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Review

Foliar application with iron as a vital factor of wheat crop growth, yield quantity and quality : A Review

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Increasing Fe concentration in food crops is an important worldwide challenge due to high incidence of Fe deficiency in human. Foliar fertilization of micronutrients is one of the most important methods of fertilizer application in agriculture practices in order to increase Fe concentration in grain because foliar nutrients help easy and quick consumption of nutrients by penetrating the stomata or leaf cuticle and enter the cells. Foliar application of Iron, either single or along with other micronutrients can help achieve favorable results on growth parameters, yield components and yield quality of wheat crop. It is evident that foliar and soil application of Fe alone or in association with other micronutrients to wheat grown on Fe deficient soils enhance plant growth, yield quantity and quality, yield components and grain Fe concentration. The available literature on biofortification of wheat with Fe through foliar and soil application of Fe fertilizers on the growth parameters, yield components yield quantity and quality of wheat are reviewed and presented below.

Key words: Biofortification, micronutrients, spray fertilization, wheat production, iron

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop in the world and is the third major cereal produced in the world, following maize and rice. (FAO, 2013).

Increased yield through intensive agriculture with high yielding crop varieties, use of NPK fertilizers, and limited use of manures along with restricted recycling of plant residues are some important factors which have to accelerate exhaustion of soil micronutrients. Micronutrients exist in very small amounts in both soils and plants, but their role is frequently as important as the primary or secondary nutrients. Important micronutrients include six elements, namely, Fe, Mn, Zn, Cu, B and Mo (Steven, 2000).

Iron is the most plentiful element on the earth as a whole and the fourth most abundant element in the earth's crust. Soils typically contain 1-5% total Fe, or 22.4 - 112 ton ha^{-1} in the plow layer. The availability of Fe in soil is an essential factor of soil properties such as soil pH, calcium carbonate content, organic matter, accumulation of phosphorus, ion imbalance, soil texture, soil temperature, poor soil aeration, high humidity and soil compaction. (Lindsay and Schwab, 1982; Koseoglu, 1995; Lucena, 2000; Mengel and Kirkby, 2001).

Iron has many important functions in plant growth and development, such as involvement in the biosynthesis of chlorophyll, respiration, chloroplast development and improves the performance of photosystems. It is an essential part of many enzymes. Iron also participates in the oxidation process that releases energy from sugars and starches and in responses that convert nitrate to ammonium in plant. It plays an essential role in nucleic acid metabolism (Romheld and Marschner, 1991; Miller et al., 1995; Eskandari, 2011; Havlin et al., 2014).

Plants growing in soils with limited availability of Fe are not able to accumulate sufficient amounts of Fe its edible parts, leading to nutrition disorders (Fe deficiency) in human body that depend on staple food crops like cereals (Rengel et al. 1999, White and Broadley 2009).

Iron deficiency is a well-documented problem in cultivated soils and seriously disturb yield quantity and nutritional quality of crops, particularly in alkaline soils (Aciksoz at al., 2014).

The amount of Fe required by cereal crops is very small but it is essential for a healthy growth and life cycle completion. The adequacy range of Fe concentrations in plant tissue is usually comprised between 50 and 250 ppm, in wheat grain is reported to be between 25 and 35 ppm (Rengel et al. 1999, Cakmak et al. 2010).

Iron deficit is probable to happen when Fe contents are 50 ppm or less in the dry matter (Pervaiz et al., 2003). Thus, in order to reach significant commensurable health effects grain Fe concentrations should be more than 50 ppm (Graham et al. 2007).

According to a recent report based on the World Health Organization (WHO) database, nutritional iron-deficiency is the most widespread disorder in the world, affecting more than two billion people, in addition to affecting a large number of pre-school children and pregnant women are under most risk of Fe deficiency (Aciksoz et al., 2011, Velu et al., 2014).

Agronomic biofortification increasing Fe concentration during agricultural approaches is a widely applied strategy to reducing the prevalence of Fe deficiency problem in human populations (Pfeiffer and McClafferty, 2007; Borg et al., 2009; Cakmak et al., 2010; Aciksoz et al., 2011; Aciksoz et al., 2014; Naz et al., 2015).

The efficiency of inorganic and chelated forms of Fe fertilizers ($FeSO_4$, FeEDTA, FeDTPA, FeEDDHA, Fe-citrate) in overcoming Fe deficiency is highly variable depending on their solubility, stability, permeation ability through leaf cuticle, mobility and translocation following diffusion into the leaf tissues (Schonherr et al., 2005; Fernandez et al., 2009).

A review of research studies showed that soil or foliar application of Fe alone or in combination with other micronutrients enhancement plant growth, grain yield and its components and grain quality of wheat compared with non-application.

The objective of this paper was to present research papers showing that application of Fe fertilizers, single or joint with other micronutrients really contribute to biofortification of wheat with Fe.

Effect of foliar fertilization of iron on growth and yield components

The foliar application of mineral nutrients using sprays, presents a method of providing nutrients to higher plants more competently than methods involving soil application when soil conditions are not suitable for Fe availability (Erdal et al., 2004; Kinaci and Gulmezoglu, 2007; Babaeian et al., 2011; Borowski and Michalek, 2011; Fernandez et al., 2013).

Foliar application of micronutrients results in quick absorption by leaf epidermis of plant and accessible to other plant parts through xylem and phloem (Hasslett et al., 2001; Nasiri et al., 2010).

Iron foliar applications are generally based on Fe-chelates or Fe-salt solutions and is taken up via the cuticle or stomata (Fernandez et al., 2009).

Westfall et al. (1971) reported that iron sulphate alone or in combination with zinc sulphate was the most effective in correcting rice seedling chlorosis (90%) grown on calcareous soils of Texas.

Channal (1978) reported that foliar application of 0.5% ferric chloride significantly increased the plant height, dry matter accumulation, number of green leaves of sunflower in black clay soil.

A study was conducted by Suryanarayana and Rao (1981) to study the effect of foliar application of Fe on growth of okra. They reported that, application of Fe beside with Zn, Cu, Mn, Mg, B and Mo in a chelated form (Agromin) resulted in increased plant height.

Rashid et al. (1987) found that grain yield of wheat increased 26.1% due to application 10 kg Zn ha^{-1}+1 kg B ha^{-1}+5 kg Cu ha^{-1}+10 kg Mn ha^{-1}+10 kg Fe ha^{-1}.

Alam et al. (1988) found that application 2.5 kg Fe ha^{-1} with 5 kg of Zn ha^{-1} increased the wheat grain yield by 10.9% and application 10 kg Fe ha^{-1}+2.5 kg B ha^{-1}+5 kg Zn ha^{-1} increased the grain yield by 11.3%.

Hussain et al. (1989) reported that foliar application of Fe in the form of ferrous ammonium citrate at 0.1 per cent beside with Zn and B (0.1%) at 30, 60 and 75 DAT resulted in significant improvement in the plant height of chilli. Wisal et al. (1990) found that wheat grain increased 14% when application 5 kg Fe ha^{-1} as compared to control.

El-Magid et al. (2000) reported that the application foliar of Fe, Cu, Zn and Mn increased grain and straw yields of wheat.

Results of a broad-based study conducted in 815 irrigated wheat to estimate the effect of micronutrients showed an increase of 4 to 11% in wheat grain yield by the application of each micronutrient (Fe, Zn, Cu, and B) or a combination of Fe+Zn+Cu+B to NPK fertilizer increased grain yield (Malakouti, 2000).

Ziaeian and Malakouti (2001) found that Fe, Mn, Zn and Cu fertilization significantly increased grain yield, straw yield, 1000 grain weight, and the number of grains per spikelet in calcareous soil. Also they reported that grain yield increases 20.8% with rate of Fe application 20 kg ha^{-1} compared to without Fe. Also showed that application of Fe significantly increased the concentration and total uptake of Fe in grain, flag leaves grain protein contents as well.

Field experiment on the effect of micronutrients, Zn, Cu, Fe, Mn, B and a commercial fritted micronutrient product called Zarzameen, on the yield and the yield components of wheat, the results showed that micronutrients increased wheat dry matter, grain yield, and straw yield significantly over an unfertilized control (Asad and Rafique, 2002).

Zeidan and Nofal (2002) showed that application of micronutrients only (Fe, Mn, Zn and Cu) or with adding 1% urea on growth and yield of wheat caused significant increases in wheat grain protein content, yield and quality of wheat.

A field experiment was conducted to study the effect of different doses of Fe (0, 5, 10, 15 and 20 kg ha^{-1}) on wheat crop. Results revealed that the grain yield increased with increase in Fe rate application (Pervaiz et al., 2003).

A field experiment was carried out to evaluate the effect of foliar application of macronutrients and micronutrients on yield and yield components of wheat. Results showed that three foliar sprays of nutrient solution at tillering, jointing and boot stages along with half of the recommended doses of N and P helped in enhancing yield and yield components of wheat (Arif et al., 2006).

Khan et al. (2006) reported that Cu, Fe, Mn and Zn contents of leaf, straw and grain of wheat increased with the application of mineral fertilizers.

Rehm and Albert (2006) they reported that, foliar sprays of $FeSO_4.7H_2O$ or Fe-chelates are found to be more effective and efficient than soil application in correcting Fe-chlorosis in wheat plant also yields were bigger for the treatments with micronutrients.

A Field research was conducted to study the effect of Fe and Zn on quantitative and quality parameters of winter wheat. Results showed that foliar application of Fe and Zn increased grain yield and protein content (Seilsepour, 2007).

Chaudry et al. (2007) reported that micronutrients (Zn, Fe, B) significantly increased the wheat yield over control when applied in single and in combination, along with basal dose of NPK, whilst Mandal et al. (2007) noticed significant optimistic interaction among physiological stages of wheat growth and fertilizer treatments.

A Field experiment was conducted to study the impact of microelements on uptake of N, P, K and yield of wheat. Results showed that increase doses up to 12 kg Fe ha^{-1} increased grain yield and its components (Abbas et al., 2009a).

A filed experiment was conducted during two growing seasons to study the effect of foliar feeding of iron, zinc and potassium on grain yield, and protein percentage of bread wheat. Results indicated that the combination of the foliar applications of Fe and Zn increased plant height, flag leaf area, number of grain per spike, grain yield and wheat grain protein content (Abu-Dahi et al., 2009a).

Abu-Dahi et al. (2009b) reported that interaction between 120 kg $K.ha^{-1}$ soil and foliar application with concentration of 100 ppm Fe improved chlorophyll content. Results showed that foliar application with the combination of 100 ppm Fe and 30 ppm Zn gave highest plant height and flag leaf area. Also results showed that grain yield in second season had significant compared with the first season.

A field trial was conducted to investigate the effect of foliar application of Zn and Fe on wheat yield and quality at tillering and heading stage. Results showed that foliar application of Zn and Fe increased seed yield and its quality compared to control. (Habib, 2009).

An experiment was conducted in order to study the effect of Fe and Zn yield and yield components on yield and components of wheat mutant line. Results showed that application Fe and Zn had significantly effect on grain yield (Ghorbani et al., 2009).

Seadh et al. (2009) found that the foliar application by 500 ppm Fe on wheat enhanced grain yield, yield component and protein content over untreated.

Two field experiments were conducted to investigate the effect of micronutrient foliar application on wheat yield and quality of wheat grains. Results indicated that straw yield, 1000-grain weight, number of grains per spike, grain yield Fe, Zn and Mn concentration in flag leaves and grains as well as protein content in grain of wheat were significantly increased due to application of these nutrients (Zeidan et al., 2010).

Foliar application of micronutrients (Fe= 1%, Mn= 2%, Zn= 2%, Cu= 1%, B= 1%) at different growth stages of wheat increased plants height, grains per spike, 1000-grain weight, biological yield, harvest index, straw and grain yield (Khan et al., 2010).

A pot experiment was conducted to investigate the influence of two different Fe sources (Fe-EDTA and Fe-EDDHA) were sprayed on to the leaves and applied to the soil in levels were involved 0, 10, 20 and 30 ppm, both fertilizers were applied to leaves at two times on lentil plant (*Lens esculenta* L.). The results indicated that there was significant effect of the combination among two types, concentration, and method of Fe application on total dry matter and on the concentration of N, P, Ca, Mg, K and Fe in plant (Darwesh, 2011).

A pot experiment was conducted to study the effects of foliar application of microelements (Cu, Zn and Fe) on growth and productivity of wheat. The results showed that all microelement treatments showed significant increase in height of plant, leaf number, leaf area, branch number, total dry weight for shoots and roots, chlorophyll content, concentrations of N, P, K, Fe, Zn, Cu, starch, protein in grains, 1000-grain weight and grain yield. Also results showed that application of Fe gave increases in grain yield, protein and starch in grains by 29, 30 and 6%, respectively compared to the control treatment (Farhan and Al-Dulaemi, 2011).

A pot trial was conducted to investigate the effect of foliar application of micronutrients (Fe, Mn, and Zn) compound on improving wheat for salt tolerance. Foliar spraying with suspension micronutrient induced stimulatory effects on growth parameters and nutrients uptake either before or after the salinization treatments. The results showed that foliar spray with micronutrient could be useful for improving the nutrient status, root features and physiological performance of wheat plants (El-Fouly et al., 2011).

Ali (2012) reported that foliar application of Fe by the rates from 200 to 600 ppm at different growth stages enhanced plant height, spike length, 1000-grain weight, grain weight per spike, grain yield, grain protein content and protein yield of wheat plant in both seasons as compared to untreated treatment.

Bameri et al. (2012) A field experimental was conducted to study the effects of foliar micronutrient application on growth and yield of wheat. Results showed that application

of micronutrient (Fe, Zn, and Mn) significantly improve the plants height, number of spike per plant, number of grain per spike, 1000-grain weight, grain yield, biological yield and harvest index. Application of Fe and Zn alone or combination had positive effect on grain yield and its components.

Applications of Fe affected the yield and growth parameter of wheat and NPK uptake at all the rates. The rate of doses 12 kg Fe ha^{-1} improved the number of tillers per square meter, straw yield, spike length, 1000-grain weight and grain yield of wheat in first year, whilst in second year it increased the spikelets per spike, spike length, 1000-grain weight and grain yield on recommended NPK (Abbas, et al., 2012).

Safyan et al. (2012) reported that foliar application of Fe (3 ppm) increased on corn grain yield 30% as compared to control. Also results showed that total content of grain's carbohydrates, starch, Indole acetic acid and protein was increased by foliar application Fe and Zn.

A field study was conducted to evaluate the effect of foliar application of Fe and B on some early growth parameters of wheat at early tillering stage. Results revealed that plant height, number of leaves, number of tillers square meter as well as root depth were significantly increased through application of Fe+B as compared to control treatment. (Rawashdeh and Sala, 2013).

Ghafari and Razmjoo (2013) showed that the foliar application of 2 g L^{-1} nano-iron oxide increased antioxidant enzymes activities and chlorophylls contents, yield, yield components and the grain quality of wheat.

A field experiment was carried out to evaluate the influence of foliar application of Fe-chelate on growth and physiological parameters of wheat at various growth stages. Results showed that using foliar application of Fe at different growth stages significantly increased and improved the plant height, number of plants per square meter, flag leaf area and flag leaf chlorophyll content as compared to without Fe application (Rawashdeh and Sala, 2014).

Armin et al. (2014) found that foliar application of Nano-Fe fertilizer had a significant effect on tillers number, seeds per spike, grain yield, biological yield and thousand grains weight of wheat.

A field study was conducted to investigate the effect of iron nano chelated fertilizers foliar application on three wheat cultivars. Results showed that effect of iron nano chelate foliar application, wheat cultivars and interaction of them had significant effects on spike number, grain per spike, 1000 grain weight, biological yield and harvest index compared to control (Rezaeei et al., 2014).

Two field experiments were carried out to study the effect of micronutrients (Cu, Fe, Mn, and Zn) foliar spray application on yield and quality of four wheat cultivars. Results indicated that foliar spray application by all micronutrients recorded significant effect on yield characters and protein content in both seasons as compared to control treatment (Mekkei et al., 2014).

Rezapour-Osalou et al. (2015) carried out a trial on corn to study the effect of foliar application of nano-iron oxide on grain yield production and seed set of corn. He observed that foliar application of nano Fe_3O_4 fertilizer significantly increased phytase activity and iron concentrations in corn seed.

Two field experiments were conducted to investigate the effect of N, K and some micronutrients application on production, chemical compositions, and quality of wheat. Results showed that the foliar application of mixture nutrients (Zn+Fe) gave the highest grain and yield components, chemical compositions, quantitative and technological of wheat grain (Gomaa et al., 2015).

Zain et al., (2015) showed that the application of micronutrients (Fe, Zn and Mn) substantially improved plant height, spike length cm, spikelets per spike, grains per spike, 1000 grain weight, number of tillers square meter, grain yield, biological yield and harvest index of wheat.

Effect of foliar application of iron on the nutrient uptake by wheat

Two or supplementary growth features are supposed to interrelate when their influence independently is customized by the attendance of one or more of the others (Sumner and Farina, 1986). Interactions may be positive or negative depending on the growth response. If the growth response is better with tow combined feature as evaluated to the sum of their individual effects, it is a positive interaction, and when the combined effects are less, the interaction is negative (Fageria et al., 1990).

The deficiency of Fe has been reported in an ever increasing range of crops and the use of Fe fertilizer has increased as a result (Dobermann. and Fairhurst, 2000; Cakmak et al., 2010). Also foliar Fe fertilization is increasingly being used in wheat when there is no leaf chlorosis to increase the Fe concentration in grains, applied Fe has been shown to re-translocate efficiently to other plant organs (Cakmak et al., 2010; Zhang et al., 2010; Aciksoz et al., 2011).

Foliar sprays of ferrous sulphate or chelates are found to be more effective and efficient than soil application in correcting Fe-chlorosis in wheat (El-Fouly et al., 2011).

Fe uptake by grain sorghum were higher with the use of Fe-EDDHA than with $FeSO_4$ or $Fe_2(SO4)_3$ in calcareous soil having pH 7.5 with low available Fe (Mortvedt and Giordano, 1971).

Mortvedt et al. (1972) reported that, application of Fe to soil and plant cause synergistic relationship between K and Fe.

Nitrogen content increased 2% of sorghum leaves when 10 kg $FeSO_4$ ha^{-1} was applied to the soil over control (Belavanaki, 1979).

Kalyan et al. (1992) reported that the application of 25 kg $FeSO_4$ ha^{-1} significantly increased uptake of iron content in grain and straw in rice over other treatments.

Pande et al. (1993) observed that the foliar application of 3% $FeSO_4$ to groundnut increased uptake N, K and Fe as compared with other treatments. Modak and Chavan

(1999). Reported that application of 20 ppm as $FeSO_4$ with NPK application significantly increase in rice grain uptake of N, P, K and Fe in grain rice over NPK application alone.

The application of Fe-EDDHA significantly increased soybean shoot Fe concentration and uptake but decreased shoot Mn concentration by 91%. Admittedly, transportation of Fe and Mn from roots to shoots affected by antagonistic effects of these elements and thus it differ from the uptake by roots from the soil (Ghasemi et al., 2002).

Soil application of 50 kg $FeSO_4$ ha^{-1} significantly increased content and uptake of Fe, P and N by chickpea over control (Singh et al., 2004).

A filed experiment was conducted to investigate the effect of foliar Fe applications ($FeSO_4.7H_2O$ and Fe-EDTA) at different growth stages on Fe and some nutrient concentrations in strawberry. The results showed that the leaf Fe concentration of strawberry increased continuously with repeated foliar Fe application from both sources. Although the leaf Fe and Zn concentrations increased with foliar Fe applications, leaf P, K and Mg concentrations did not significantly affect, but leaf Ca and Mn concentrations were negatively affected by foliar Fe applications (Erdal et al., 2004).

Ravi et al. (2008) reported that application 30 kg S ha^{-1} with foliar spray Fe+Zn (0.5 %) increased the uptake of nitrogen, phosphorus, potassium, sulphur, zinc and iron in safflower.

Increasing the dose of Zn showed the uptake of Fe increased by applying Zn up to 8 kg ha^{-1}, whilst high Zn doses resulted in reduced Fe uptake by wheat (Abbas, et al., 2009b).

Field research was carried out by (Aref, 2012) to evaluate the effects of Zn and B fertilizers on Fe, Mn and Cu concentrations in the maize leaf. The results indicate that the use of B and Zn, by spraying, increased leaf Fe content.

Aciksoz et al. (2011) reported that, adding urea to inorganic or chelated forms of foliar Fe fertilizers at rates of 1 per cent (w/v) had a positive effect on rising grain Fe concentrations in wheat

A nutrient solution experiment was conducted to investigate the effect of Fe and Zn supply on Fe, Zn, Cu, and N concentrations in wheat plants. Results showed that the supply of Fe reduced wheat Mn concentrations, especially in stems and leaves (Ai-Qing, 2011).

Foliar spray of 1 per cent Fe sulfate improved plant Fe content and had no negative effect either on soybean shoot dry matter yield or on shoot Mn concentration (Moosavi and Ronaghi, 2011).

Field experiments were carried out to study the influence of effects of Iron on take up of phosphorus, potassium and nitrogen on wheat yield. Results of the different studies conducted showed that application of Fe increased NPK uptake and their concentration in soil significantly over control (Abbas et al. 2012).

(Bameri et al., 2012) reported that the triple combination (Fe+Zn+Mn) significantly decreased yield and yield components. Negative response to foliar application of (Zn+Fe+Mn) on wheat growth may be recognized to micronutrient uptake problems and antagonistic effect among Fe, Zn, and Mn in their combination.

Soil and foliar Fe application affected the copper content of peanut. There were negative correlations between Fe application and Cu contents of leaf and grain samples collected in two years. Increasing Fe application decreased the Cu content of leaf and grain. (Irmak et al., 2012).

A field experiment was conducted to study the effect of molybdenum and iron on the nodulation, nitrogen fixation and yield of two chickpea genotypes. Results showed that the maximum nitrogen content and uptake was obtained for treatment receiving Fe at 2 kg ha^{-1} for both chickpea genotypes. Results also showed that the maximum Fe concentration and uptake in leaves were obtained for the same treatment (Khan et al., 2014).

A pot experiment was conducted to estimate the biofortification potential of wheat crop by exogenously applied Fe and Zn. Soil and foliar application with two levels of Fe and Zn (2 ppm and 4 ppm) were applied at milking stage of wheat. Results showed that soil application at level 4 ppm of Fe and Zn is significant effect on plant available nutrients and nutrient concentration in wheat straw and grain. Application of Fe and Zn also increased and improved growth parameters. (Naz et al., 2015).

Gomaa et al. (2015) reported that the mixed foliar application of micronutrient (Zn+Fe) significantly increased N, P and K content, Zn and Fe concentration in wheat grain as compared to the control.

A field experiments were carried out to study the effect of foliar spraying with urea (1%) and spraying micronutrients (Fe, Zn, Mn) single or in combination on growth and yield of wheat. Results showed that spraying plants with Fe+Mn+Zn increases in grain Fe, Zn and Mn concentrations as compared with control treatment. The increase of grain-Fe concentration ranged between 8-37% (Yassen et al., 2010).

CONCLUSION

Regarding to the above review of research papers it can be concluded that the application of iron fertilizers (soil and foliar) single or in mixture with other micronutrients has a positive effect on growth, yield components, grain yield and grain Fe concentration in wheat.

It is in addition very practical when plants are not able to absorb the iron from soil due to many soil physical and chemical properties such as soil texture, very high or low soil temperature, poor soil aeration, high humidity, compaction, soil pH, calcium carbonate, organic matter content and accumulation of phosphorus. As a result, foliar application of Fe develops plant growth, grain yield and its quality of wheat.

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