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Review Article

Growth, Yield and Nutrient Uptake of Maize as Affected by Zinc Application – A Review

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ABSTRACT

Maize or corn is the third most important cereal crop in India after rice and wheat. Maize is used in many ways for human food as well as animal feed. It is also used in some agro based industry. To increase total production of maize productivity can be increased by efficient nutrient management practices through zinc application. Zinc is such an essential nutrient required for maintenance of optimal health, DNA repair, enzyme activity, immune response and many other biological processes. Each increment of zinc application through soil application, seed treatment and foliar spray improves growth. The plant drymatter (DM) yields increases with a moderate Zn addition level. The Zn-based treatments increases grain yield indicates that there is much more benefit in grain quality than just yield after external Zn application. Addition of Zn results in increase in maize grain and stover Zn concentration. Maize with combined application of Zn as seed priming and foliar spray produced significantly more grain zinc content Total Zn uptake along with NPK also increases with Zn application through different sources of zinc fertilizer.

Keywords: *Growth, Maize, Methods of application, Nutrient uptake, Source of zinc, Zinc and yield*

INTRODUCTION

Maize is considered as high nutrient demanding crop and needs balanced nutrition. Nutrient management has crucial role in increasing crop productivity and to achieve self sufficiency in food grain production. Among the micro nutrient zinc is an essential element for plants, animals and human beings. It is startling to find in the 21st century that an estimated 2 billion people on the planet are zinc deficient. Zinc deficiency is more prevalent in developing countries of the world (Gibbson, 2006). Zinc is such an essential nutrient required for maintenance of optimal health, DNA repair, enzyme activity, immune response and many other biological processes. It is required for a number of metabolic processes.

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Therefore, Zn deficiency can result in a number of health problems like diarrhea, low birth weight, and stunted growth in children (Brown, 2003; Rivera et al., 2003). Increased risk of Zn deficiency in human beings is attributed to low levels of Zn intake. People in developing countries consuming mostly cereals have low Zn in their diet. More than 300 enzymes involved in the key metabolic processes (e.g. carbohydrate and protein metabolism) in humans contain Zn (FAO/WHO, 1996; Cakmak et al., 1999). This emphasizes the need for adequate grain Zn in cereal-based human diets. About two- thirds of all global deaths in children are associated with micronutrient nutritional deficiencies and sub-optimal growth and mortality are some of the severe symptoms associated with Zn deficiency (Welch, 2002). In pregnant women, Zn deficiency symptoms may include high rates of infectious diseases and complications during pregnancy or at birth (Ruel and Bouis, 1998; Welch, 2002).

Adequate zinc (Zn) in maize (*Zea mays* L.) is required for obtaining Zn-enriched corn and optimum yield. Thus increasing Zn levels in maize could deliver more Zn to people whose diet relies directly or indirectly on maize-derived food. Maize is one of the most susceptible cereal crops to Zn deficiency. Because high yielding maize varieties are selected to grown, chemical fertilizers are of increased purity and cropping has become increasingly intensive, Zn deficiency in soil-crop system has become more prevalent in last decades (Fageria et al., 2002). Recent studies indicated that it is possible to increase Zn concentration in maize grain by either soil Zn application or seed priming with Zn in South Asia (Harris et al., 2007; Hossain et al., 2008). As well documented by plant physiologists, zinc exerts a great influence on basic plant life processes, such as (i) nitrogen metabolism – uptake of nitrogen and protein quality; (ii) photosynthesis – chlorophyll synthesis, carbon anhydrase activity; (iii) resistance to abiotic and biotic stresses – protection against oxidative damage (Alloway, 2004; Cakmak, 2008). Overall, the effect of Zn application on crop yield and Zn status is influenced by applying methods and soil moisture condition.

Effect of Zn on growth attributes of maize

Abunyewa et al. (2004) experimented on maize plant and it was grown in Zn deficient soil with increasing Zn (0 and 10 mg kg^{-1} soil) and harvested under 45 days of growth under green house conditions. At the end of experiment, dry matter yield of maize plant increased with increasing Zn application. Another field experiment was conducted by Kumar et al. (2014) during the *pre-kharif* season of 2012 and 2013 at Varanasi to study the effect of nitrogen, phosphorus and potassium (NPK) (100% and 125% RDF), sulfur (0, 25 and 50 kg S ha^{-1}) and zinc (0, 5 and 10 kg Zn ha^{-1}) fertilization. Growth attributes like plant height, number of green leaves, stem girth, dry matter $plant^{-1}$, crop growth rate (CGR) was taken. Each increment of zinc application up to 10 kg Zn ha^{-1} correspondingly improved growth. Hong and Ji-yun (2007) also conducted an experiment on the combinative effects of applied zinc (Zn) and soil moisture on the plant growth, Zn uptake in maize (*Zea mays* L.) plants. He examined this through pot experiments under greenhouse conditions by taking maize variety Zhongdan 9409 in cumulic cinnamon soil with five Zn treatments (0, 3.0, 9.0, 27.0, and 81.0 mg Zn kg^{-1} soil). There was no apparent difference in plant growth among Zn application rates from 3.0 to 81.0 mg Zn kg^{-1} soil. The dry matter weights of shoots were enhanced by Zn application and adequate water supply. In a pot experiment conducted by Chen et al. (2004) investigated on the uptake of Zn from experimentally contaminated calcareous soil of low nutrient status by maize inoculated with the arbuscular mycorrhizal (AM) fungus *Glomus caledonium*. EDTA was applied to the soil to mobilize Zn and thus maximize plant Zn uptake. The highest plant drymatter (DM) yields were obtained with a moderate Zn addition level of 300 mg kg^{-1}. Plant growth was enhanced by mycorrhizal colonization when no Zn was added and under the highest Zn addition level of 600 mg kg^{-1}.

Goos et al. (2000) was conducted an experiment to compare the availability of Zn from different method of Zn application in a calcareous sandy loam soil with low content available Zn and there Zn rates used were 0, 4, 8, 16, and 32 mg pot^{-1} and two crops of maize (*Zea mays* L.) were grown. For the first crop, all Zn sources provided an excellent dry matter response when powdered and mixed with the soil. The ZnEDTA was superior with regard to Zn uptake. The availability of $ZnSO_4$ granules was almost zero for the first crop. The availability of the ZnHL(Zn humate-lignosulfonate) complex was better than $ZnSO_4$ when applied in granular form, but not when the two materials were powdered and mixed with the entire soil mass, suggesting that availability differences between these sources were due to physical, not chemical, factors. After mixing with the soil, only small differences existed between the Zn sources for the second crop. All sources provided for a good dry matter and Zn uptake response, and all Zn sources were about the same in increasing DTPA-extractable Zn levels.

Seed priming treatments different micronutrients (Fe, Zn, Mn) were studied by Imran et al., (2013) with maize seedlings exposed to low root zone temperature (RZT 12 ^{0}C). Model experiments were performed in nutrient solution and soil culture using rhizo-boxes with root observation windows under green house conditions. Zn seed priming resulted in a significant increase in seed contents of the Zn (500%). At low RZT, biomass production and total root length of maize plants were significantly increased after Fe and Zn + Mn priming treatments, both in nutrient solution and in rhizo-box culture. There was no prominent difference in shoot Fe, Zn, Mn and P concentrations but total shoot contents per plant were significantly increased after nutrient seed priming. In another experiment Mohsin et al. (2014) found that maize (*Zea mays* L.) is high nutrient demanding crop but sensitive to zinc (Zn) deficiency in soil. Zinc as seed priming (1.0, 2.0% Zn solution) or foliar application (1.0, 2.0% Zn foliar spray) alone and in combinations were evaluated. Results showed that maize hybrid Pioneer 30-Y-87, with combined application of Zn as seed priming (2.0%) and foliar spray (2.0%), significantly improved plant height, cob length, and cob diameter.

Effect of Zn on yield attributes of maize

Ashoka et al. (2008) reported that integration of RDF (150:75:40 kg NPK ha^{-1}) along with 25 kg $ZnSO_4$, 10 kg $FeSO_4$ and 35 kg Vermicompost on baby corn-chickpea sequence resulted in significantly maximum yield and yield attributes namely; ear length, weight of ear, yield (64.43 q ha^{-1}) as well as green fodder yield (232.33 q/ha) over sole application of inorganic sources. Another study was carried out by Manzeke et al. (2014) over two cropping seasons in Hwedza district in eastern Zimbabwe to assess the added grain yield and nutritional benefits of zinc (Zn) fertilizer application to maize (*Zea mays* L.). Application of Zn (11 kg ha^{-1}) in combination with organic nutrient resources (5 t ha^{-1}), and mineral fertilizers (90 kg N ha^{-1} and 26 kg P ha^{-1}) gave the highest maize grain yields of up to 3.9 t ha^{-1} which translated to 1.3 times more yield than under sole mineral NPK fertilizers. The Zn-based treatments increased grain yield by 29%, respectively, indicating that there was much more benefit in grain quality than just yield after external Zn application. Combined organic resource and Zn fertilization also resulted in a significant build up of plant available soil P and EDTA extractable Zn and the concentrations are 7.4 mg P kg^{-1} and 5.5 mg Zn kg^{-1} were measured after application of organics. Ruffo et al. (2016) also experimented in eight states in the USA and the treatments consisted of four Zn rates of a physical blend of MAP + AS + $ZnSO_4$ (0, 2.24, 4.48, 6.72, and 11.2 kg ha^{-1} Zn) and micro essentials at a Zn rate of 2.24 kg ha^{-1} Zn. Nitrogen, phosphorus (P), and sulfur (S) rates were balanced across treatments (40 kg ha^{-1} P, 22 kg ha^{-1} S) and fertilizers were broadcast and incorporated immediately prior to planting. Maize responded positively to Zn fertilization; average yields across locations increased from 10,540 kg ha^{-1} without Zn to 11,530 kg ha^{-1}

with 11.21 kg Zn ha^{-1} applied as a physical blend. Eteng et al. (2014) also conducted an experiment in coastal plain of south eastern Nigeria, on maize (*Zea mays* L.). In both the greenhouse and field experiments, hydrated Zn sulphate fertilizers were applied to the soils in separate experiments at seven levels (0, 2, 4, 6, 8, 10 and 12 kg ha^{-1}) Zn. The recommended N, P, and K at rates of 120, 60, 30 kg ha^{-1}, respectively, were also used as basal application. The application Zn into the soils significantly increased maize dry matter production, concentration, uptake and grain yields. The estimated optimum rates Zn under greenhouse environments were established at 8 kg Zn ha^{-1}. Maximum uptake and grain yields in maize were also established at 8 kg Zn ha^{-1}. However, maize response curve showed that for optimum grain yield, concentration for Zn it was 8 mg kg^{-1}. Furthermore, Behera et al. (2015) were conducted during rainy season of 2010 and 2011 at research farm of Indian Institute of Soil Science, Bhopal, India to assess the influence of Zn application through zinc sulfate monohydrate (33% Zn), zinc polyphosphate (21% Zn) and Zn EDTA (12% Zn) on yield and micronutrient concentration and uptake by maize (*Zea mays* L.). In both the years, grain and vegetative tissue (stover) yield of maize increased significantly with successive application of Zn upto 1 kg ha^{-1} added through zinc sulphate monohydrate and zinc polyphosphate. Addition of 2.5 kg Zn ha^{-1} did not increase yield. However, Asif (2013) found that the impact of different nitrogen and zinc sulphate levels on the phenology, yield and quality of maize. Maize hybrid "Pioneer (SS-2525)" was subjected to four rates of N (0, 200, 250 and 300 kg ha^{-1}) and $ZnSO_4$ (0, 9, 18 and 27 kg ha^{-1}). The results showed that nitrogen and zinc sulphate application significantly affected the yield and quality parameters of maize. In case of interaction of N and Zn number of grains per cob (539.6), 1000-grain weight (316.0 g), grain yield (7.9 t ha^{-1}) and protein contents (9.9%) were noted in N_3Zn_3 level (300 kg N + 27 kg $ZnSO_4$). Abunyewa and Mercer-Quarshi (2004) were also conducted an experiment in a three year (1997-1999) trial investigating the effect of magnesium and zinc on maize production in the semi arid zone of waste Africa. Three levels of Mg (0, 15 and 25 kg ha^{-1}) as magnesium sulphate ($MgSO_4$) and three levels of Zn (0, 5 and 10 kg ha^{-1}) as zinc sulphate ($ZnSO_4$) were applied to maize. His experimental design was split-plot with two levels of nitrogen (40 and 90 kg N ha^{-1}) as the main plot and Mg and Zn as the subplots with six replications. Initial soil analysis indicated medium levels of Mg and low levels of Zn. Maize grain yield due to Zn application ranged during 0.9 and 3.2 t ha^{-1} representing 84-108% increase in the three year period. Zn and Mg interaction was synergetic resulting in grain yield ranging between 0.97 and 2.2 t ha^{-1} indication 27 to 150% increase over the control in the three year period. While $ZnSO_4$ application resulted in significant increase in soil Zn level that of $MgSO_4$ did not.

Potarzycki and Grzebisz, (2009) were conducted an experiment on zinc foliar spray to maize plants at the 5th leaf stage. The optimal rate of zinc foliar spray for achieving significant grain yield response was in the range from 1.0 to 1.5 kg Zn ha^{-1}. The number of kernels per plant showed the highest response and simultaneously the highest dependence on N uptake. For this particular zinc treatment, however, the length of cob can also be applied as a component of yield structure significantly shaping the final grain yield. In another field experiment Ehsanullah et al. (2015) also investigated on the $ZnSO_4$ treatments comprised; soil application at the time of sowing @ 12 kg ha^{-1}, foliar application at vegetative stage (9 leaf stage) @ 1% $ZnSO_4$ solution and foliar application at reproductive stage (anthesis) @ 1% $ZnSO_4$ solution and one treatment was kept as a control. Statistically maximum grain yield (8.76 t ha^{-1}) was obtained with foliar spray of $ZnSO_4$ at 9-leaf stage in case of Monsanto-6525. Foliar spray of $ZnSO_4$ increased 38% and soil application gave 23.7% more grain yield than control treatment.). Ghaffari et al. (2011**)** also conducted an experiment to evaluate the integrated nutrients effect on growth, yield and quality of maize (*Zea mays* L.) during spring, 2009, at University of Agriculture, Faisalabad. The recommended dose of NPK (200-120-125 kg ha^{-1}) in addition with single spray of Multi-nutrients(a solution mixture of micronutrients i.e; Zn = 2%, Fe = 1%, B = 1%, Mn= 1%, Cu = 0.2% and macronutrients N = 1%, K2O = 2%, S = 2%) @ 1.25 L ha^{-1}) substantially improved all growth parameters, ear characteristics and also enhanced macronutrients use efficiency up to 11.5% which induced significant increase in grain yield as compared to control and also in the treatment where recommended dose of NPK was applied alone. The quality parameter of maize (oil contents) significantly improved by foliar application of multi-nutrients solution but recommended dose of fertilizer in addition to single spray of Multi-nutrients was economical.

Mohsin et al. (2014) experimented on sandy loam soil. Zinc as seed priming (1.0, 2.0% Zn solution) or foliar application (1.0, 2.0% Zn foliar spray) alone and in combinations were evaluated. Results showed that maize hybrid Pioneer 30-Y-87, with combined application of Zn as seed priming (2.0%) and foliar spray (2.0%), significantly improved 1000-grain weight, biological yield, grain yield and harvest index. Another field trials were conducted by Marwat et al. (2007) at NWFP Agricultural University Peshawar during summer 2006 to investigate the effect of tillage and Zinc application methods on maize yield and its associated weeds. The main plot consisted of conventional tillage (CT) and reduced tillage (RT) while Zn application methods were assigned to the subplots which included seed priming (dry seed, soaking seed in water, 0.01, 0.02 and 0.03% Zn solutions), foliar spray of 0.01% Zn solution, soil application @ of 5 kg ha^{-1} and combination of soil application (@ 5 kg ha^{-1}) plus foliar spray (0.01% Zn solution). Yield was higher in CT as compared to RT. Likewise water soaking and Zn application methods improved maize yield as compared to control. It is concluded that CT resulted in lower WD and higher yield of maize. Furthermore, water soaking and Zn application methods enhanced grain yield of maize as compared to control. Harris et al. (2007) was conducted an experiment on calcareous, Zn deficient soils in the North West Frontier Province of Pakistan in vitro, on-station and in on-farm trials by seed priming with zinc sulphate solution. Mean grain yield was significantly increased from 3.0 t ha^{-1} in crops from non-primed seed to 3.4 t ha^{-1} (14%) in crops from seeds primed with water alone and to 3.8 t ha^{-1} (27%, a similar response to that following soil application) using seeds primed with 1% Zn. Hence, the contribution of water alone and zinc contributed about equally to the overall increase.

Iqbal et al. (2014) also conducted an experiment on Zinc application is required for optimum crop growth especially in calcareous soils located in semiarid to arid regions. Effect of Zn application (0, 3 and 9 mg kg^{-1}) and sodium absorption ratio of irrigation water (SARiw; distilled-water control, 8 and 16 (mmole $L^{-1})^{1/2}$) evaluated in a pot study. Plant shoots showed a significant decrease (up to 31%, on average basis) due to increasing levels of SARiw and a significant increase (up to 13%, on average basis) in dry matter with the application of Zn to soil. Both cultivars varied significantly in response to Zn application and SARiw. Conclusively, Zn application to maize improved growth by balancing K:Na and Ca:Na concentration ratios in shoots of stressed maize.

Effect of Zn on nutrient uptake of maize

Hong and Ji-yun (2007) conducted an experiment on the combinative effects of applied zinc (Zn) and soil moisture on the plant growth, Zn uptake in maize (*Zea mays* L.) plants. He examined this through pot experiments under greenhouse conditions by taking maize variety Zhongdan 9409 in cumulic cinnamon soil with five Zn treatments (0, 3.0, 9.0, 27.0, and 81.0 mg Zn kg^{-1} soil). The increases of plant growth and Zn uptake due to Zn application were found more significant under well-watered condition than under drying condition. Zhang et al. (2013) also conducted two pot experiment to investigate the effect of soil Zn heterogeneity by mixing $ZnSO_4 \cdot 7H_2O$ (10 mg Zn kg^{-1} soil on an average) in 10–15, 0–15, 25–30, 0–30, 30–60 and 0–60 cm soil layers on maize shoot Zn content at flowering stage in experiment-1, and assessing effects on grain Zn accumulation at mature stage in experiment-2. In experiment-1, Zn placements created a large variation in soil DTPA-Zn concentration (0.3–29.0 mg kg^{-1}), which induced a systemic and positive response of shoot Zn content was increased by 102–305% depending on Zn placements. In experiment-2, Zn placements increased grain Zn concentration by up to 51%.

Puga et al. (2013) was conducted an experiment at FCAV/UNESP, Jaboticabal-SP, in Oxisolclay to evaluate methods of Zn application on soil and nutritional status of maize. Nine treatments with three doses of Zn in soil banded application (in furrows) and three doses of Zn by incorporation in soil (0–20 cm depth), foliar application, seed application and control (no Zn). Regardless of the method, Zn application promoted higher contents of this micronutrient in soil and higher accumulation in the shoots as well as increasing Zn in the maize grain. The Zn application in the soil resulted in a greater Zn uptake by plants and maize yield, compared to Zn application in the plant by seed or foliar. Another study was carried out by Manzeke et al. (2014) over two cropping seasons in Hwedza district in eastern Zimbabwe to assess the added grain yield and nutritional benefits of zinc (Zn) fertilizer application to maize (*Zea mays* L.). Maize grain under combinations of mineral NPK, Zn and leaf litter gave the highest grain Zn concentration of up to 35 mg kg^{-1}. The Zn-based treatments increased grain Zn concentration by 67%, indicating that there was much more benefit in grain quality than just yield after external Zn application. Furthermore, Behera et al. (2015) were conducted during rainy season of 2010 and 2011 at research farm of Indian Institute of Soil Science, Bhopal, India to assess the influence of Zn application through zinc sulphate monohydrate (33% Zn), zinc polyphosphate (21% Zn) and Zn EDTA (12% Zn) on yield and micronutrient concentration and uptake by maize (*Zea mays* L.). Addition of 2.5 kg Zn ha^{-1} resulted in highest stover Zn concentration. Zinc concentration in maize grain varied from 22.2 to 27.6 mg kg^{-1} in both the years. Maize stover had 25.9 to 36.2 mg kg^{-1}Zn. Total Zn uptake significantly increased with Zn application from 0.5 to 2.5 kg ha^{-1} supplied through zinc sulfate monohydrate and zinc polyphosphate. Potarzycki and Grzebisz, (2009) were conducted an experiment on zinc foliar spray to maize plants at the 5th leaf stage. Plants fertilized with 1.0 kg Zn ha^{-1} significantly increased both total N uptake and grain yield. Mohsin et al. (2014) experimented on sandy loam soil. Zinc as seed priming (1.0, 2.0% Zn solution) or foliar application (1.0, 2.0% Zn foliar spray) alone and in combinations were evaluated. Similarly, maize hybrid DK-919, with combined application of Zn as seed priming (2.0%) and foliar spray (2.0%) produced significantly more grain zinc content (mg kg^{-1}). Harris et al. (2007) was conducted an experiment on calcareous, Zn deficient soils in the North West Frontier Province of Pakistan in vitro, on-station and in on-farm trials by seed priming with zinc sulphate solution. Grain Zn concentration was 15.4 mg kg^{-1} in a non-primed crop and was significantly higher in a crop grown from seeds primed with water (16.5 mg kg^{-1}) and with 1% Zn (18.3 mg kg^{-1}).

CONCLUSION

Focus should be given for zinc fortification to enhance zinc concentration on maize grains and to eradicate malnutrition due to zinc deficiency. Further experiments are required to know the most effective sources of zinc fertilizer. As zinc can be applied in different ways like soil application, seed priming and foliar spray etc. And combined methods of applications are more effective. As per soil zinc status deciding optimum dose of zinc fertilizer is also essential to reduce cost of cultivation and to increase profit.

REFERENCES

Abunyewa, A.A., & Mercer-Quarshie, H., (2004). Response of maize to magnesium and zinc application in the semi-arid zone of West Africa. *Asian Journal of Plant Science 3*(1), 1−5.

Alloway, B. (2004). Zinc in soils and crop nutrition. Areas of the World with Zinc Deficiency Problems. Available at: http://www.zinc-crops.org/Crops/Alloway-all.php. Accessed in March 24, 2016.

Ashoka, P., Mudalagiriyappa, Pujari, B.T., Hugar, P.S., & Desai, B.K. (2008). Effect of micronutrients with or without organic manures on yield of baby corn (*Zea mays* L.) – Chickpea (*Cicer artietinum* L.) sequence. *Karnataka Journal of Agricultural Science 21*(4), 485−487.

Asif, M., Anjum, S.A., Wahid, M.A., & Bilal, M.F. (2013). Effect of nitrogen and zinc sulphate on growth and yield of maize (*Zea mays* L.). *Journal of Agricultural Research 51*(14), 455−464.

Behera, S.K., Shukla, A.K., Singh, M.V., Wanjari, R.H., & Singh, P. (2015). Yield and zinc, copper, manganese and iron concentration in maize (*zea mays* L.) grown on vertisol as influenced by zinc application from various zinc fertilizers. *Journal of Plant Nutrition 38*, 1544−1557.

Brown, K. H. (2003). Commentary: Zinc and child growth. *International Journal of Epidemiology*. *32*, 1103–1104.

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

Cakmak, I., Kalayci, M., Ekiz, H., Braun, H.J., Kilinc, Y., & Yilmaz, A. (1999). Zinc deficiency as a practical problem in plant and human nutrition in Turkey. *Field Crops Research. 60*, 175–188.

Chen, B., Shen, H., Li, X., Feng, G., & Christie, P. (2004). Effects of EDTA application and arbuscular mycorrhizal colonization on growth and zinc uptake by maize (*Zea mays* L.) in soil experimentally contaminated with zinc. *Plant and Soil*. *261*, 219–229.

Ehsanullah, Tariq, A. Randhawa, M.A., Anjum, S.A., Nadeem, M., & Naeem, M. (2015). Exploring the role of zinc in maize (*Zea mays* L.) through soil and foliar application. Universal *Journal of Agricultural Research 3*(3), 69−75.

Eteng1, E.U., Asawalam1, D.O., & Ano, A.O. (2014). Effect of Cu and Zn on maize (*Zea mays* L.) yield and nutrient uptake in coastal plain sand derived soils of southeastern Nigeria. Open *Journal of Soil Science*. *4*, 235−245.

Fageria N.K., Baligar C., &Clark, R.B. (2002). Micronutrients in crop production. *Advances in Agronomy 77*, 185–268.

FAO/WHO, (1996). Human vitamin and mineral requirements. No. 32. Report of a Joint FAO/IAEA/WHO Expert Consultation. Corporate Document Repository. FAO/WHO, Rome.

Ghaffari, A., Ali, A., Tahir, M., Waseem, M., Ayub, M., Iqbal, A., & Mohsin, A.U. (2011). Influence of integrated nutrients on growth, yield and quality of Maize (*Zea mays* L.). *American Journal of Plant Sciences 2*, 63−69.

Gibbson, R.S. (2006). Zinc: The missing link in combating micronutrient malnutrition in developing countries. *Proceedings of the Nutrition Society*. *65*, 51–60.

Goos, R.J., Johnson, B.E., & Thiollet, M. (2000). A comparison of the availability of three zinc sources to maize (*Zea mays* L.) under greenhouse conditions. *Biology and Fertility Soils*. *31*(3), 343−347.

Harris, D., Rashid, A., Miraj, G., Arif, M., & Shah, H. (2007). On-farm seed priming with zinc sulphate solution—A cost-effective way to increase the maize yields of resource-poor farmers. *Field Crops Research 102*, 119–127.

Hong, W., & Ji-yun, J. (2007). Effects of zinc deficiency and drought on plant growth and metabolism of reactive oxygen species in maize *(Zea mays* L.). *Agricultural Sciences in China 6*(8), 988−995.

Hossain, M.A., Jahiruddin, M., Islam, M.R., Mian, M.H. (2008). The requirement of zinc for improvement of crop yield and mineral nutrition in the maize–mung bean–rice system. *Plant and Soil*. *306*, 13–22.

Imran, M., Mahmood, A., Romheld, V., & Neumann, G. (2013). Nutrient seed priming improves seedling development of maize exposed to low root zone temperature during early growth. *European Journal of Agronomy 49*, 141–148.

Iqbal, J., Kanwal, S., Hussain, S., Aziz, T., & Maqsood, M.A. (2014). Zinc application improves maize performance through ionic homeostasis and ameliorating devastating effects of brackish water. *International Journal of Agriculture & Biology 16*(2), 383–388.

Kumar, R., & Bohra, J.S. (2014). Effect of NPKS and Zn application on growth, yield, economics and quality of baby corn. *Archives of Agronomy and Soil Science*. *60*(9), 1193–1206.

Manzeke, G.M., Mtambanengwe, F., Nezomba, H., & Mapfumo, P. (2014). Zinc fertilization influence on maize productivity and grain nutritional quality under integrated soil fertility management in Zimbabwe. *Field Crops Research*. *166*, 128–136.

Marwat, K.B., Arif, M., & Khan, M.A. (2007). Effect of tillage and zinc application methods on weeds and yield of maize. *Pakistan Journal of Botany 39*(5), 1583−1591.

Mohsin, A.U., Ahmad, A.U.H., Farooq, M., & Ullah, S. (2014). Influence of zinc application through seed treatment and foliar spray on growth, productivity and grain quality of hybrid maize. *The Journal of Animal & Plant Sciences. 24*(5), 1494−1503.

Potarzycki, J., & Grzebisz, W. (2009). Effect of zinc foliar application on grain yield of maize and its yielding components. *Plant Soil Environment. 55*(12), 519–527.

Puga, A.P., Prado, R.D.M., Fonseca, I.M., Vale, D.W.D, & Avalhaes, C.C. (2013). Ways of applying zinc to maize plants growing in Oxisol: effects on the soil, on plant nutrition and on yield, IDESIA (Chile) *31*(3), 29−37.

Rivera, J. A., Hotz, C., Gozales-Cossio, T., Neufeld, L., & Garcia-Guerra, A. (2003). The effect of micronutrient deficiencies on child growth: A review of results from community-based supplementation trials. *Journal of Nutrition. 133*, 4010–4020.

Ruel, M.T., & Bouis, H.E. (1998). Plant breeding: a long-term strategy for the control of zinc deficiency in vulnerable populations. *American Journal of Clinical Nutrition. 68*, 488–494.

Ruffo, M., Olson, R., & Daverede, I. (2016). Maize yield response to zinc sources and effectiveness of diagnostic indicators. *Communications in Soil Science and Plant Analysis. 47*(2), 137–141.

Welch, R.M. (2002). The impact of mineral nutrients in food crops on global human health. *Plant and Soil. 247*, 83–90.

Zhang, Y.Q., Pang, L.L., Yan, P., Liu, D.Y., Zhang, W., Yost, R., Zhang, F.S., & Zou, C.Q. (2013). Zinc fertilizer placement affects zinc content in maize plant. *Plant and Soil. 372*, 81–92.