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Iron (Fe) and iron chlorosis in plant nutrition

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Abstract: *Iron (Fe) and iron chlorosis in plant nutrition.* Iron (Fe) is an important element for plant growth since it provides the chlorophyll formation in a plant. Iron deficiency (chlorosis) is more common in plants that are growing in calcareous and alkaline soils. It can be seen when the amount of P and pH is high in the soil. Vineyards, fruits, tomatoes, strawberries, and cotton are plants which are susceptible to Fe deficiency (chlorosis). Cultivation techniques such as uncontrolled fertilization, spraying, irrigation, and planting are also effective in treating Fe chlorosis. Iron deficiency (chlorosis) is the most abundant micronutrient deficiency in Turkey's soils. One of the most significant factors that causes Fe chlorosis in cultivated plants is $CaCO_3$ (% lime), exchangeable Ca and alkaline pH. To prevent iron chlorosis, the quality of the soil should be improved and the plant variety should be enhanced. In order to prevent chlorosis, application of iron chelates (Fe-EDTA, DTPA, HEDTA and EDDHA) into the soil is especially important. Chelate Fe-EDDHA is more effective than inorganic iron sources and it can be applied into the soil or as a foliar spray. Therefore, the significance of iron for plant nutrition (the availability of iron in plants, its contents and metabolic functions), the reasons for Fe chlorosis (deficiency) and information about its elimination will be investigated in this study.

Key words: micronutrients, Iron deficiency, plant nutrition, inorganic iron salts, chelates

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INTRODUCTION

Iron has a great significance in terms of the growth of a plant and the quality of agricultural production. Iron constitutes about 5% of the earth's crust and exists in every type of soil. Although the requirement of Fe for plants is low, Fe deficiency (chlorosis) can be seen in plants since the solubility and availability of Fe in the soil are low. Iron exists in the soil in a complex structure with oxides, hydroxides, silicate minerals, amorphous oxides, adsorbed Fe and organic matter. Iron exists in the form of oxides as Fe^{3+} and Fe^{2+}. Certain primary minerals, which contain Fe are olivine, augite, hornblende, biotite, hematite (Fe_2O_3), ilmenite, goethite, magnetite (Fe_3O_4), and ferromagnesian minerals.

Compared to the total Fe content, the soluble Fe contents of soils are fairly low. Soluble inorganic Fe forms are Fe^{3+}, $Fe(OH)_2$ and Fe^{2+}. The Fe^{2+} ion in well-aerated soils constitutes a very small part of total soluble inorganic Fe except for places where soil pH is high [Marschner, 1995]. Iron deficiency (chlorosis) is the main micronutrient deficiency in Turkey's soils. About 27%

of the soil's useful Fe content is under 4.5 mg·kg^{-1}, which is a critical value [Güneş et al., 2000].

Plants that uptake inefficient iron and encounter iron stress try to rectify this problem in various ways. Iron is found in plants in the form of Fe^{2+}, Fe^{3+} and Fe chelates. The Fe^{2+} ion is used in the metabolism of a plant. Hence, the plant uptakes the Fe^{2+} ion or reduced form of Fe. During the reduction, Fe^{3+} is reduced to the Fe^{2+} form, making this form soluble and available to plants [Mengel and Guertsen, 1988; Marschner, 1995]. Iron uptake depends on the strength of the plant roots able to reduce Fe^{3+} to Fe^{2+}. Therefore, plants have been determined as strategy-I in terms of efficient iron uptake (iron-efficient, such as sunflower, peanut, dicotyledonous and monocotyledonous plants) or as strategy-II in terms of inefficient iron uptake (iron-inefficient, such as wheat, barley, rye, oat and corn). Iron is important for plant nutrition and enables chlorophyll formation in a plant. There is a positive relationship between iron and chlorophyll content, as well as photosynthesis and its products [Mengel and Kirkby, 1987]. Iron does not exist in the structure of chlorophyll, like magnesium, but it has a catalytic effect on the synthesis of chlorophyll [Bergman, 1992]. Iron had been accepted as immobile in the plant structure for many years, whereas recent studies have found that iron was a moderately mobile micronutrient. For this reason, the yellowing (chlorosis) that arises from iron deficiency takes place due to low chlorophyll concentrations which form, especially in young leaves [Abadia, 1992; Güneş et al., 2000].

The aim of the study is to explain the significance of iron in plant nutrition (iron uptake, transfer, contents and metabolic functions in plants) and provide the reasons for Fe deficiency (chlorosis) and its elimination.

UPTAKE, TRANSFER, CONTENTS, METABOLIC FUNCTIONS AND DEFICIENCY OF IRON IN PLANTS

Iron is absorbed by the active root tips of plants as a form of Fe^{3+}, Fe^{2+} and Fe chelates. The uptake of iron by plants in soil depends on the strength of the plant roots' ability to reduce Fe^{3+} to Fe^{2+} and in that sense, notable differences in iron reduction are observed from one plant to another [Mengel and Kirkby, 1987]. When iron is applied in the form of Fe chelates to the roots of plants, a significant difference in the uptakes of Fe chelates by plants is observed. The chelate-micronutrient complexes cycle that occurs in the soil is a very important mechanism. This cycle increases the availability of Fe and other micronutrients for plants [Smith, 1984].

Iron uptake in the soil through plants is influenced negatively by high pH and high concentration of P and Ca in the soils [Marschner, 1986; Roasta and Mohsenian, 2012]. As iron is a micronutrient which cannot be transferred easily into the plants' organs, Fe transfer occurs slowly from old leaves to young ones. Therefore, plants need Fe during their growth. Iron that is uptaken by the roots of plants is transferred to the other organs and is accumulated there. It was found that 80% of Fe accumulates in chloroplasts [Marschner, 1986]. Prior to its transfer in the plant body, Fe creates a chelate form with malic acids, citric acids, phenols, polysaccharides, and amino acids [Brown, 1978]. Adequate Fe amounts in plant leaves is usually between 50 and 250 mg·kg^{-1} of dry matter. Where it is less than 50 mg·kg^{-1}, Fe deficiency (chlorosis) occurs in plants [Bergman, 1992].

The total Fe amount which is found in plants is not a reliable indication to show the Fe nutrition status of plants. Although Fe^{2+} is metabolically active in plants, the majority of iron in soils consists of an unavailable Fe^{3+} form. Iron exists in a plant in two forms which are active and inactive, and soluble and insoluble (or available or unavailable) [Marschner, 1995; Fernandez et al., 2005]. The iron uptake of a plant is also related to the reduction of Fe^{3+} to Fe^{2+}. The studies found that green leaves have higher Fe^{2+} contents (active Fe) than leaves with chlorosis (Fe^{3+}). This outcome proves that the total iron contents of plants does not address Fe deficiency (chlorosis) directly. Therefore, a plant should be examined for active Fe contents to determine Fe deficiency (chlorosis) [Lang and Reed, 1987; Mehrotra and Gupta, 1990]. Various factors affect the iron content of plants. These are as follows: the species of the plant, the age of the plant, the soil reaction, the lime content of the soil, the sort and amount of heavy metals in soils and the phosphorous content of the soil [Aktaş, 1995].

METABOLIC FUNCTION OF IRON IN PLANTS

The functions of iron in plants are very diverse [Mengel and Kirkby, 1987; Marschner, 1995].

a) Iron does not exist in the structure of chlorophyll, but it works as a catalyst in chlorophyll synthesis;
b) It is placed in enzymatic systems and used for photosynthesis, protein synthesis, respiration and metabolism.
c) It regulates oxidation and reduction reactions by accelerating enzymatic activities, such as: hydrogenase, catalysis, peroxidase, cytochrome, and oxidase;
d) As iron has the features of oxidation and reduction, it also participates in transferring the ions in plants;
e) It is a micronutrient which is necessary in terms of nodule formation in *Leguminosae*.

The conditions of soil that cause Fe deficiency (chlorosis) in plants are; low Fe content of the soil, rich $CaCO_3$, high HCO_3^- concentration, very high or very low soil humidity, high heavy metal contents, high soil P, inadequate aeration of the soil or high CO_2 content of air in the soil, extreme temperatures, the excessive fertilization of alkaline soils with organic fertilizers, low organic matter content in soils, and excessive soil acidity [Aktaş, 1995; Marschner, 1995]. Iron deficiency (chlorosis) also occurs depending on various environmental conditions such as water or plant related factors. It was found that having Ca^{2+} ions and phosphate anions abundant in the soil affected iron uptake and transfer in plants negatively by causing the deposition of iron in the form of iron (III) compounds [Hewitt, 1983; Güneş et al., 2000].

Different nitrogen forms (NH_4^+, NO_3^-) also have an effect on iron availability and uptake. Nitrogen affects the cation anion ratio such that NO_3-N is taken in large quantities from the soil and as a result of that, HCO_3 is released into the rhizosphere of roots. This causes a reduction of Fe uptake in plants [Chen and Barak, 1982]. The $(NH_4^+$ nitrogen form shows the opposite effect of NO_3^- nitrogen form.

IRON DEFICIENCY IN PLANTS

Iron chlorosis is more common in plants that are growing in calcareous and alkaline soils. It can be seen when the amount of P and pH is high in the soil. Vineyards, fruits, tomatoes, strawberries, and cotton are plants which are susceptible to Fe deficiency (chlorosis).

The signs of Fe deficiency (chlorosis) are first seen especially in newly grown and young leaves because Fe is an immobile element. In the further phases of the deficiency, old leaves can be affected. Iron deficiency (chlorosis) in plants appears in the form of yellowing between the veins. The most characteristic feature of iron deficiency is that even the thinnest veins remain green and the color between the veins turns completely yellow. The large leaves appear almost like a green web on a yellow background. In further phases of the deficiency, all the veins, including the thin veins, become yellow. Because of the lack of chlorophyll formation, the youngest leaves can turn white. Young buds become dry [Chaney, 1984; Bergman, 1992].

Iron deficiency (chlorosis) occurs when the lime content of soil is more than 20% because of high HCO_3^- concentrations [Schinas and Rowell, 1977]. The most important factor that causes Fe chlorosis in cultivated plants grown in Turkey is that the soils are rich in $CaCO_3$. Cultivation techniques, such as: uncontrolled fertilization, spraying, irrigation, and planting, also have an effect on Fe chlorosis [Kovancı et al., 1986; Özgümüş, 1988; Saatçi and Yağmur, 2000; Çoban et al., 2005].

THE PREVENTION AND RECTIFICATION OF IRON (Fe) CHLOROSIS

The applications used to prevent iron chlorosis are explained as follows [Güneş et al., 2000]:

a) genetic control;
b) rectification of the environmental conditions that cause chlorosis;
c) application of ferrous fertilizers into the soil and onto the leaves.

There are very important differences between plant species and varieties in terms of their susceptibility to Fe deficiency (chlorosis). In order to prevent this, the soil conditions need to be rectified. Hence, the need to take action to reduce the pH in alkaline soils, and to prevent water accumulation being produced during drainage in calcareous soils because of bad drainage application. Rectifying soil structure could be another approach to reduce Fe deficiency (chlorosis). Considering the Ca content of the soil, it must be balanced between P and K fertilizers, and acidic fertilizers such as ammonium nitrate and urea must be used instead of fertilizers containing S. It is necessary to avoid thick grassland mulching, which prevents gas exchange in wet seasons [Güneş et al., 2000].

Iron deficiency (chlorosis) can be corrected through applying iron sources into the soil, spraying them onto the leaves, or adding them to the irrigation water. There are organic chelates containing iron and inorganic iron salts sprayed onto leaves or applied to soils in order to rectify iron chlorosis. The chelates are produced also commercially, and are considered organic compounds. They create a complex structure with iron and prevent Fe from turning into insoluble compounds in the soil. The most common inorganic Fe fertilizers are ferrous sulfate ($FeSO_4 \cdot 7H_2O$), ferric sulfate and ferrous ammonium sulfate. However, it is known that inorganic iron salts are usually inadequate for rectifying iron chlorosis although they are cheap. Iron fertilizers in the form of chelates are more preferred today since they are very effective and have less burning effect compared to inorganic Fe fertilizers, even though the iron chelates are more expensive [Lindsay, 1974; Wallace, 1983; Mengel and Kirkby, 1987; Davarpanah et al., 2013].

The most commonly used organic chelates are EDTA (ethylenediaminetetraacetic acid), EDDHA (ethylenediamine di-o-hydroxyphenylacetic acid), DTPA (diethylenetriaminepentasetic acid) and HEDTA (hydroxyethylethylenediamine triacetic acid). The forms of these chelates containing iron are available under various commercial titles. Lignosulfamates, poliflavonoids and iron frits (effective in soil with acidic reactions) as organic compounds are less effective and cheaper than synthetic chelates. The effectiveness of iron chelates depends on their degree of stability in different soil pH. It was found that Fe-EDDHA is relatively more effective than the others (especially in calcareous soils) [Fernandes et al., 2005; Davarpanah et al., 2013].

Both soluble inorganic Fe salts and Fe chelates are applied into the soil and onto leaves. However, it has been reported that sufficient results cannot always be obtained with foliar applications of inorganic Fe salts. It was found that plant tissues were burnt [Mengel and Kirkby, 1987; Reed et al., 1988; Roosta and Mohsenian 2012].

CONCLUSIONS

Iron deficiency (chlorosis) is more common in plants that are growing in calcareous and alkaline soils. It can be seen when the amount of P and pH is high in the soil. Vineyards, fruits, tomatoes, strawberries, and cotton are plants which are susceptible to Fe deficiency (chlorosis). Cultivation techniques such as uncontrolled fertilization, spraying, irrigation, and planting are also effective in treating Fe chlorosis.

As a result, among micronutrient deficiencies, Fe deficiency (chlorosis) is one of the most widespread deficiencies in Turkey. The most important reasons for this are high $CaCO_3$ (% lime), exchangeable Ca and the pH in Turkey's agricultural soils. Considering the Ca content of the soil, it must be balanced between P and K fertilizers, and acidic fertilizers such as ammonium nitrate and urea must be used instead of fertilizers with S. It is necessary to avoid thick grassland mulching, which prevents gas exchange in wet seasons.

Correcting the Fe deficiency (chlorosis) depends on the rectification of the soil characteristics, the choice of plant varieties, and the applications of ferrous preparations (fertilizers). Ferrous chelates, especially Fe-EDDHA is more effective than inorganic iron sources, and it can be both applied to the soil and sprayed onto the leaves.

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Streszczenie: *Żelazo (Fe) i jego deficyt w żywieniu roślin*. Żelazo jest pierwiastkiem niezbędnym do wzrostu roślin, gdyż m.in. stymuluje syntezę chlorofilu. Deficyt żelaza (chloroza) jest szczególnie powszechna u roślin rosnących na glebach wapiennych i alkalicznych. Poza wysokim odczynem niekorzystna dla roślin jest także duża zawartość fosforu, gdyż występuje wtedy wytrącanie fosforanu żelaza, co utrudnia pobieranie żelaza. Winorośl, rośliny sadownicze, pomidory, truskawki czy bawełna są szczególnie wrażliwe na deficyt żelaza w glebie. Deficyt żelaza jest często obserwowany w glebach występujących w Turcji. Jednym z czynników sprawczych jest duża zawartość węglanów ($CaCO_3$), wymiennego wapnia oraz wysoki alkaliczny odczyn. Aby zapobiec niedoborom żelaza w roślinie (chlorozie roślin), trzeba poprawiać jakość środowiska glebowego oraz stosować dobór odpowiednich odmian. Chlorozie można zapobiec, stosując żelazo w formie schelatowanej: Fe-EDTA, DTPA, HEDTA and EDDHA. Stosowanie Fe-EDDHA, zarówno doglebowo, jak i dolistnie, jest bardziej efektywne w porównaniu z nieorganicznymi źródłami żelaza. Podsumowując, niezbędność żelaza w żywieniu roślin (jego dostępność, zawartość i funkcje metaboliczne), przyczyny deficytu żelaza i sposoby przeciwdziałania są przedmiotem niniejszego opracowania.