoot Zn, Cu and Fe contents of maize (Heggo and Barakah, 1994). The highest dry matter production, number of grains per spike, 1000-grain weight, grain and straw yields of wheat were recorded with the application of 75 kg/ha P_2O_5 and 10 kg $ZnSO_4$/ha. However, further increase in phosphorus level (up to 112.5 kg/ha P_2O_5) resulted in lower uptake of Zn and Fe (Nataraja et al., 2005). Hussain et al. (2005) recorded significant interaction effect of P and Zn on plant height, spike length, spikelets per spike, number of grains per spike, biological yield, straw yield and harvest index of wheat. According to Kizilgoz and Sakin (2010) increasing soil P supply increased shoot P concentration, while decreased shoot dry matter of wheat (due to P-induced Zn deficiency) and shoot Zn concentration of maize (due to P toxicity and Zn deficiency).

According to Barben et al. (2007) high P levels in potato did not directly reduce Zn content or cause Zn deficiency, but high P may reduce the activity of Zn by interacting with other micronutrients such as Mn. Excessive P fertilizer application to potatoes can reduce Zn uptake (Christensen and Jackson, 1981), yield and tuber size (Idaho Potato Commission, 1997).

Izsaki (2008) reported that the increasing P supplies increased the P and reduced the Zn concentration in the maize leaves at the beginning of tasselling as well as the P/Zn ratio became wider. Muner et al. (2011) found that the critical levels of Zn were higher when P was placed in smaller soil volumes. P placement affected the Zn content in corn plant. Ronaghi et al. (2002) proposed that applied P increased P concentration and total uptake in plants, but decreased Zn concentration and had no effect on Zn uptake in corn.

According to Singh et al. (1997) P application had an antagonistic effect on Zn concentration in barley, however uptake of Zn was increased with up to 60 mg P/kg soil. Li et al. (2003) recorded that tissue Zn concentrations decreased significantly with an increase in P supply in barley cultivars. The increase in P supply drastically reduced the molar ratio of Zn to P in shoots (MRZP), and addition of Zn compensated for the reduction in MRZP due to P addition.

P applications had been reported to increase wheat grain yield, but reduce Zn concentration in both grain and straw of winter wheat (Ryan and Angus 2003; Ryan et al. 2008; Zhang et al. 2012). The physiological processes such as the uptake of Zn by root, the root-to-shoot translocation of Zn may contribute to the stable shoot Zn content and, consequently, a reduced grain Zn concentration by increasing P applications (Zhang et al. 2012). Zhang et al. (2012) also concluded that foliar Zn application may be needed to achieve both favourable yield and grain Zn quality of wheat in production areas where soil P is building up.

Role of Zn in plants

Zinc is one of the eight trace elements that are essential for normal, healthy growth and reproduction of plants. It is required as a structural component of a large number of proteins, such as transcription factors and metalloenzymes (Figueiredo et al., 2012). The Zn plays very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome (Tisdale et al., 1984). Plant enzymes activated by Zn are involved in carbohydrate metabolism, maintenance of the integrity of cellular membranes, protein synthesis, regulation of auxin synthesis and pollen formation (Marschner, 1995). The regulation and maintenance of the gene expression required for the tolerance of environmental stresses in plants are Zn dependent (Cakmak, 2000). Zinc seems to affect the capacity for water uptake and transport in plants and also reduce the adverse effects of short periods of heat and salt stress (Disante et al., 2010; Peck and McDonald, 2010). As Zn is required for the synthesis of tryptophan which is a precursor of IAA, it also has an active role in the production of an essential growth hormone auxin (Alloway, 2004). The interaction of Zn with phospholipids and sulphydryl groups of membrane proteins contributes for the integrity of cellular membranes to preserve the structural orientation of macromolecules and ion transport systems (Cakmak, 2000; Disante et al., 2010; Dang et al., 2010).

Zn deficiency in plants

After N, P and K, widespread Zn deficiency has been found responsible for yield reduction in rice (Fageria et al., 2002; Quijano-Guerta et al., 2002) along with poor nutritional quality (Welch and Graham, 1999). For instance, a significant decrease (80 %) in grain Zn concentration was observed in cereals grown on soils with low plant-available Zn (Cakmak et al., 1997). This decrease in grain Zn also reduces its bioavailability in humans and may contribute to Zn deficiency in susceptible human populations (Cakmak, 2008; Hussain et al., 2012). The critical (or threshold) concentration of Zn in tissues varies with plant species, cultivar, age of the plant, plant part and the environment. The critical Zn concentrations in leaves vary between 20 mg Zn/kg in wheat, 15 mg Zn/kg in rice and 22 mg Zn/kg in maize and groundnut. However, differences can also occur between different varieties of these crops (Alloway, 2001).

The deficiency of this micronutrient frequently occurs in rice which is very sensitive to low Zn supply in submerged rice soils (Hazra et al., 1987). Deficiency symptom in rice appears when tissue levels fall below 20 mg/kg (Takkar, 1991). Zn deficiency causes multiple symptoms that usually appear 2 to 3 weeks after transplanting (WAT) rice seedlings. Common deficiency symptoms of Zn are interveinal chlorosis, first appearing on the young leaves, reduction in the size of young leaves, characteristic brown rusty spots, which coalesce and form continuous brown areas. In the case of acute deficiency, the whole leaf turns brown and dries and plants may succumb. An uneven stand of rice and stunted plants with brown rusty appearance are indicative of Zn deficiency. "Khaira" disease is another name for Zn deficiency in rice. The "Khaira" disease first described from terai soils of the Nainital district in U.P. was reproduced by Mandal and Das (2013) in rice variety, "IR-8" in refined sand culture at Lucknow.

Biofortification

Zinc deficiency in humans affects physical growth, the functioning of the immune system, reproductive health and neurobehavioural development. Therefore the zinc content of staple foods, such as rice and wheat, is of major importance. Biofortification can be achieved in two distinct ways: (1) increase the enrichment of bioavailable micronutrients in the plant parts to be consumed through breeding or genetic engineering (genetic biofortification) (Welch and Graham 2004; White and Broadley 2005), and (2) enhance the total accumulation of the deficient micronutrients through agricultural methods of crop cultivation, in particular fertilization (agronomic biofortification) (Graham et al. 2001; Welch 2002). Although the plant breeding route is likely to be the most cost-efficient approach in the long run, for the time being, the use of fertilisers is necessary to improve the zinc quantity in diets while the plant breeding programmes are being carried out. Hence, in addition to ensuring that crop yields are not restricted by deficiency, zinc fertilisers will be used, where necessary, to increase the zinc quantity of staple foods. Increasing mineral content of staple food crops through bio-fortification is the most feasible strategy of combating micronutrient malnutrition. Additionally, it will also enhance the agronomic efficiency of crops on mineral poor soils. Agronomic biofortification strategy appears to be essential in keeping sufficient amount of available zinc in soil solution and maintaining adequate zinc transport to the seeds during reproductive growth stage. Finally, agronomic biofortification is required for optimizing and ensuring the success of genetic biofortification of cereal grains with zinc. Prasad et al. (2013) suggested that agronomic bio-fortification is an effective and faster method for increasing grain Zn concentration in cereals. Hazra et al. (2015) also revealed that foliar application of Zn was effective than soil application regarding Zn biofortification of rice. They also reported that two foliar spraying of Zn along with basal application increased the grain and straw Zn concentration up to two to three folds.

Zinc deficiency can be corrected by either soil application or foliar spray of Zn through zinc sulphate ($ZnSO_4.7H_2O$) which contains around 22% Zn. As an emergency treatment spray application is done. It is suggested to use 5-10 kg actual Zn per hectare, representing about 25 to 50 kg zinc sulphate material. Low Zn levels (25 kg $ZnSO_4$ ha^{-1}) are recommended for sandy soils and high Zn levels (50 kg $ZnSO_4$ ha^{-1}) for heavy texture clayey soils and in areas where rice is grown on saline-alkali and permanently wet soils. Generally, Zn does not move far in the soil, so it is important to place it where the roots can get it. The successful methods of application are to broadcast zinc sulphate and to plough it in or to drill it in the soil below and on a side of the seed. For Zn treatment to be fully effective, it is essential to apply it prior to sowing or transplanting of the crops.

In case Zn deficiency is diagnosed after sowing or transplantation of a crop, it is preferentially cured by two to four, weekly foliar sprays. Foliar applications of micronutrients are more suitable than the soil application, due to, easy to use, reduce the toxicity caused by accumulation and prevent of elements stabilization in the soil. It is expected that large increases in loading of Zn into grain can be achieved when foliar Zn fertilizers are applied to plants at a late growth stage. In case of greater bioavailability of the grain zinc derived from foliar applications than from soil, agronomic biofortification would be a very attractive and useful strategy in solving zinc deficiency related health problems globally and effectively (Cakmak, 2008; Abd El-Baky et al., 2010; Yosefi et al., 2011).

Shivay et al. (2008) have reported that Zn application to soil as $ZnSO_4$ or Zn enriched/coated urea not only increased yield but also Zn concentration in rice and wheat grain. Gao et al. (2012) also concluded that addition of Zn fertilizers by soil or foliar application have been shown to increase Zn concentration in cereal grains. Cakmak (2008) summarized that the most effective method for increase in grain Zn concentration was the soil plus foliar application method that result in about 3.5 fold increase in the grain Zn content. He also stated that timing of foliar Zn application is an important factor for determining the effectiveness of the foliar applied Zn fertilizers in increasing grain Zn concentration.

Depending on the plant species, soil application of Zn can increase Zn concentration of plants by as much as 2-3 fold (Rengel et al., 1999). Large increases in grain yield by Zn applications were also demonstrated in Australia (Graham et al., 1992) and India (Tandon, 1998). On the other hand, Zhang et al. (2012) and Wang et al. (2012) found that zinc fertilizer application did not improve the biomass and grain yields of wheat and maize in rain-fed calcareous soil. Wei et al. (2012) also found that in the Zn sufficient soil, excess foliar application of Zn did not affect the biomass, grain yield, harvest index and thousand seed weight in rice.

Interestingly, it has been shown in field experiments in Central Anatolia and Australia, Zn deficiency in wheat can easily be corrected, and yield maximized by broadcast application of Zn fertilizers; however, broadcast application of Zn is not very effective in increasing Zn concentrations in grains up to desired levels to meet human requirements (Graham et al., 1992; Yilmaz et al., 1997).

Katyal and Rattan (2003) observed that Zn deficiency could be eradicated satisfactorily either by soil application or by foliar spray of Zn fertilizer. Ali and Venkatesh (2009) observed that among micronutrients, application of 10-25 kg $ZnSO_4$ per hectare depending upon the soil status was found optimum for increasing pulse productivity. Gill and Singh (2009) reported that foliar application of micronutrients particularly Zn, Fe and Mn proved highly economical than their soil application to enhance the food grain production. Dhaliwal et al. (2009) also reported that foliar application of Zn and Fe significantly increased the grain yield of wheat varying from 2.5 to 5.1 percent irrespective of varieties.

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CONCLUSION

Our extensive review of literature has shown that P gets build up due to long term P fertilization in intensively cultivated area of rice based cropping system especially in Indogangetic plain which affects Zn availability in soil and leads to Zn deficiency in plants. When the Zn concentration is low in soil, these symptoms becomes aggravated with higher doses of P supply, indicating P-induced Zn deficiency. As a result its deficiency in increasing in all parts of the world in different t types of soils. Under these conditions application of Zn fertilizer is necessary for healthy crop growth and higher yields. Soil and foliar applications of Zn fertilizer are recommended to correct the deficiencies. Foliar Zn application may be integrated with improved P management to achieve both high grain yield and high grain Zn quality.

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