Chapter 3. Iron deficiency

RICE (*Oryza sativa* L.)

Description of symptoms

The symptoms of iron deficiency are yellowing or chlorosis of the interveinal areas of the emerging leaf. Later the entire leaf turns yellow, and finally turns white. If the deficiency is severe, the entire plant becomes chlorotic and dies. Iron deficiency can easily be mistaken for nitrogen deficiency. However, nitrogen deficiency affects the older leaves first, while iron deficiency affects the emerging leaves first.

Plate 10

Plate 11

Plate 12

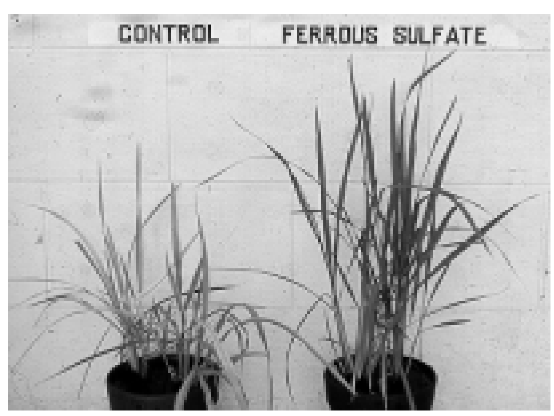

Plate 13

Plate 10. Rice leaf showing typical symptoms of iron deficiency
Plate 11. Iron deficiency injury in rice
Plate 12. Ameliorating Fe deficiency by incorporating straw into the soil
Plate 13. Ameliorating Fe deficiency in rice by the application of ferrous sulfate

Soil conditions likely to produce iron deficiency in rice

The iron requirement of rice is greater than that of other plants. Iron deficiency is a common disorder of rice growing on well-drained (aerobic) soils, whether these are neutral, calcareous or alkaline. The severity of the disorder increases with the pH. Iron deficiency may also be observed in rice on upland acid soils.

In flooded rice paddies, iron deficiency is likely to be found in calcareous and alkaline soils low in organic matter, and in soils irrigated with alkaline water.

Iron deficiency may also be a problem in peat soils, especially if these are well-drained, and with a high pH.

Diagnosis by soil analysis

Well-drained soils with a pH of more than 6.5 are likely to be deficient in available iron. The severity of the problem increases with a high pH.

In flooded rice soils, iron deficiency may occur if the redox potential of the soil at a pH of 7 is more than 0.2 volt. In this situation, the total soil iron content may be high, but the level of availabale iron in the soil remains low.

Iron deficiency is likely to be observed if the iron concentration in the soil is:

- Less than 2mg iron/kg extracted by ammonium acetate, with a pH of 4.8.
- Less than 4-5mg iron/kg, extracted by DTPA-Calcium chloride, with a pH of 7.3.

Diagnosis by plant analysis

The critical level for iron deficiency in rice is 50 mg iron/ kg, in shoots sampled from the stages of tillering to panicle initiation.

Interaction with other elements

A high concentration of calcium carbonate in the soil or irrigation water is likely to make iron deficiency of rice more severe. Iron deficiency can sometimes be caused by too much nitrate, which raises the pH of the soil around the roots. High phosphate applications may cause iron deficiency, or make it worse, by precipitating iron in the soil solution. High phosphate levels may also hinder the uptake of iron by plants, and the translocation of iron from the root system to the shoots.

How to correct iron deficiency in rice

Soil amendments and foliar sprays

Iron deficiency can be amended by applying a foliar spray of 2-3% ferrous sulfate solution. Another way of correcting the deficiency is to apply about 30 kg/ha of iron as ferrous sulfate to the soil. Because of the low mobility of iron in the plant, split applications may be necessary.

Fertilizer application

Ammonium sulfate and ammonium chloride are recommended nitrogen sources for soils with a high pH.

Other cultivation practices

Growers should plant rice varieties which are tolerant of iron deficiency and alkaline soils. Applications of organic manure will help lower soil pH.

Photos and information by courtesy of Dr. Corinta Quijano-Guerta, International Rice Research Institute, Philippines

CORN (*Zea mays rugosa*)

Plate 14

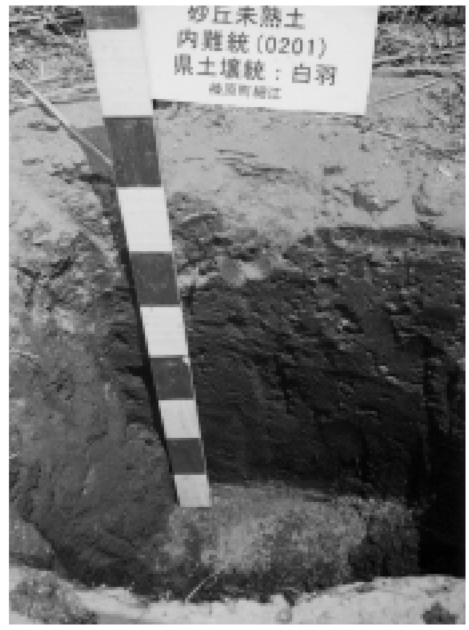

Plate 15

Plate 16

Plate 14. Sweet corn showing severe chlorosis from iron deficiency
Plate 15. Soil profile of field with corn suffering from iron deficiency (sand-dune Regosol, Shizuoka Prefecture, Japan)
Plate 16. Field of sweet corn with iron deficiency

Japan: Temperate climate

Soil conditions likely to result in iron deficiency in corn

The sand-dune Regosol where this condition was found was a poorly drained sandy soil, to which had been applied excessive NP fertilizer. Iron deficiency in crops growing on such soils is more likely if temperatures are low and there is little sunlight.

How to correct the iron deficiency

The application of a sufficient quantity of high-quality compost is recommended.

Photos and information from Dr. Yuuji Kaneda, Shizuoka Prefectural Agricultural Experiment Station, Japan

SOYBEAN (*Glycine max* Merr.)

Plate 17

Plate 17. Soybean plants showing light yellow to yellow color in young leaves, a typical symptom of iron deficiency. Leaves become paler as iron deficiency becomes more severe.

Taiwan ROC: Subtropical climate

Photo by Hwalien District Agricultural Improvement Station, Taiwan ROC

Description of symptoms

The symptoms of iron deficiency are yellowing or chlorosis of the interveinal areas of the emerging leaf. Later the entire leaf turns yellow, and finally white. If the deficiency is severe, the entire plant becomes chlorotic and dies. Iron deficiency can easily be mistaken for nitrogen deficiency. However, nitrogen deficiency initially affects the older leaves, while iron deficiency affects first the emerging leaves.

Soil conditions likely to produce iron deficiency in soybean

Iron deficiency is a common micronutrient disorder on neutral, calcareous and alkaline aerobic soils. The severity of the disorder increases with the pH. It may also be observed on upland acid soils. In upland soils, iron deficiency may occur in calcareous soils.

Diagnosis by soil analysis

Aerobic soils with a pH greater than 7 are likely to be deficient in available iron. The severity of the problem increases with an increase in the pH to 7.8 or more in calcareous soils.

Iron deficiency is also likely to be observed if iron concentration in the soil is:

- Less than 2 mg iron/kg, tested by ammonium acetate, pH 4.8 extraction
- Less than 4-5 mg iron/kg, tested by DTPA-Calcium chloride, pH 7.3 extraction

Diagnosis by plant analysis

The critical level for iron deficiency is 5 mg/kg iron in the young leaf.

Interaction with other elements

A high concentration of calcium carbonate in soil or irrigation water aggravates iron deficiency. Iron deficiency can be also induced by high nitrate levels, which raise the pH of the soil around the roots. Applications of phosphate may induce or aggravate iron deficiency by precipitating iron. Phosphate applications may also inactivate uptake by the plant, or hinder translocation of iron to the shoot and iron metabolism.

How to correct iron deficiency

Iron deficiency in soybean can be amended by applying a foliar spray of 2-3% ferrous sulfate solution, or by the soil application of about 30 kg/ha of iron in the form of ferrous sulfate. Because of the low mobility of iron in the plant, split applications may be necessary. Ammonium sulfate and ammonium chloride are recommended nitrogen sources for soils with a high pH. Organic manure may help to lower the soil pH. In iron deficient soils, tolerant varieties should be used, if these are available.

Information from Dr. Zueng-Sang Chen, National Taiwan University

PEANUT (*Arachis hypogaea* L.)

Plate 18

Plate 19

Plate 20

Plate 21

Plate 22

Plate 23

Plate 18. Light yellow to yellow leaves, typical of iron deficiency in younger leaves of peanut (Taiwan). Leaves with deficiency are smaller and thinner than normal leaves. The more severe the iron deficiency, the paler the leaf

Plate 19. This picture shows different conditions of iron deficiency from normal leaves (lower left) to severely deficient (upper right)

Plate 20. Light yellow to yellow color, typical symptoms of iron deficiency in younger leaves of peanut

Plate 21. Plots in field showing light yellow to yellow color typical of iron deficiency in younger leaves of peanut. The leaves of plants in some treated plots turned green after applying sulfur (4 mt/ha) to increase the soil pH to 7. Some plots were given a foliar spray of 2% ferrous sulfate solution, or in soil application of about 30 kg/ha of iron as ferrous sulfate, both of which were also effective.

Plate 22 and Plate 23. Peanut fields showing varied light yellow to yellow color in younger leaves of iron deficient plants

Taiwan ROC: Subtropical climate

Photos by Hwalien District Agricultural Improvement Station, Taiwan ROC

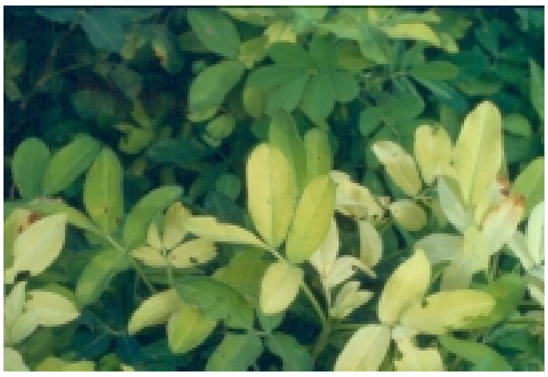

Plate 24

Plate 24. Serious iron deficiency of the younger leaves of peanut, which are pale in color

Thailand: Tropical climate

Description of symptoms

The symptoms of iron deficiency are the result of a failure in chlorophyll production. They begin in the younger leaflets, which become pale green. The leaf veins remain green, even when yellow interveinal tissue (interveinal chlorosis) appears.

Soil conditions likely to produce iron deficiency

Iron deficiency is a common micronutrient disorder of peanut growing in calcareous soils containing a high level of calcium carbonate.

Diagnosis by soil analysis

Soils with a high pH of 7.5-8.2 are likely to be deficient in available iron. Iron deficiency of peanut is likely to be observed if the iron concentration in the soil is:

- Less than 4 mg iron/kg by DTPA extractable calcium, *or*
- Less than 30,000 mg iron per kg of exchangeable calcium.

Diagnosis by plant analysis

The critical level for iron deficiency of peanut is 5.5 mg iron/kg in the young leaf. A solution of ophenanthroline is used for extraction.

Interaction with other elements

The symptoms of iron deficiency are more marked if the peanut is growing in soil with a high lime content (lime induced chlorosis). Heavy applications of phosphate fertilizer may have the same effect.

How to correct the deficiency

Iron deficiency of peanut can be corrected by a foliar application of 0.5-1.0% ferrous sulfate solution.

Photos and information from Dr. Youngyuth Osotsapar, Kasetsart University, Thailand

TOMATO (*Lycopersicon esculentum* Mill.)

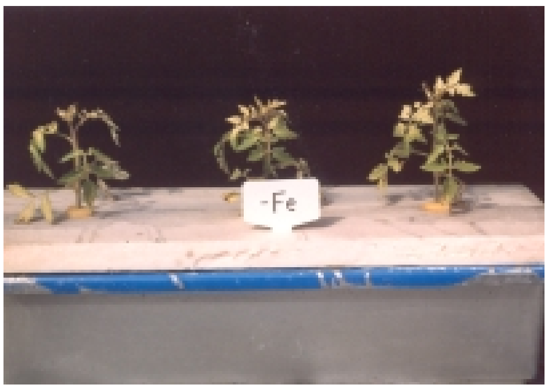

Plate 25

Plate 26

Plate 27

Plate 25. Young tomato plants grown in a hydroponic system in Korea, with symptoms of iron deficiency. The plant did not receive any iron nutrition. The youngest leaves are yellow with chlorosis.
Plate 26. Tomato plant with typical symptoms of iron deficiency in younger leaves
Plate 27. The first symptoms of iron deficiency occur in the younger leaves, which become yellow.

Korea: Temperate climate

Description of symptoms

The tomato plants shown above were grown in a hydroponic system in a plastic greenhouse. Plants grown in soil which are deficient in iron show the same symptoms.

How to correct iron deficiency in tomato

In plants grown in soil, iron deficiency is corrected by three soil applications of 1 % EDTA iron solution. The pH of the soil should be adjusted to 5.5-6.5, as should the nutrient solution for plants grown in a hydroponic system.

Photos and information from Dr. Byoung-Choon Jang, National Institute of Agricultural Science and Technology, Korea

CHINESE LEEK (*Allium tuberosum* L.)

Plate 28

Plate 29

Plante 28 and Plate 29. Leaves of Chinese leek showing different levels of iron deficiency. Green leaves on the left are only slightly affected, while white leaves on the right are showing severe iron deficiency.

Taiwan ROC: Subtropical climate

Photos by Hwalien District Agricultural Improvement Station, Taiwan ROC

Description of symptoms

The symptoms of iron deficiency are yellowing or chlorosis of the leaves. Severe deficiency causes the entire plant to become chlorotic and die. The symptoms are similar to those of nitrogen deficiency, but affect the young leaves first. In contrast, nitrogen deficiency affects older leaves first.

Soil conditions likely to cause iron deficiency in Chinese leek

Soil conditions likely to produce symptoms of iron deficiency in Chinese leek are the same as those for rice (p. 16 above), ginger and grape.

Diagnosis by soil analysis

Well-drained (aerobic) soils with a pH higher than 6.5 are likely to be deficient in available iron. The severity of the problem increases if the pH rises above 7.8 in calcareous soils.

Diagnosis by plant analysis and interaction with other elements, measures for correction

The same as for paddy rice (see page 15 above).

WATER SPINACH, WATER CONVOLVULUS (*Ipomoea aquatica* Forsk)

Plate 30. Iron deficiency in young leaves of water spinach. The paler the color of the leaves, the more serious is the iron deficiency.

Taiwan ROC: Subtropical climate

Photo by Hwalien District Agricultural Improvement Station, Taiwan ROC

Description of symptoms

The symptoms of iron deficiency in this crop are yellowing or chlorosis of the interveinal areas of the emerging leaf. Later, the entire leaf turns yellow, and finally white. If the deficiency is severe, the entire plant becomes chlorotic and dies. Iron deficiency can easily be mistaken for nitrogen deficiency. However, nitrogen deficiency affects older leaves first, while iron deficiency affects first the emerging leaves.

Soil conditions likely to produce iron deficiency in water conulvulus

These are the same as for soybean growing in Taiwan (page 17 above).

Diagnosis by soil analysis and remedial measures

Well-drained soils with a pH of more than 7.0 are likely to be deficient in available iron. The severity of the problem increases with an increase of the pH to 7.8 or more in calcareous soils. Diagnosis by soil analysis and interaction with other elements follow are the same as for paddy rice (see p. 15 above). The measures to correct iron deficiency are also the same.

Information from Dr. Zueng-Sang Chen, National Taiwan University

CUCUMBER (*Cucumis sativus* L.)

Plate 31

Plate 32

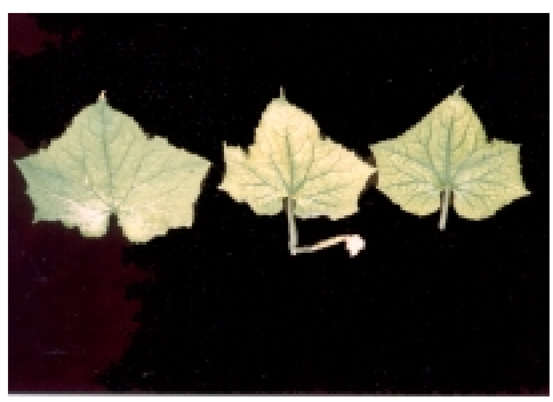

Plate 33

Photo 31. Young cucumber plant grown by hydroponic culture with very severe symptoms of iron deficiency. The youngest leaves show severe chlorosis, and are white in color.

Photo 32. Leaves of cucumber plant with early, slight symptoms of iron deficiency. Interveinal chlorosis is beginning at the base of the leaves.

Photo 33. Leaves from a cucumber plant with symptoms of iron deficiency. The principal veins are still their normal green color, but the leaf between the veins becomes pale, or even white in extreme cases.

Korea: Temperate climate

Photos by Dr. Byoong-Choon Jang, National Institute of Science and Technology, Korea

MELON (*Cucumis melo* L.)

Plate 34

Plate 35

Plate 36

Plate 34. Young melon plant, with first symptoms of iron deficiency. The youngest leaves are yellow in color.

Plate 35. Leaves of melon plant with symptoms of iron deficiency. The interveinal areas are mottled, although the principal veins retain their normal green color. A healthy plant is shown on the right.

Plate 36. The leaves of melon plants with severe iron deficiency become pale yellow to almost white.

Korea: Temperate climate

Photos by Dr. Byoung-Choon Jang, Korea

Description of Symptoms

The cucumber and melon plants (Plates 31-36) were all grown in plastic greenhouses in Korea. They were grown by hydroponic culture, without any iron nutrition. The symptoms are the same as those found in plants with iron deficiency grown in the open field.

How to correct iron deficiency in cucumber and melon

For cucumber or melon grown in soil, iron deficiency is corrected by three applications of 1% EDTA iron solution. The soil pH should be adjusted to 5.5-6.5.

GINGER (*Zingiber officinale* Roscoe)

Plate 37

Plate 38

Plate 37. Ginger plant showing typical symptoms of iron deficiency in the young leaves, which are light yellow to pale green in color
Plate 38. Serious iron deficiency of the young ginger leaves, which are white

Taiwan: subtropical climate

Photos by Hwalien District Agricultural Improvement Station, Taiwan ROC

Description of symptoms

The symptoms of iron deficiency in ginger are yellowing or chlorosis of the interveinal areas of the emerging leaf. Later, the entire leaf turns yellow, and finally white. If the deficiency is severe, the entire plant becomes chlorotic and dies. Iron deficiency can easily be mistaken for nitrogen deficiency. However, nitrogen deficiency affects older leaves first, while iron deficiency first affects younger leaves.

Soil conditions likely to produce iron deficiency in ginger

Iron deficiency is a common micronutrient disorder of ginger growing in neutral, calcareous or alkaline aerobic soils. The severity of the disorder increases with a higher pH. Iron deficiency may also sometimes be observed on upland acid soils. Other soil conditions are the same as for paddy rice (p. 15 above)

Diagnosis by soil analysis

Well-drained soils with a pH greater than 6.5 are likely to be deficient in available iron. The severity of the problem increases with an increase of the pH to 7.8 or more in calcareous soils. Diagnosis by soil analysis and interaction with other elements are the same as for paddy rice (see p. 15 above). Measures to correct iron deficiency in ginger are also the same as for rice.

Information by Dr. Zueng-Sang Chen, National Taiwan University

ANGELICA (*Angelica keiskei* L.)

Plate 39

Plate 40

Plate 41

Plate 39. Young angelica plants with severe symptoms of iron deficiency

Plate 40. Leaves of angelica plant showing symptoms of iron deficiency. The interveinal areas show chlorosis, although the principal veins retain their normal green color.

Plate 41. The first symptoms of iron deficiency occur in the youngest leaves, which turn yellow. Older leaves remain green in the early stages, but show chlorosis as severe iron deficiency spreads to the older leaves.

Korea: Temperate climate

Photos by Dr. Byoung-Choon Jang, Korea

Description of symptoms

The angelica plants shown above were grown in the open field, in soil with a pH of 7.8. The soil was waterlogged, and somewhat saline from salt accumulation. Symptoms of chlorosis began to disappear after the soil application of 1% EDTA-iron solution.

How to correct iron deficiency in angelica

Three soil applications of 1 % EDTA-iron solution remedied the deficiency problem. The soil pH should adjusted to 5.5-6.5, as should the nutrient solution of angelica grown in a hydroponic system.

CHRYSANTHEMUM (*Chrysanthemum morifolium*)

Plate 42

Plate 43

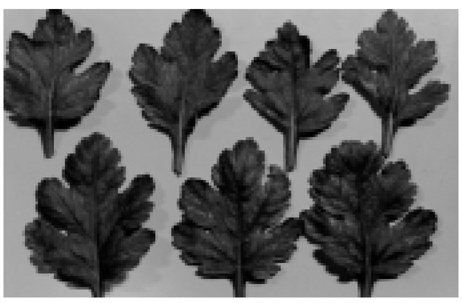

Plate 44

Plate 42. Greenhouse crop of chrysanthemum (var. Shu-hou No Chikara) with symptoms of iron deficiency. The soil is a Gray lowland soil, with a medium to coarse texture and a very low pH.

Plate 43. Leaves of chrysanthemum with iron deficiency. The veins are yellow, and chocolate-colored spots appear on the leaves. In case of severe iron deficiency, the margins of the leaves become necrotic.

Plate 44. In general, the symptoms of iron deficiency in chrysanthemum are interveinal chlorosis in young leaves (above) and chocolate colored spots in the older leaves (below).

Japan: Temperate climate

Soil conditions likely to result in iron deficiency in chrysanthemum

Iron deficiency is likely to occur where chrysanthemum are growing in a poorly drained soil with a low pH.

Diagnosis by soil analysis

Manganese (Mn) and iron (Fe) content (mg/kg) in soil

	pH	Exchangeable* Mn	Exchangeable* Fe	Mn/Fe
Normal**	4.7	33	600	0.06
Deficient	4.0	387	180	2.15

* Exchangeable: 1M ammonium acetate (neutral) extraction
** Soil from the same greenhouse, with a pH lower than that of ordinary field soils.

Diagnosis by plant analysis

Manganese (Mn) and iron (Fe) in upper (younger) leaves

	Mn	Fe	Mn/Fe
Normal	360	68	5.3
Deficiency	671	45	14.9

How to correct iron deficiency

Soil amendments

The application of calcium carbonate raised the soil pH to 6.0. The symptoms of iron deficiency were not seen in the subsequent crops of chrysanthemum in the following years.

Fertilizer applications

With the foliar application of 0.2% iron sulfate, the leaves recovered from the interveinal chlorosis, but the chocolate-colored spots remained.

Photos and information from Dr. Susumu Eguchi, Ferro Enamels (Japan) Ltd.

GRAPE (*Vitis vinifera* L., *Vitis Labrusca* L. cv. Golden Muscat)

Plate 45

Plate 46

Plate 47

Plates 45 and 46 by the Hwalien District Agricultural Improvement Station, Taiwan ROC

Plate 47 by Dr. Su-San Chang, Taiwan ROC

Plate 45. Young leaves of grape (*Vitis Labrusca* var. Golden Muscat). The leaves are light yellow to whitish in color, and show typical symptoms of iron deficiency. The lighter the leaf, the more serious the iron deficiency. Bottom left is a normal leaf.

Plate 46. Serious iron deficiency of the younger leaves of grape (*Vitis Labrusca* var. Golden Muscat), which are white in color.

Plate 47. Grape leaves (*Vitis vinifera*) which are yellow to whitish in color, showing symptoms of iron deficiency typical of younger leaves.

Taiwan: Subtropical climate

Description of symptoms

The symptoms of iron deficiency in grape are yellowing or chlorosis of the interveinal areas of the emerging leaf. Later, the entire leaf turns yellow, and finally white. The symptoms of iron deficiency are similar to those of nitrogen deficiency. However, the latter initially affects the older leaves, while iron deficiency affects the emerging leaves first.

Soil conditions likely to produce iron deficiency in grape

Iron deficiency is a common micronutrient disorder in grapes growing in neutral, calcareous and alkaline soils which are well-drained (aerobic). The severity of the disorder increases with the pH. It may also be observed on upland acid soils, and in peat soils. Other soil conditions are the same as for paddy rice (see p. 15 above).

Diagnosis by soil and plant analysis, interaction with other elements

The critical levels for iron deficiency and interaction with other elements in grape leaves, and for soil where grape vines are growing, are the same as for rice (see p. 15 above).

How to correct iron deficiency in grape

Same as for paddy rice (p. 15 above).

CACAO *(Theobroma cacao)*

Plate 48

Plate 49

Plate 50

Plates 48-50. Iron deficiency in cacao (cocoa) in Southern Mindanao, Philippines. The trees are growing on clay soils: Tropuldalfs, Calciustolls; Eutrandept

Philippines: Tropical climate

Description of symptoms

Cacao trees suffering from iron deficiency usually show general chlorosis of the upper and younger leaves. Normally, the chlorosis begins with leaves becoming pale in color. Later, the interveinal areas of the new leaves turn yellow, although the main veins remain green. The whole leaf turns yellow (chlorotic) as the iron deficiency becomes severe, and may develop necrotic spots. The chlorosis retards growth, and in the most severe cases, may eventually cause the death of the trees.

Under field conditions, iron deficiency occurs in an irregular or random pattern. Trees with apparently normal green leaves are found side-by-side with iron-deficient ones.

Symptoms of iron deficiency are similar to those of manganese deficiency. Leaves of trees which lack enough manganese are also chlorotic, with the main and the smaller leaf veins dark green. The contrast between the dark veins and the yellowish area between the veins gives the leaf a “chequered” appearance. Leaf analysis, supplemented by soil analysis, can differentiate between the two kinds of two nutrient deficiency.

Climatic Conditions which make iron deficiency likely

The availability of iron in soils for the nutritional needs of cacao is influenced by climatic factors. Iron deficiency is induced by high rainfall or high moisture conditions, as in soils saturated as a result of too much irrigation. Iron availability is also influenced by either low temperatures (less than 10^{o}C) or high temperatures (more than 33^{o}C), particularly during long, dry periods or season. Exposure of leaves to high light intensities causes them to have a higher degree and extent of chlorosis.

Soil conditions likely to produce iron deficiency in cacao

The obvious soil condition likely to produce iron deficiency is a low pH, aside from the low inherent level of available iron in the soil. Other soil factors which may induce iron deficiency in cacao are as follows:

- Poor aeration.
- Damage to plant roots by nematodes and other pathogens, which may aggravate iron deficiency.
- Strongly acidic conditions (pH lower than 5) or strong alkalinity (pH higher than 8);
- High levels of calcium carbonate in the soil;
- High levels of bicarbonate in the soil or irrigation water;
- High phosphate and nitrate levels;
- High levels of manganese, copper and zinc;
- Poor aeration.

Diagnosis by soil analysis

Plants can best absorb iron in its reduced form (Fe^{+2}) or as iron chelate. Only a small fraction of the total iron present in the soil is exchangeable and available. Thus, the total iron content of the soil does not determine the iron nutrition of crops.

DPTA extractable iron has been widely used to assess the iron status of soils. As a guide, less than 1 mg/kg DPTA iron is very low (probably most crops will be deficient). At 1-1.5 mg/kg iron content is low many crops (will be deficient). A 6-100 mg/kg iron content is moderate for most crops. More than 100 mg/kg iron is adequate for most crops and excessive for some).

Diagnosis by plant analysis

In many crops including cacao, an iron concentration of less than 50 mg/kg in the plant is considered a deficiency, while more than 300 mg/kg iron is considered to represent toxicity.

To determine the total iron in the leaves, recently mature leaves (usually the second or third leaf of the latest maturing flush) are used.

For normal growth and development, an iron content in the leaf of 65-175 mg/kg is desirable.

Interaction with other elements

Very high or excessive levels of other nutrients, such as calcium phosphorus, copper, manganese, zinc and molybdenum, interfere with the iron uptake by plants. This may induce a state of iron deficiency.

How to correct iron deficiency in cacao

Soil amendments

In the Philippines, it was recently reported that chicken manure contains 1.2-6.3% iron. Thus, chicken manure may be a practical source of iron for deficient plants, and applying it may increase the iron content of the soil.

Fertilizer applications

Iron deficiency in most plants is difficult to correct by the application of fertilizer. Usually, repeated sprays every 3-4 weeks with 2-3% ferrous sulfate solution are recommended, until the deficiency is corrected. About 300-400 liter/ha of spray solution is needed to drench the foliage of cacao trees. Some time after spraying, iron deficiency is likely to recur in very alkaline soils with a high calcium content (pH > 8.5).

Applying iron by hammering nails into the trunk

Iron deficiency in cacao trees can be corrected by hammering iron nails into the trunk. Two two-inch iron nails are inserted into the trunk on opposite sides, about 0.5 m from the ground, leaving about ¼ inch of the nail outside the bark. Cacao trees given this treatment generally recover from iron deficiency. The reduced iron (Fe^{+2}) from the nails seems to correct the iron deficiency of the trees, thus restoring the normal green color to the leaves and improving yields. This practice seems to protect trees from iron deficiency for three or four years. It is thus an economical and practical field technique for cacao trees, and other tree crops with woody stems.

Photos and information from Dr. Severino S. Magat, Philippine Coconut Authority

MULBERRY (*Morus bombycis* Koidz.)

Plate 51

Plate 52

Plate 53

Plate 54

Plate 51. An example of iron deficiency in mulberry (var. Ichinose), growing on Red and Yellow soils, Hawada, Tottori Prefecture. Damaged leaves and normal ones appear in turn, which shows that the iron deficiency comes and goes repeatedly. In this field, manganese deficiency occurs together with iron deficiency

Plate 52. Soil profile. The subsoil is a sticky red-brown clay soil, and the surface soil is a dark brown loam to clay loam that has a high humus content. Most of the soils are alkaline

Plate 53. A mulberry tree (var. Takowase) deficient in iron, growing in serpentine soil, Miyake, Hyogo Prefecture. Chlorosis is observed over the whole leaf

Plate 54. Typical iron deficiency of mulberry, cultured 233 days in quartz sand without any iron

Japan: Temperate climate

Soil conditions likely to produce iron deficiency in mulberry

Iron deficiency is common in mulberry growing in naturally alkaline soils with a low iron content. Even if the iron content is high, it may be in an insoluble form, or iron absorption by plants may be prevented by nitrate toxicity. For example, the iron content (extracted by 0.1 M HCl) in the surface soil of the Miyake field with the mulberry trees shown in Plate 53 is 2 mg iron/kg. In contrast, the level of iron in the soil of the Hawada field with the tree shown in Plate 51 is 520 mg/kg.

Diagnosis by soil analysis

If the iron content is less than 2-3 mg per kilogram of soil, the soil is likely to be deficient in iron, regardless of whether symptoms appear in the plant.

Diagnosis by plant analysis

A high occurrence of iron deficiency is found in plants with less than 100 mg/kg iron in their upper leaves.

Photos and information from Dr. Syozo Higashino, National Institute for Agro-Environmental Sciences, Japan

STARFRUIT (CARAMBOLA) (*Averrhoa carambola* L.)

Plate 55

Plate 56

Plate 55. Iron deficiency of young leaves of starfruit. The lower left leaf is normal, the upper six leaves show serious iron deficiency.

Plate 56. Serious iron deficiency in young leaves of starfruit, which are white in color.

Plate 55 by Hwalien District Agricultural Improvement Station, Taiwan ROC
Plate 56 by Mr. Ching-Hsee Lin, Taiwan ROC

WAX APPLE (*Syzygium samarangense* Merr. et Perry)

Plate 57

Plate 58

Plate 57. Serious iron deficiency in the young leaves of wax apple, which are white in color.

Plate 58. Different levels of iron deficiency. The lower left two leaves are normal, while the three upper leaves show serious iron deficiency.

Taiwan ROC: Temperate climate

Photos by Mr. Ching-Hsee Lin, Taiwan ROC

Description of symptoms

In both startfruit and wax apple, the symptoms of iron deficiency are yellowing or chlorosis of the interveinal areas of the emerging leaf. Later, the entire leaf turns yellow, and finally white. If the deficiency is severe, the entire tree may become chlorotic and die. Iron deficiency can easily be mistaken for nitrogen deficiency, but if affects emerging leaves first. Nitrogen deficiency, on the other hand, affects the older leaves first.

Soil conditions likely to produce iron deficiency in startfruit and wax apple

Iron deficiency is a common micronutrient disorder of both crops on neutral, calcareous and alkaline aerobic soils. The severity of the disorder increases with the pH. It may also be observed on upland acid soils, and on upland iron calcareous soils.

Diagnosis by soil analysis

Aerobic soils with a pH of more than 7 are likely to be deficient in available iron. The severity of the problem increases with an increase of pH to 7.8 or more in calcareous soils.

Iron deficiency is also likely to be observed if the iron concentration in the soil is less than 2mg Fe kg^{-1} by ammonium acetate, pH 4.8 extraction less than 4-5 mg Fe kg^{-1} by DTPA-Calcium chloride, pH 7.3 extraction.

Diagnosis by plant analysis

The critical level for deficiency is 50 mg Fe/kg in the young leaves.

Interaction with other elements

A high concentration of calcium carbonate in the soil or irrigation water is likely to aggravate iron deficiency.

Iron deficiency can be induced by high levels of nitrate, which raise the pH of the rhizosphere. Heavy phosphate applications may induce or aggravate iron deficiency, by precipitating iron, and by the inactivation of iron uptake of translocation to the shoot, and of iron metabolism.

How to correct iron deficiency in starfruit and wax apple

Iron deficiency can be amended through a foliar spray of 2-3% ferrous sulfate solution, or the soil application of about 30 kg/ha of iron in the form of ferrous sulfate. Because of the low mobility of iron in the tree, split applications may be necessary. Ammonium sulfate and ammonium chloride are recommended nitrogen sources for soils with a high pH.

Other cultivation practices

Growers should use tolerant varieties. The application of organic manure should help lower the soil pH.

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