DOI: 10.32606/IJSR.V10.I1.00036 Received: 25-03-2019 Accepted: 27-07-2019

Indian J.Sci.Res. 10 (1): 225-229, 2019 Review Article ISSN: 0976-2876 (Print)
ISSN: 2250-0138 (Online)

SOIL FACTORS AFFECTING ZINC AVAILABILITY FOR CEREAL CROPS

DEVASHISH SINGH[a1] AND SUMAN SHARMA[b]

[ab]Department of Botany, Harishchandra P.G. College, Varanasi, Uttar Pradesh, India

ABSTRACT

Zinc (Zn) deficiency is one of the most important micronutrient disorders affecting human health. Among cereal crops, wheat is the most sensitive to Zn deficiency. Wheat is the staple food for 35% of the world's population and is inherently low in Zn, which increases the incidence of Zn deficiency in human. Zn deficiency is most likely to occur in plants growing on calcareous soils with inherently very low organic matter content. Zinc is most often applied to crops through soil and foliar methods. The application of Zn through seed treatments has improved grain yield and grain Zn status in wheat.

KEYWORDS: Zinc, Wheat, Biofortification

Zinc (Zn) deficiency in higher plants was first reported by Sommer and Lipman (1926). Zinc deficiency is prevalent in cereal crops, several parts of the world, resulting in low yields and poor quality grains (Cakmak *et al*. 1999). In extremely Zndeficient areas where wheat could barely produce grain, Zn fertilization alone increased wheat grain yield by 550%. Wheat also has higher concentrations of fiber and phytate, which further reduces Zn absorption by humans. The phytic acid concentration in wheat grains varies greatly depending on the milling fraction, with bran having the largest and endosperm (i.e. processed white flour) the smallest share. Zinc deficiency is widespread in RWCSdue to the sequential cropping of rice and wheat, high soil pH, and the formation of insoluble complexes of Zn with carbonates and bicarbonates (Rehman *et al.* 2012).

The zinc concentration in soil varies depending on soil type. However, the mean concentration varies from 17– 125 µg g^{-1} with an average worldwide soil Zn concentration of ~64 µg g^{-1} for uncontaminated soils. Solonchaks, alluvial and rendzinas soils have the highest mean Zn concentrations while light organic and mineral soils have the lowest mean values .Soils with less than 10 µg g^{-1} Zn are considered deficient while soils with >200 µg g^{-1} Zn are contaminated from different sources (Alloway 2009). Availability of soil Zn to plant roots is determined by the physiochemical properties of soils (e.g. Zn content, pH, organic matter and clay content, temperature, moisture) as well as root exudates and soil microorganisms. The following section discusses the factors affecting Zn availability to wheat.

SOIL pH

Soil pH is the most critical factor influencing Zn availability to crop plants, as Zn availability to crops largely depends on differences in soil pH. Zinc uptake decreases significantly with increasing soil pH from 4.6 to 6.8 (Fageria *et al*. 2002). Wheat grown on high pH/alkaline soils with high clay contents may suffer Zn deficiency as Zn availability decreases on calcareous soils due to increasing soil pH and high concentrations of $CaCO_3$. $CaCO_3$ is highly adsorptive and retains Zn through chemisorptions. Sorption/desorption experiments with Zn indicated that the lack of availability of Zn in these soils was due to chemisorption on $CaCO_3$. In Zn-sufficient soils, $CaCl_2$ subsequently desorbed about 20% of the additional sorbed Zn, but in Zn-deficient soils, only 1% of additional sorbed Zn was desorbed (Cakmak 2008). The Zn-binding strength increased up to seven-fold with 0.05% Fe coating on calcite which severely reduced Zn availability to plants resulting in a higher incidence of Zn deficiency (Uygur and Rimmer 2000). High soil pH reduces Zn availability.Plant uptake zinc as Zn^{2+} via the ZIP transporter or secretion of phytosiderophores. Soil physiochemical properties (soil pH, organic matter, moisture, soil microflora and root structure) influence Zn availability in the soil. Moreover, wheat roots and soil microbes release organic acids, such as citrate and malate, to increase Zn solubility. Zinc moves through apoplastic and symplastic pathways followed by loading in the xylem and transfer to the phloem. Xylem loading ofZn takes place through HMA pumps. Some of the Zn may sequester in the vacuole route to xylem after absorption from soil. Zinc moves from xylem with the help of transport proteins to living xylem parenchyma cells in the leaf symplast; from here, it is transferred to the leaf apoplast and then to phloem, which is the vascular route of Zn translocation into developing seed. Zn transfers from the ear to maternal tissue and then to endosperm. Loamy soils or heavily limed sandy soils may also have high calcite contents with pH>7, which can reduce plant Zn uptake. However, soils with low pH and calcite are common in tropical regions and should be limed to increase cereal production (Fageria and Stone 2008). In summary, high soil pH/alkaline soils are linked to Zn sorption on carbonates,

[1]Corresponding author

hydroxides and clay minerals, and thus limit Zn uptake by plants.

SOIL ORGANIC MATTER

Soil organic matter plays an important role in Zn solubility and its availability to growing plants. Zinc deficiency is prevalent in soils, which are naturally high or low in organic carbon, waterlogged, or light-textured (Ahmad *et al.* 2012). In soils with low organic matter content, increasing the amount of soil organic matter can enhance the formation of soluble complexes, which may increase Zn uptake by plants .The addition of organic matter to such soils, enhances Zn bioavailability to plants. Soil organic matter itself can influence Zn adsorption; soils with high organic matter content may exhibit higher Zn adsorption than soils with low organic matter content (Gurpreet-Kaur *et al.* 2013). Moreover, soil type affects Zn adsorption as peat soils are naturally deficient in Zn due to adsorption, and further liming of these soils reduces Zn availability to plants (Abat *et al.* 2012). Alloway (2004) noted a significant positive correlation between soil extractable Zn and soil organic matter content. Mandal *et al.* (1988) reported that the addition of organic matter increased Zn bioavailability to rice plants. Clark (1982) stated that. In general, soils with very low organic matter cannot maintain ample reserves of available Zn and are more vulnerable to Zn deficiency. In mineral soils, organic matter content rapidly decreases with increasing soil depth accompanied by a decline in DTPA-extractable Zn (Alloway 2008). However, the addition of organic matter that decomposes quickly, such as manure, will form soluble Zn complexes and thus enhance Zn mobility and absorption by roots. Chelation of Zn by organic matter resists the formation of insoluble oxides and carbonates so that Zn in more accessible to plant roots in the rhizosphere (Schulin *et al.* 2009). In conclusion, Zn availability in soils is influenced by soil organic matter. Furthermore, the nature and content of organic matter are decisive factors for the availability and thus uptake of Zn by plant roots. Organic matter that decomposes promptly increases Zn availability due to the formation of soluble Zn complexes**.**

SOIL TEMPERATURE, MOISTURE AND LIGHT INTENSITY

Environmental factors influence Zn availability as Zn deficiency is most prevalent in arid and semiarid regions where the topsoil is often low in plant-available water under rainfed conditions. Plants become more sensitive to Zn deficiency under low water availability. Under limited water supply, Zn movement in the soil is limited that restricts the Zn uptake by plants (Marschner 2012). Several studies concluded that the growth of Zn-deficient plants is poor under water-limited conditions and that the sensitivity to Zn deficiency is more pronounced when plants are drought-stressed (Hajiboland and Amirazad 2010). These studies also pointed out that, in drought-stressed plants, the effect of irrigation on grain yield is maximized with adequate Zn fertilization. Soil temperature also influences Zn availability as wet and cool seasons result in reduced Zn availability due to the reduced rate of soil mineralization (i.e. the liberation of Zn in organic matter by decomposition. Zinc deficiency is exacerbated in cool seasons as low temperatures restrict organic matter decomposition, root growth (Alloway 2008) and mycorrhizal colonization, which further limit plant Zn uptake. Long day lengths and exposure to high light intensity also induce Zn-deficiency symptoms (necrosis and chlorosis of leaves) and related physiological responses such as impaired ROS detoxification (Marschner and Cakmak 1989). To summarize; environmental factors such as low soil temperature, less precipitation, long day lengths and high light intensity are linked to Zn deficiency owing to poor root growth and physiological impairments due to ROS.

SOIL SALINITY AND INTERACTION OF Zn WITH OTHER ELEMENTS

Zinc deficiency is most common in arid and semiarid environments in saline soils. Higher Ca together with high pH reduces Zn availability to plants (Alloway 2008). Zinc uptake decreases under saline soils due to strong competition between Zn and salt cations at the root interface. For example, in saline–sodic soils, the exchange sites are occupied by Na^+ resulting in leaching of Zn, especially if the irrigated water has high Na^+ (Alloway 2008). The uptake of Zn declines in salt-affected soils contaminated with Cd due to the negative interaction of Zn with Cd and the formation of $CdCl_2$ (Khoshgoftar *et al.*, 2004). In addition, high soil electrical conductivity and pH, and a higher concentration of Ca, Na, Mg, and HCO_3 are the principal reasons for low Zn availability. The application of Zn to saline soil improves plant growth by limiting the uptake and translocation of Na^+, Cd^{2+} and Cl^- (Abd El-Hady, 2007). Zinc is a cation that interacts with almost all plant nutrients present in the soil, especially anions. For instance, Zn has a positive interaction with N in cereals as enhanced N supply increased the seed Zn concentration possibly by influencing the abundance of Zn transporters and level of Znchelating nitrogenous compounds (Kutman *et al.* 2010). For instance, increasing the rates ofN application to wheat enhanced root uptake and shoot translocation rate of Zn by 300% (Erenoglu *et al.* 2011). Increasing the rate of applied N also enhanced grain Zn concentration in wheat (Kutman et al. 2011). In contrast, Zn has a negative interaction with P. For example, increasing P application rates from 0 to 400 kg ha^{-1} reduced grain Zn concentration from 29 mg kg^{-1} to 13 mg kg^{-1} as higher rates of P application widened the P:Zn molar ratio thus reducing the bioavailability of Zn (Zhang *et al*. 2012). Recently, the negative interaction of P on grain Zn concentration was shown to be dependent on mycorrhizal infection as low or high P supply did not affect grain Zn when soil was sterile of mycorrhiza (Ova *et al*. 2015). Nevertheless, Zn had a positive interaction with K as Zn maintains membrane integrity and reduces leakage of K and amides. Sulfur application enhanced the Zn concentration in wheat. However, Zn suppressed the availability of Ca. High Ca concentration reduced Zn uptake and translocation, while Zn had a negative interaction with Cu and Mn. However, Zn can help to overcome B toxicityas it reduces B uptake. The Zn and Fe interaction is complex as Zn application either decreases, increases or does not influence Fe status. Under Zn deficiency, reduced expression of MTP3 and HMA3 in a Fedeficient mutant showed that Fe deficiency is linked with Zn accumulation as stunted growth and chlorotic leaves were visible at high levels of Zn (Gupta *et al*. 2016). In summary, saline soils limit Zn uptake due to a high concentration of Na on exchangeable sites together with other ions, i.e. Ca^{2+}, Cd^{2+}, and Cl^{-}. Zinc has a positive interaction with some elements (N, K and Mg, and Ca) while it suppresses the availability and uptake of others (P, Cu, Mn and B).

ZINC INTERACTION WITH SOIL BIOTA/MYCORRHIZAL COLONIZATION

Soil microorganisms can increase Zn uptake in plants. For instance, mycorrhizal colonization can effectively enhance the absorption of nutrients whose uptake is limited to diffusion from the soil solution to plant roots (Fageria *et al.* 2011). Arbuscular mycorrhizal fungi improved Zn uptake in several crops including wheat. Increased Zn uptake is due to colonization of AMF on plant roots, which increases the surface area via a hyphal network beyond the nutrientdeficient zone of roots. In a meta-analysis of 33 field studies, Pellegrino *et al*. (2015) reported that AMF increased grain yield and Zn concentration in wheat. Soil bacteria also help to enhance nutrient uptake. Among soil microbes, PGPRs are the most important as they increase nutrient uptake by colonizing the root surface due to signal transduction between the host plant and bacteria.In one study, identified *Bacillus subtilis*, *Bacilluscereus*, *Flavobacterium* spp. and *Pseudomonas aeruginosa* as Zn-tolerant bacteria that help to enhance Zn availability in soil and its uptake by plants. Bacillus aryabhttai also improved Zn accumulation in wheat grains by solubilizing the Zn bound to organic complexes and $CaCO_3$, and increasing soil exchangeable Zn due to enhanced activities of soil microbes and increased redistribution of available Zn in the rhizosphere (Ramesh *et al*. 2014). Naz *et al*. (2016) reported that Zn-solubilizing bacteria improved Zn uptake and partitioning in vegetative parts at different growth stages when used in combination with N and P fertilizer, as shoot Zn concentration increased with inoculation of *Azospirillum*; while inoculation with *Rhizobium*, *Pseudomonas* and *Azospirillum* increased the grain Zn concentration. For example, Rana *et al*. (2012) reported that inoculation of seed with *Providencia* sp. PW5 strain + recommended fertilizer increased protein and grain Zn concentrations by 18 and 24.3%, respectively, compared to the control. In conclusion, PGPR and AMF are effective for improving wheat Zn status by increasing root growth and Zn solubilization, and could be used along with chemical fertilizers to overcome Zn deficiency.

ZINC IN SOIL AND ITS DYNAMICS IN DIFFERENT WHEAT-BASED CROPPING SYSTEMS

Zinc is present in different inorganic and organic forms in the soil that influence its availability to plants. Zinc concentration varies depending on soil type. For instance, in mineral and organic soils, the Zn concentration is about 50 and 60 mg Zn kg^{-1} of soil, respectively. However, most agricultural land has a broad range from 10 to 300 mg Zn kg^{-1} of soil (Barber 1995).

Rice–Wheat Cropping Systems

The rice–wheat cropping system is a major cropping system around the globe, particularly in South Asia where more than 75% of this cropping system occurs in the Indo-Gangetic Plains of Pakistan (2.2 Mha), India (9.2 Mha), Bangladesh (0.4 Mha) and Nepal (0.6 Mha) which are severely deficient in Zn (Alloway 2009). The Green Revolution helped in the development of short-duration wheat and rice varieties to allow the rotation of two crops per season. Most soils in RWCS in the IndoGangetic. Zinc availability declines under anaerobic conditions compared with aerobic conditions. Under anaerobic conditions, soil pH decreases with a concurrent decline in macro and microelement availability, while in acidic soil, the soil pH increases and redox potential decreases. Most soils in RWCS are calcareous with a basic soil pH, which reduces the availability of Zn (Farooq *et al.* 2018). Soil pH is the key factor influencing Zn availability in the Indo-Gangetic Plains.Additionally, Zn translocation and uptake is restricted by the presence of high bicarbonate (HCO_3) in soils. Flooding initially increases the Zn concentration in soil solution, but will decline with time due to the formation of insoluble compounds such as franklinite, zinc carbonate ($ZnCO_3$) and zinc sulfide (ZnS). The formation of these compounds occurs due to the decomposition of soil organic matter. Moreover, green manure crops enhance Zn uptake and grain yield in wheat. For instance, in a basmati rice–durum wheat cropping system, the incorporation of dhaincha (Sesbania culeate) increased grain yield and grain Zn concentration in durum wheat (Singh and Shivay 2013). Zinc deficiency is widespread in RWCS due to the alkaline nature of soils, the presence of $CaCO_3$, and the conventional production practices for rice and wheat. The use of green manure crops along with chemical fertilizers can help to alleviate Zn deficiency in this cropping system.

REFERENCES

Abat M., Mc Laughlin M.J., Kirby J.K. and Stacey S.P., 2012. Adsorption and desorption of copper and zinc in tropical peat soils of Sarawak, Malaysia. Geoderma, **175–176**:58–63.

Abd El-Hady B.A., 2007. Effect of zinc application on growth and nutrient uptake of barley plant irrigated with saline water. J. Appl. Sci. Res., **3**:431–436.

Ahmad W., Watts M.J., Imtiaz M., Ahmed I. and Zia M.H., 2012. Zinc deficiency in soils, crops and humans: A review. Agrochimica, **2**:65–97.

Alloway B.J., 2008. Zinc in soils and crop nutrition, 2nd edition. International Zinc Association and International Fertilizer Industry Association, Brussels.207.

Alloway B.J., 2009. Soil factors associated with zinc deficiency in crops and humans. Environ Geochem Health, **31**:537–548.

Barber S.A., 1995. Soil nutrient bioavailability, 2nd edition. Wiley, New York.

Cakmak I., 2008. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? Plant Soil, **302**:1–17.

Cakmak I., Kalayci M., Ekiz H., Braun H.J. and Yilmaz A., 1999. Zinc deficiency as an actual problem in plant and human nutrition in Turkey: A NATO-science for stability project. Field Crop. Res., **60**:175–188.

Clark R.B., 1982. Plant response to mineral element toxicity and deficiency. In: Christiansen MN, Lewis CF (eds) Breeding plants for less favorable environments. Wiley, New York, pp. 71–142.

Cui Y. and Wang Q., 2005. Interaction effect of zinc and elemental sulfur on their uptake by spring wheat. J. Plant Nutr., **28**:639–649.

Erenoglu E.B., Kutman U.B., Ceylan Y., Yildiz B. and Cakmak I., 2011. Improved nitrogen nutrition enhances root uptake, root-to shoot translocation and remobilization of zinc (65Zn) in wheat. New Phytol., **189**:438–448.

Fageria N.K., Baligar V.C. and Clark R.B., 2002. Micronutrients in crop production. Adv. Agron., **77**:189–272.

Fageria N.K., Baligar V.C. and Jones C.A., 2011. Growth and mineral nutrition of field crops. CRC Press, Boca Raton.

Fageria N.K. and Stone L.F., 2008. Micronutrient deficiency problems in South America. In: Alloway BJ (ed.) Micronutrient deficiencies in global crop production. Springer, Dordrecht, pp 245–266.

Farooq M., Amanullah R.A., Nawaz A., Nadeem A., Wakeel A., Nadeem F. and Siddique K.H.M., 2018. Application of zinc improves the productivity and biofortification of fine grain aromatic rice grown in dry seeded and puddled transplanted production systems. Field Crops. Res., **216**:53–62.

Gupta N., Ram H. and Kumar B., 2016. Mechanism of Zinc absorption in plants: uptake, transport, translocation and accumulation. Rev. Environ. Sci. Biotechnol., **15**:89–109.

Gurpreet-Kaur, Sharma B.D. and Sharma S., 2013. Effects of organic matter and ionic strength of supporting electrolyte on zinc adsorption in benchmark soils of Punjab in Northwest India. Commun Soil Sci. Plant Anal., **44**:922–938.

Hajiboland R. and Amirazad F., 2010. Growth, photosynthesis and antioxidant defense system in Zn–deficient red cabbage plants. Plant Soil Environ., **56**:209–217.

Khoshgoftar A.H., Shariatmadari H., Karimian N., Kalbasi M., van der Zee S.E.A.T.M. and Parke D.R., 2004. Salinity and zinc application effects on phytoavailability of cadmium and zinc. Soil Sci. Soc. Am. J., **68**:1885–1889.

Kutman U.B., Yildiz B. and Cakmak I., 2011. Improved nitrogen status enhances zinc and iron concentrations both in thewhole grain and the endosperm fraction of wheat. J. Cereal Sci., **53**:118–125.

Kutman U.B., Yildiz B., Ozturk L. and Cakmak I., 2010. Biofortification of durum wheat with zinc through soil and foliar application of nitrogen. Cereal Chem., **87**:1–9.

Mandal B., Hazra G.C. and Pal A.K., 1988. Transformation of Zn in soils under submerged conditions and its relation with zinc nutrition of rice. Plant Soil, **106**:121–126.

Marschner H. and Cakmak I., 1989. High light intensity enhances chlorosis and necrosis in the leaves of zinc, potassium and manganese deficient bean (*Phaseolus vulgaris* L.) plants. Plant Physiol., **134**:308–315.

Marschner P., 2012. Marschner's Mineral Nutrition of Higher Plants, 3rd edition. Academic Press, London.

Naz I., Ahmad H., Khokhar S.N., Khan K. and Shah A.H., 2016. Impact of zinc solubilizing bacteria on zinc contents of wheat. Am. Eurasian J. Agric. Environ. Sci., **16**:449–454.

Ova E.A., Kutman U.B., Ozturk L. and Cakmak I., 2015. High phosphorus supply reduced zinc concentration of wheat in native soilbut not in autoclaved soil or nutrient solution. Plant Soil, **393**:147–162.

Pellegrino E., Öpik M., Bonari E. and Ercoli L., 2015. Responses of wheat to arbuscular mycorrhizal fungi: a meta-analysis of promoting rhizobacteria and cyanobacteria. Eur. J. Soil Biol., **50**:118–126

Ramesh A., Sharma S.K., Sharma M.P., Yadav N. and Joshi O.P., 2014. Inoculation of zinc solubilizing Bacillus aryabhattai strains for improved growth, mobilization and biofortification of zinc in soybean and wheat cultivated in Vertisols of central India. Appl. Soil Ecol., **73**:87–96.

Rana A., Joshi M., Prasanna R., Shivay Y.S. and Nain L., 2012. Biofortification of wheat through inoculation of plant growth promoting rhizobacteria and cyanobacteria. Eur. J. Soil Biol., **50**:118–126.

Rehman H., Aziz T., Farooq M., Wakeel A. and Rengel Z., 2012. Zinc nutrition in rice production systems: a review. *Plant Soil* 361: 203–226. Rev. Environ. Sci. Biotechnol., **15**:89–109.

Schulin R., Khoshgoftar A., Afyuni M., Nowack B. and Frossard E., 2009. Effect of soil management on zinc uptake and its bioavailability in plants. In: Banuelos GS, Lin Z (eds) Development and uses of biofortified agricultural products, CRC Press, Boca Raton, pp. 95–114.

Singh A. and Shivay Y.S., 2013. Residual effect of summer green manure crops and Zn fertilization on quality and Zn concentration of durum wheat (*Triticum durum*Desf.) under a Basmati rice–durum wheat cropping system. Biol. Agric. Hort., **29**:271–287.

Sommer A.L. and Lipman C.B., 1926. Evidence on the indispensable nature of zinc and boron for higher green plants. Plant Physiol., **1**:231–249.

Uygur V. and Rimmer D.L., 2000. Reactions of zinc with iron coated calcite surfaces at alkaline pH. Eur. J. Soil Sci., **51**:511–516.

Zhang Y.Q., Deng Y., Chen R.Y., Cui Z.L., Chen X.P., Yost R., Zhang F.S. and Zou C.Q., 2012. The reduction in zinc concentration of wheat grain upon increased phosphorus-fertilization and its mitigation by foliar Zn application. Plant Soil, **361**:143–152.