J. Appl. Environ. Biol. Sci., **1(10)448-452, 2011**

ISSN: 2090-4215
Journal of Applied Environmental and Biological Sciences
www.textroad.com

The Importance of Iron (Fe) in Plant Products and Mechanism of Its Uptake by Plants

Hamdollah Eskandari*

Department of Agriculture, Ramhormoz Branch, Islamic Azad University, Ramhormoz, Iran

ABSTRACT

Yield and quality of agricultural products increased with micronutrients application, therefore human and animal health is protected with feed of enrichment plant materials. Each essential element only when can perform its role in plant nutrition properly that other necessary elements are available in balanced ratios for plant. Iron is an necessary element for enzyme system which brings about oxidation reduction reactions and electron transport chain in the plant, synthesize chlorophyll, maintain the structure of chloroplasts, and enzyme activity, also it regulates respiration, photosynthesis, reduction of nitrates and sulphates, that these reactions are essential to plant development and reproduction. Different plants have two strategies to uptake iron in aerobic conditions. In first strategy trivalent iron (Fe^{3+}) will be converting to solution iron (Fe^{2+}) with phytosiderophores secreted by plant roots. In iron deficiency conditions some disorders occur in plants, such as increasing in formation and activity carrier cells in the plant roots and reducing the lateral roots. Iron deficiency symptoms appear on the youngest leaves, and area between the leaf veins becomes pale yellow or white (interveinal chlorosis).

Key words: Iron, deficiency, micronutrient, plant nutrient, uptake.

INTRODUCTION

The first and most important need of every human is needs to food, and food supply for humans associated with agriculture directly and indirectly. Micronutrients in addition to its role in increasing quality and quantity yield of agricultural products have a significant effect on human and animal health that feed of plant materials. Deficiency of micronutrients such as iron (Fe), zinc (Zn) and manganese (Mn), has an expansion global, and about a third of the world's agricultural soils, are facing with these elements deficiency due to being calcareous and uncontrolled use of phosphate fertilizers (Mousavi *et al*., 2007; Mousavi, 2011). Each essential element only when can perform its role in plant nutrition properly that other necessary elements are available in balanced ratios for plant. Use of fertilizers containing micronutrients increased extensively with progress science and technology on the role of micronutrients in crops (Alloway, 2008).

In most of the Iran's soils pH is high and they are also calcareous, in this type of soils solvability of micronutrient is less and cause decline uptake these elements and finally requirement of plants to this elements is increasing (Mousavi *et al.,* 2011; Alloway, 2008; Malakouti and Tehrani, 1999). Also irregular use of phosphate fertilizers in the poor soils of micronutrients such as iron (Fe), zinc (Zn) and manganese (Mn) causes an imposed deficiency of these elements; therefore concentration of micronutrients will decline in crop products and its dry matter (Abdou *et al*., 2011; Salimpour *et al*., 2010; Ibrahim and Ali, 2009; Khorgamy and Farnia, 2009). With increasing utilization of chemical fertilizer and on the other hand increasing fertilizer prices due to their dependence on fossil fuels, water, air and soil pollution and ignorance in the use of chemical fertilizers are problems that must be solved with appropriate methods (Mousavi, 2011; Alloway, 2008).

Iron in the soil is the fourth abundant element on earth, but its amount was low or not available for the plants and microorganisms needs, due to low solubility of minerals containing iron in many places the world, especially in arid region with alkaline soils. Iron is an importance element in crops, because it is essential for many important enzymes, including cytochrome that is involved in electron transport chain, synthesize chlorophyll, maintain the structure of chloroplasts, and enzyme activity (Mamatha, 2007; Ziaeian and Malakouti, 2006; Zaharieva and Abadia, 2003; Welch, 2002).

Often iron is found in the form of trivalent (Fe^{3+}) in aerobic soils, which has low solubility, and in most cases this is not enough iron to meet the needs of plants. Considering the effect of pH on the solubility of Iron (Fe), in the pH = 7 amount of water soluble iron is about 10^{-18} mol L (moles per liter); while the required concentrations for normal growth of plants is about 10^{-8} mol L. Generally solubility of trivalent iron decreases by increasing pH (Briat, 2005; Schulte, 2004).

Iron deficiency has a powerful effect on chloroplast protein, so that chloroplast protein is reduced significantly by iron deficiency. In conditions of severe iron deficiency, cell division stops and therefore leaf growth decreases (Mohamed and Aly, 2004; Manthey and Crowley, 1997). Iron is needed to produce

***Correspondence Author:** Hamdollah Eskandari, Department of Agriculture, Ramhormoz Branch, Islamic Azad University, Ramhormoz, Iran. Tell: +98- 0691-222-5520, Email: ehamdollah@gmail.com

chlorophyll; hence its deficiency causes chlorosis. For example, iron is used in the active site of glutamyl-tRNA reductase, an enzyme needed for the formation of 5-Aminolevulinic acid which is a precursor of chlorophyll (Kumar and Soll, 2000). Iron-deficient fields, when viewed from a distance, exhibit irregularly-shaped yellow areas. Because iron is not translocated in the plant, deficiency symptoms appear on the new growth first. Iron deficiency on individual plants is characterized by yellow leaves with dark green veins (interveinal chlorosis). On corn and sorghum, this gives the plants a definite striped appearance. If the condition is severe, the whole plant may be affected and turn a very light yellow or even white. In many cases where moderate deficiencies occur early in the season, plants tend to recover later (Follett and Westfall, 2008).

Iron solution concentrations in flooding soils to may be increased several-fold due to low redox potential. In these conditions large amounts of iron may available for plant, and can be toxic to plants. Brown plant tissues, black and soft roots are the iron toxicity symptoms. In addition, at these higher iron (Fe) solution concentrations plants exhibited visual symptoms of possible iron toxicity, including root flaccidity, reduced root branching, increased shoot die-back and mottling of leaves. Plant species in wet regions have mechanisms to oxidize iron in roots area to limit the excessive absorption of iron (Batty and Younger, 2003; Schmidt, 1994).

Plants in soils aerobic conditions have two strategy-oriented for access to the iron compounds: first siderophore secretion (non-protein amino acid) (This strategy is found in Gramineae family); and second separation iron of soil chelate or restore trivalent iron (Fe^{3+}) to bivalent that occurs through the proton leakage (This strategy can be found in other monocotyledon and dicotyledons plants) (Romheld, 1997; Romheld and Marschner, 1996).

First strategy of plants for iron uptake

The first strategy is a complex substance secreted as a phytosiderophores, which combine it with iron surrounding roots produces solution iron compounds. Gramineae (grasses) including agriculturally important species such as barley and wheat are able to efficiently sequester iron by releasing phytosiderophores via their root into the surrounding soil rhizosphere (Kraemer *et al*., 2006). Chemical compounds produced by microorganisms in the rhizosphere can also increase the availability and uptake of iron. Plants such as oats are able to assimilate iron via these microbial siderophores. It has been demonstrated that plants are able to use the hydroxamate-type siderophores ferrichrome, rodotorulic acid and ferrioxamine B; the catechol-type siderophores, agrobactin; and the mixed ligand catechol-hydroxamate-hydroxy acid siderophores biosynthesized by saprophytic root-colonizing bacteria. All of these compounds are produced by rhizospheric bacterial strains, which have simple nutritional requirements, and are found in nature in soils, foliage, fresh water, sediments, and seawater (Carrillo-Castanedaa *et al*., 2002). Inorganic iron is a poor substrate for uptake by roots system. Trivalent iron ions are fewer uptakes than trivalent iron (Fe^{3+}) chelate due to low reductase enzyme activity. In addition to root secretions, iron chelate can arise of organic matter decomposition by microorganisms naturally (Schmidt, 1999; Romheld, 1997).

Second strategy of plants for iron uptake

The second strategy is done with proton leakage and revival material by plant which trivalent iron (Fe^{3+}) (with very low solubility) is converted to divalent iron (Fe^{2+}) (with more solubility). This method exists in other monocotyledon and dicotyledons plants. In higher plants the ability to convert the extracellular Fe^{3+} to Fe^{2+} is due to physiological and morphological changes; that is done in accordance with intracellular iron levels. This structural change, will determine the efficiency of iron uptake by the plants species. After the complex fragmentation and metal ions release, divalent ions (Fe^{2+}) are uptake by the plant roots. A part or all revival of iron is caused by the chelate reductase enzyme activity that is located in root plasma membrane (Schmidt, 1999; Romheld, 1997).

Rhizosphere pH has an important ecological impact on nutrient mobility and activity of organisms. According to nutritional status of plants, soil buffering capacity and age of plant rhizosphere pH may be difference more than two units of soil mass. Acidic reaction in root area may be result of changes in uptake cation and anion and nitrogen metabolism, which increases the leakage of protons through the ATPase proton pump in iron or phosphorus deficiency. This proton can affect on amount of iron oxide solution through the weaken band of iron and oxygen. In addition to stimulating proton leakage, other role of iron stress, is stimulating Fe^{3+} reductase enzyme activity (Fig. 1) (Buchanan *et al*., 2000; Marschner *et al*., 1999; Schmidt *et al*., 1997; Toulon *et al*., 1992; Schwertmann, 1991). ATPase pump activity in root membrane of cucumber increased two times for proton leakage in iron deficiency conditions (Rabotti and Zocchi, 1994).

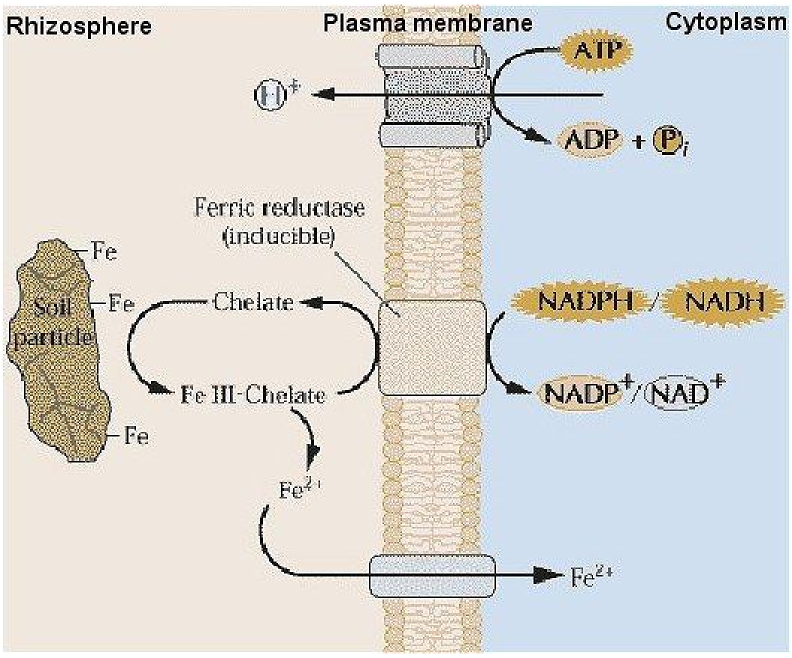

Fig. 1: Model of iron (Fe) uptake by dicotyledons and non grass monocotyledon (Buchanan *et al*., 2000).

Release of organic compounds with low molecular weight is one of the plants mechanisms to iron uptake. Types of organic compounds are released from plants roots as activate or deactivate that are included revival sugars, amino acids, phenols and organic acids. Although the cause of leakage is genetic, but environmental factors may have a greater influence on its amount and composition than the genetic factors (Cieslinski *et al*., 1997). The amount and composition of leakage materials are depends on the soil pH, light intensity, temperature, nutritional status of plant, plant age and the presence of microorganisms such as mycorrhizae. Phenols and organic acids leakage may be increased in food deficiency (especially iron and phosphorus) conditions. Root leakage, has directly impact on the micronutrients availability for plant roots through acidify the rhizosphere, and Fe^{3+} revival. Riboflavin released in some plant species helps to iron uptake (Jones *et al*., 1996; Susin *et al*., 1993; Pedersen *et al*., 1991).

Iron (Fe) is transported to the leaves through the xylem as chelate with citrate, but iron in leaves should be revival same the roots, which this is done by enzyme. In leaves, high pH of apoplast may affect on the activity of plasma membrane reductase or ATPase hydrogen pumps, and therefore iron uptake will be incomplete (Schmidt, 1999).

Iron (Fe) deficiency

If an adequate amount of iron is not available to plants, iron deficiency (iron chlorosis) will result. Symptoms of iron deficiency appear on the youngest, newest leaves. The area between the leaf veins becomes pale yellow or white (this is called interveinal chlorosis). No noticeable physical deformity occurs, but in severe cases the youngest leaves may be entirely white and stunted. Note that it may be difficult to distinguish iron deficiency symptoms from those of other nutrients, particularly zinc, on some plants. Susceptibility to iron deficiency varies greatly between plants. Desert plants are less susceptible to iron deficiency because they have mechanisms that enable them to solubilize and uptake iron from high pH soils. Plants from regions with acidic soils do not have this ability. Most humid tropical and subtropical regions fall into this category and therefore many of the ornamental and crop plants we have imported from these areas are susceptible to iron deficiency (Follett and Westfall, 2008; Walworth, 2006).

In plants, many morphological and physiological changes occur in response to iron deficiency. Formation carrier cells can be seen in response to iron deficiency. Formation carrier cells are as a mechanism for increased nutrient transport in the apoplast-symplast band. Carrier cells are cells with significant growth in the secondary wall and come forward to within the lamina cells and their level is higher than volume. Carrier cells are responsible for increase in proton release and revival activity in iron-deficient roots. Citrate increasing is the first effect in iron deficiency, which is affects by increasing in glyco citrates and then PEPS carboxylation (Schmidt, 1999; Romheld, 1997; Pich *et al*., 1994).

Reduce the length of lateral roots is one of the most important morphology changes in iron deficiency conditions. Stop growing often is associated with reduction length of lateral roots and increasing relative number to roots. Formation filaments root and root tip swelling occurs before the root growth reduction, however the root filaments increasing is observed in hypoxia and phosphate deficiency (Li *et al*., 2008).

REFERENCES

Abdou, A.S., F.H. Al-Darwish, M.E. Saleh, K.A. El-Tarabily, M.S. Azirun and M.M. Rahman, 2011. Effects of elemental sulfur, phosphorus, micronutrients and Paracoccus versutus on nutrient availability of calcareous soils. Australian Journal of Crop Science, 5: 554-561.

Alloway, B.J., 2008. Zinc in soils and crop nutrition. Second edition, published by IZA and IFA, Brussels, Belgium and Paris, France.

Batty, L.C. and P.L. Younger, 2003. Effects of external iron concentration upon seedling growth and uptake of fe and phosphate by the common reed, *phragmites australis* (cav.) trin ex. steudel. Annals of Botany, 92: 801-806.

Briat, J.F., 2005. Iron from soil to plant products. Bull Acad Natl Med, 189: 1609-19.

Buchanan, B., W. Gruissem and R. Jones, 2000. .Biochemistry & molecular biology of plants. 1st edition, American Society of Plant Biologists.

Carrillo-Castanedaa, G., J. J. Munosa, J.R. Peralta-Videab, E. Gomezb, K.J. Tiemannb, M. Duarte-Gardeac and J.L. Gardea-Torresdey, 2002. Alfalfa growth promotion by bacteria grown under iron limiting conditions. Advances in Environmental Research, 6: 391-399.

Cieslinski, G., K.C.J. Van-Rees, A.M. Szmigielska and P.M. Huang, 1997. Low molecular weight organic acid released from roots of durum wheat and flax into sterile nutrient solutions. Journal of Plant Nutrition, 20: 753-764.

Follett R.H. and D.G. Westfall, 2008. Zinc and Iron deficiencies. Colorado State University Cooperative Extension, No. 0.545.

Ibrahim, M.S. and M.H.M. Ali, 2009. Total iron and manganese status and availability under various land use. Australian Journal of Basic and Applied Sciences, 3: 698-705.

Jones, D.L., P.R. Darrah and L.V. Kochian, 1996. Critical evaluation of organic acid mediated iron dissolution in the rhizosphere and its potential role in root iron uptake. Plant and Soil, 180: 57-66.

Khorgamy, A. and A. Farnia, 2009. Effect of phosphorus and zinc fertilisation on yield and yield components of chick pea cultivars. African Crop Science Conference Proceedings, 9: 205-208.

Kraemer, S.M., D. Crowley and R. Kretzschmar, 2006. Siderophores in plant iron acquisition: geochemical aspects. Advances in Agronomy, 91: 1-46.

Kumar, A.M. and D. Soll, 2000. Antisense HEMA1 RNA expression inhibits heme and chlorophyll biosynthesis in arabidopsis. Plant Physiologists, 122: 49-56.

Li, J., X.D. Wu, S.T. Hao, X.J. Wang and H.Q. Ling, 2008. Proteomic response to iron deficiency in tomato root. Proteomics, 8: 2299-311.

Malakouti, M.J. and M.H. Tehrani, 1999. Effect of micronutrients on the yield and quality of agricultural products: micro-nutrients with macro-effects. Tarbiat Modares University publication, Iran.

Mamatha, N., 2007. Effect of sulphur and micronutrients (iron and zinc) on yield and quality of cotton in a vertisol. Department of soil science and agricultural chemistry college of agriculture, dharwad university of agricultural sciences, dharwad-580 005.

Manthey, J.A. and D.E. Crowley, 1997. Leaf and root responses to iron deficiency in avocado. Journal of Plant Nutrition, 20: 683-93.

Marschner, H., M. Treeby and V. Romheld, 1999. Role of root-induced changes in the rhizosphere for iron acquisition in higher plants. Zeitschrift für Pflanzenernährung und Bodenkunde, 152: 197-204.

Mohamed A.A. and A.A. Aly, 2004. Iron deficiency stimulated some enzymes activity, lipid peroxidation and free radicals production in *borage officinalis* induced in vitro. International Journal of Agriculture & Biology, 6: 179-184.

Mousavi, S.R., 2011. Zinc in crop production and interaction with phosphorus. Australian Journal of Basic and Applied Sciences, 5(9): 1503-1509.

Mousavi, S.R., M. Shahsavari and M. Rezaei, 2011. A general overview on manganese (Mn) importance for crops production. Australian Journal of Basic and Applied Sciences, 5(9): 1799-1803.

Mousavi, S.R., M. Galavi and G. Ahmadvand, 2007. Effect of zinc and manganese foliar application on yield, quality and enrichment on potato (*Solanum tuberosum* L.). Asian Journal of Plant Sciences, 6: 1256-1260.

Pedersen, C.T., G.R. Safir, J.O. Siqueira and S. Parent, 1991. Effect of phenolic compounds on asparagus mycorrhiza. Soil Biology and Biochemistry, 23: 491-494.

Pich, A., G. Scholz and U.W. Stephan, 1994. Iron-dependent changes of heavy-metals, nicotianamine, and citrate in different plant organs and in the xylem exudate of 2 tomato genotypes-Nicotianamine as possible copper translocator. Plant and Soil, 165: 189-196.

Rabotti, G. and G. Zocchi, 1994. Plasma membrane-bound H+-ATPas and reductase activities in Fe-deficient cucumber roots. Physiologia Plantarum, 90: 779-785.

Romheld, V. and H. Marschner, 1996. Evidence for a specific uptake system for iron phytosiderophores in roots of grasses. Plant physiology, 80: 175-180.

Romheld, V., 1997. Different strategies for iron acquisition in higher plants. Physiologia Plantarum, 70: 231-234.

Salimpour, S., K. Khavazi, H. Nadian, H. Besharati and M. Miransari, 2010. Enhancing phosphorous availability to canola (*Brassica napus* L.) using P solubilizing and sulfur oxidizing bacteria, Australian Journal of Crop Science, 4: 330-334.

Schmidt, W., 1994. Root-mediated ferric reduction-responses to iron deficiency, exogenously induced changes in hormonal balance and inhibition of protein synthesis. Journal of Experimental botany, 45: 725-741.

Schmidt, W., 1999. Mechanisms and regulation of reduction-based iron uptake in plants. New Phytol, 141: 1-26.

Schmidt, W., M. Bartels, J. Tittle and C. Fuhner. 1997. Physiological effects of copper on iron acquisition processes in plantago. New phytologist, 135: 659-666.

Schulte, E.E., 2004. Soil and applied iron. Understanding Plant Nutrients, A3554.

Schwertmann, U., 1991. Solubility and dissolution of iron oxides. Plant and soil, 130: 1-25.

Susin, S., J. Abian, F. Sanchez-Baeza, M.L. Peleato, A. Abadia, E. Gelpi and J. Abadia, 1993. Riboflavin 3- and 5- sulfate, two novel flavins accumulating in the roots of iron-deficient sugar beet (*Beta vulgaris*). The Journal of Biological Chemistry, 268: 20958-20965.

Toulon, V., H. sentenac, J.B. Thibaud, J.C. Davidian, C. Moulineaz and C. Grignon, 1992. Role of apoplast acidification by the H+ Pump. Effect on the sensitivity to PH and Co2 of iron reduction by roots of Brassica napus L. Planta, 186: 212-218.

Walworth, J.L., 2006. Recognizing and treating iron deficiency in the home yard. The University of Arizona College of Agriculture and Life Sciences, az1415.

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

Zaharieva, T.B. and J. Abadia, 2003. Iron deficiency enhances the level of ascorbate, glutathione, and related enzymes in sugar beet roots. Protoplasma, 221: 269-75.

Ziaeian A.H. and M.J. Malakouti, 2006. Effects of Fe, Mn, Zn and Cu fertilization on the yield and grain quality of wheat in the calcareous soils of Iran. Plant Nutrition, Food Security and Sustainability Agro-ecosystems, 92: 840-841.