Chapter VI Mineral Nutrients - Necessary Mineral Elements

I. Mineral Nutrients

Definition: Absorption, transport and assimilation of minerals by plants

II. Elements in Plants

Ash: C, H, O, N ↑ $\xrightarrow{\Delta}$ nonvolatile embers

Mineral elements (ash elements): Exist in form of oxides in ash

III. Mineral Elements Neccessary for Plants

1. Soil culture method: A method for culturing plants in soil
2. Water culture method: A method for culturing plants in a solution containing all or some of nutrient elements

Adequate tissue levels of elements that may be required by plants

Element	Chemical symbol	Concentration in dry matter (% or ppm)[a]	Relative number of atoms with respect to molybdenum
Obtained from water or carbon dioxide			
Hydrogen	H	6	60,000,000
Carbon	C	45	40,000,000
Oxygen	O	45	30,000,000
Obtained from the soil			
Macronutrients			
Nitrogen	N	1.5	1,000,000
Potassium	K	1.0	250,000
Calcium	Ca	0.5	125,000
Magnesium	Mg	0.2	80,000
Phosphorus	P	0.2	60,000
Sulfur	S	0.1	30,000
Silicon	Si	0.1	30,000
Micronutrients			
Chlorine	Cl	100	3,000
Iron	Fe	100	2,000
Boron	B	20	2,000
Manganese	Mn	50	1,000
Sodium	Na	10	400
Zinc	Zn	20	300
Copper	Cu	6	100
Nickel	Ni	0.1	2
Molybdenum	Mo	0.1	1

3. Sand culture method: A method for culturing plants in a solution containing all or some of nutrient elements and added with clean quartz sand or glass beads

4. The mineral elements shall possess the following conditions:

   1) They are essential to completing the whole growth cycle of plants;

   2) Their functions in plants cannot be replaced by other elements and may be prevented and recovered;

   3) They take a direct part in plant metabolism.

Classification of plant mineral nutrients according to biochemical function

Mineral nutrient	Functions
Group 1	**Nutrients that are part of carbon compounds**
N	Constituent of amino acids, amides, proteins, nucleic acids, nucleotides, coenzymes, hexoamines, etc.
S	Component of cysteine, cystine, methionine, and proteins. Constituent of lipoic acid, coenzyme A, thiamine pyrophosphate, glutathione, biotin, adenosine-5′-phosphosulfate, and 3-phosphoadenosine.
Group 2	**Nutrients that are important in energy storage or structural integrity**
P	Component of sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid, etc. Has a key role in reactions that involve ATP.
Si	Deposited as amorphous silica in cell walls. Contributes to cell wall mechanical properties, including rigidity and elasticity.
B	Complexes with mannitol, mannan, polymannuronic acid, and other constituents of cell walls. Involved in cell elongation and nucleic acid metabolism.
Group 3	**Nutrients that remain in ionic form**
K	Required as a cofactor for more than 40 enzymes. Principal cation in establishing cell turgor and maintaining cell electroneutrality.
Ca	Constituent of the middle lamella of cell walls. Required as a cofactor by some enzymes involved in the hydrolysis of ATP and phospholipids. Acts as a second messenger in metabolic regulation.
Mg	Required by many enzymes involved in phosphate transfer. Constituent of the chlorophyll molecule.
Cl	Required for the photosynthetic reactions involved in O_2 evolution.
Mn	Required for activity of some dehydrogenases, decarboxylases, kinases, oxidases, and peroxidases. Involved with other cation-activated enzymes and photosynthetic O_2 evolution.
Na	Involved with the regeneration of phosphoenolpyruvate in C_4 and CAM plants. Substitutes for potassium in some functions.
Group 4	**Nutrients that are involved in redox reactions**
Fe	Constituent of cytochromes and nonheme iron proteins involved in photosynthesis, N_2 fixation, and respiration.
Zn	Constituent of alcohol dehydrogenase, glutamic dehydrogenase, carbonic anhydrase, etc.
Cu	Component of ascorbic acid oxidase, tyrosinase, monoamine oxidase, uricase, cytochrome oxidase, phenolase, laccase, and plastocyanin.
Ni	Constituent of urease. In N_2-fixing bacteria, constituent of hydrogenases.
Mo	Constituent of nitrogenase, nitrate reductase, and xanthine dehydrogenase.

5. Necessary macro-elements and trace elements

   1) Macro-elements: C, O, H, N, K, Ca, Mg, P, S and Si (>10 mmol kg^{-1} dry weight);

   2) Trace elements: Cl, Fe, B, Mn, Na, Zn, Cu, Ni and Mo.

IV. Physiological Effect of Mineral Elements Necessary for Plants

(I) The physiological effect is shown in four aspects :

1. They are components of cellular structural matters;
2. They are regulators of life activities and participate in the activities of enzymes;
3. They play an electrochemical role, i.e.: equilibrium of ion concentration, redox, electron transport and charge neutralization;
4. They are the second messengers of signal transduction in cells.

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(II) Nutrients of carbon compounds

1. **N**

1) Form of absorption: ammonium nitrogen, nitrate nitrogen and urea

2) Physiological effect: It is a component of amino acids, amides, proteins, nucleic acids, nucleotides and coenzymes. Chlorophyll, some hormones, vitamins and alkaloids also contain nitrogen, “the element of life”.

3) Deficiency: The plants are short and small, the leaves are small and in a light color or red, there are fewer branches and flowers, seeds are not full and the yield is low.

2. S

1) Form of absorption: SO_4^{2-}

2) Physiological effect: It is assimilated into Cys, cystine and Met, and is also a component of thioctic acid, coenzyme A, thiamine pyrophosphate , glutathione , biotin , APS and ATP.

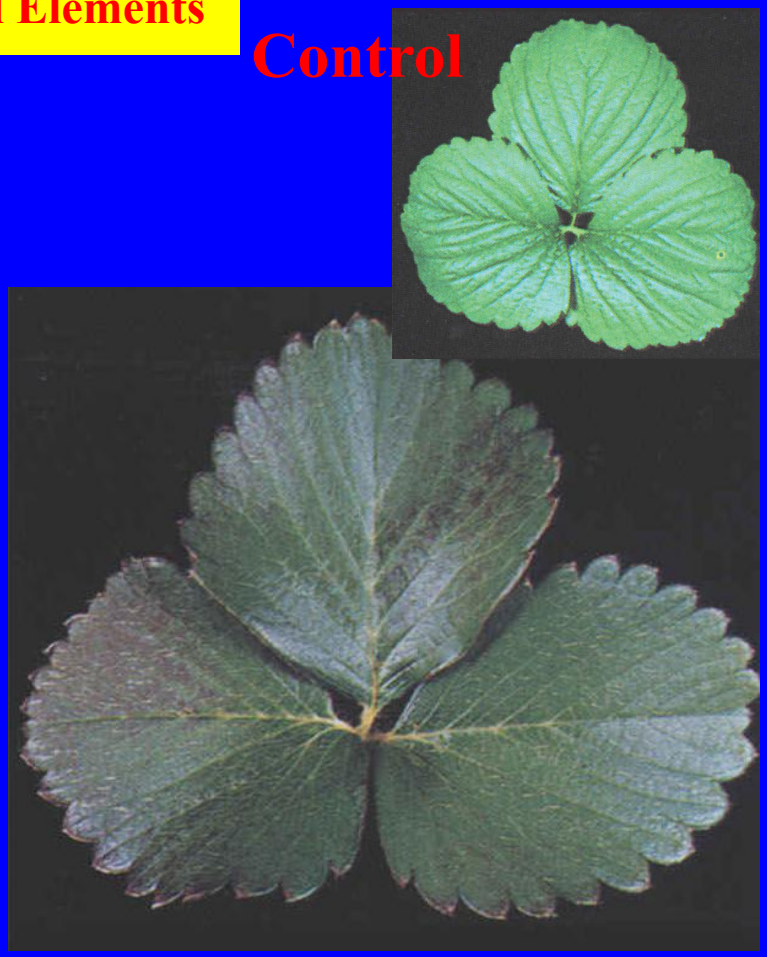
3) Deficiency: Similar to nitrogen deficiency, but chlorosis starts from tender leaves, the plants are dwarfed and anthocyanin is accumulated.

(III) Nutrients for energy storage and structural integrity

1. **P**

1) Form of absorption: n-phosphate

2) Physiological effect: It exists in phosphosugar, nucleic acids, nucleotides, coenzymes, phospholipid and phytic acid, and plays an important role in ATP reaction and carbonhydrate, protein and lipid metabolism.



3) Deficiency: Protein synthesis is hampered, cell division is affected, the growth is slow, the leaves are small, there are fewer branches, the plants are short and small, leaves are dark green, sometimes red or purple, the flowering period and maturation period are delayed, the resistance is weakened and the yield is reduced.

2. **Si**

1) Form of absorption: H_4SiO_4

2) Physiological effect: It is deposited on cell walls or in intercellular spaces in form of amorphous hydrate, or is bound with polyphenols into cell wall thickening matter to boost rigidity.

3) Deficiency: Transpiration is accelerated, growth is hampered and it is vulnerable to lodging and fungal infection.

3. **B**

1) Form of absorption: H_3BO_3

2) Physiological effect: It forms complexes with mannitol, mannan, polymannuronic acid and other cell wall components and participates in cell elongation and nucleic acid metabolism.

3) Deficiency: Anther and filament shrink and pollen is not developed well. The content of toxic phenolic compounds is excessively high, and the tender shoots and apical buds are necrotic and there are many branches.

(IV) Nutrients for keeping ionic condition

1 **K**

1) Form of absorption: KCl, K_2SO_4

2) Physiological effect: It serves as an activator of enzymes and is a cofactor of more than 40 enzymes; a major cation promoting cell expansion and maintaining electrical neutrality; located at the most active locations.

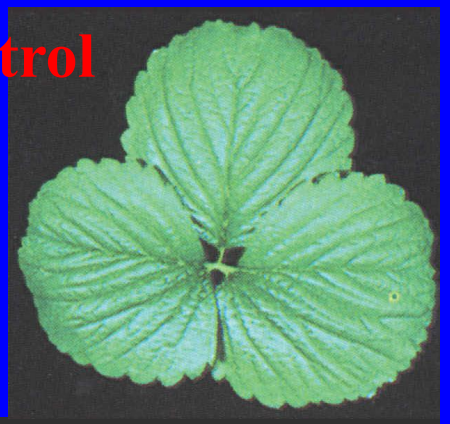
3) Deficiency: The plant stalk is weak and liable to lodging and has poor resistance to drought and cold; leaves turn yellow and are gradually necrotized; leaf margins are withered and blades are bent or shrink.

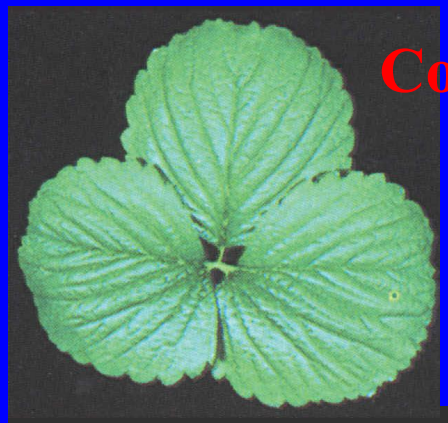
2. **Ca**

1) Form of absorption: $CaCl_2$, etc.

2) Physiological effect: It is a bridge between phospholipid phosphate radical and protein carboxyl to maintain stability of the membrane structure; is an element of cell wall; calcium is bound with calmodulin to form a complex, serving as "a second messenger" in regulation of metabolism.

3) Deficiency: The formation of cell wall is hampered, affecting division, resulting in growth inhibition, canker and necrosis of young organs in serious cases.





Control

3. **Mg**

1) Form of absorption: Mg^{2+}

2) Physiological effect: It is a component of chlorophyll; and activates transphosphorylase and phosphokinase as well as the synthetic process of nucleic acids.

3) Deficiency: Leaf veins are still green and the inter-veins turn yellow, sometimes red purple, and in serious cases, necrotic brown spots are formed.

4 **Cl**

1) Form of absorption: Cl^-

2) Physiological effect: It is an activator of hydrolysis and promotes release of O_2; the cell division of roots and leaves needs Cl.

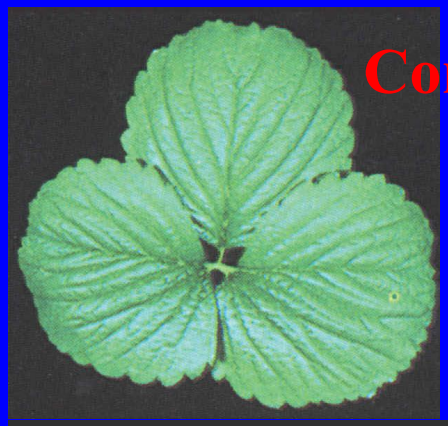
3) Deficiency: The plants are short and small, the leaf apexes are withered and yellowed and eventually necrotic; the roots grow slowly and the root tips are thick.

5 **Na**

1) Form of absorption: Na^+

2) Physiological effect: It catalyzes PEP regeneration in C_4 and CAM pathways; increases cell expansion to promote growth; partially replaces K contribution ψ_S

3) Deficiency: The plants are yellowed and necrotic, even not flowered.



6. **Mn**

1) Form of absorption: Mn^{2+}

2) Physiological effect: It is an activator of related enzymes and nitrate reductase in glycolysis and tricarboxylic acid cycle to crack water into O_2 during photosynthesis.

3) Deficiency: The inter-veins are chlorotic (old leaves and tender leaves are all chlorotic), generating necrotic spots.

(V) Nutrients for redox

1 **Fe**

1) Form of absorption: Oxidized iron (Fe^{2+}, Fe^{3+})

2) Physiological effect: It is a component of cytochrome and nonheme-iron protein and plays a role of electron transport in redox; is essential to the synthesis of chlorophyll-protein complex.

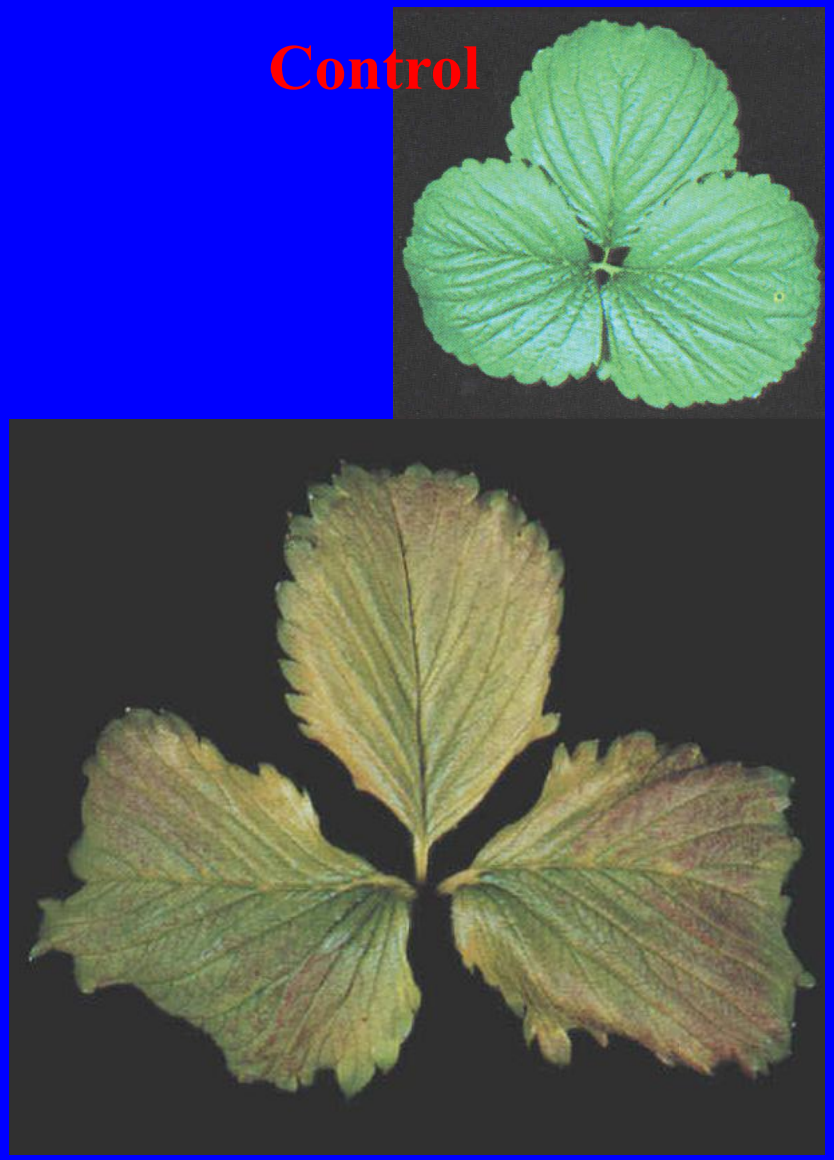
3) Deficiency: The inter-veins of tender leaves are chlorotic. In serious cases, leaf veins will be chlorotic, too and whole leaves are whitened.

2. **Zn**

1) Form of absorption: Zn^{2+}

2) Physiological effect: It is a component of some dehydrogenases and carbonic anhydrases, and an element essential to biosynthesis of chlorophyll.

3) Deficiency: The ability to synthesize Trp is lost and the content of heteroauxin is low; internodes are short and rosette-shaped, and leaves are small, deformed and chlorotic.



Control

3. **Cu**

1) Form of absorption: Cu^{2+}

2) Physiological effect: It is a component of some oxidases, affecting redox process; exists in plastocyanin and influences electron transport of photosynthesis.

3) Deficiency: Black-green first appears on the apexes of tender leaves, there are necrotic spots, leaves are wrinkled or deformed; if deficiency is serious, leaves will fall.

4 **Ni**

1) Form of absorption: Ni^{2+}

2) Physiological effect: It is a component of urease and hydrogenase.

3) Deficiency: Urea is accumulated in leaf apexes, causing necrosis.

5 **Mo**

1) Form of absorption: MoO_4^{2-} and $HMoO_4^-$

2) Physiological effect: It is a component of nitrate reductase and nitrogenase, mainly manifested in the aspect of nitrogenous metabolism.

3) Deficiency: The inter-veins of old leaves are chlorotic and necrotic; broccoli leaves are wrinkled, even necrotic, not flowered, or flowers are withered early.

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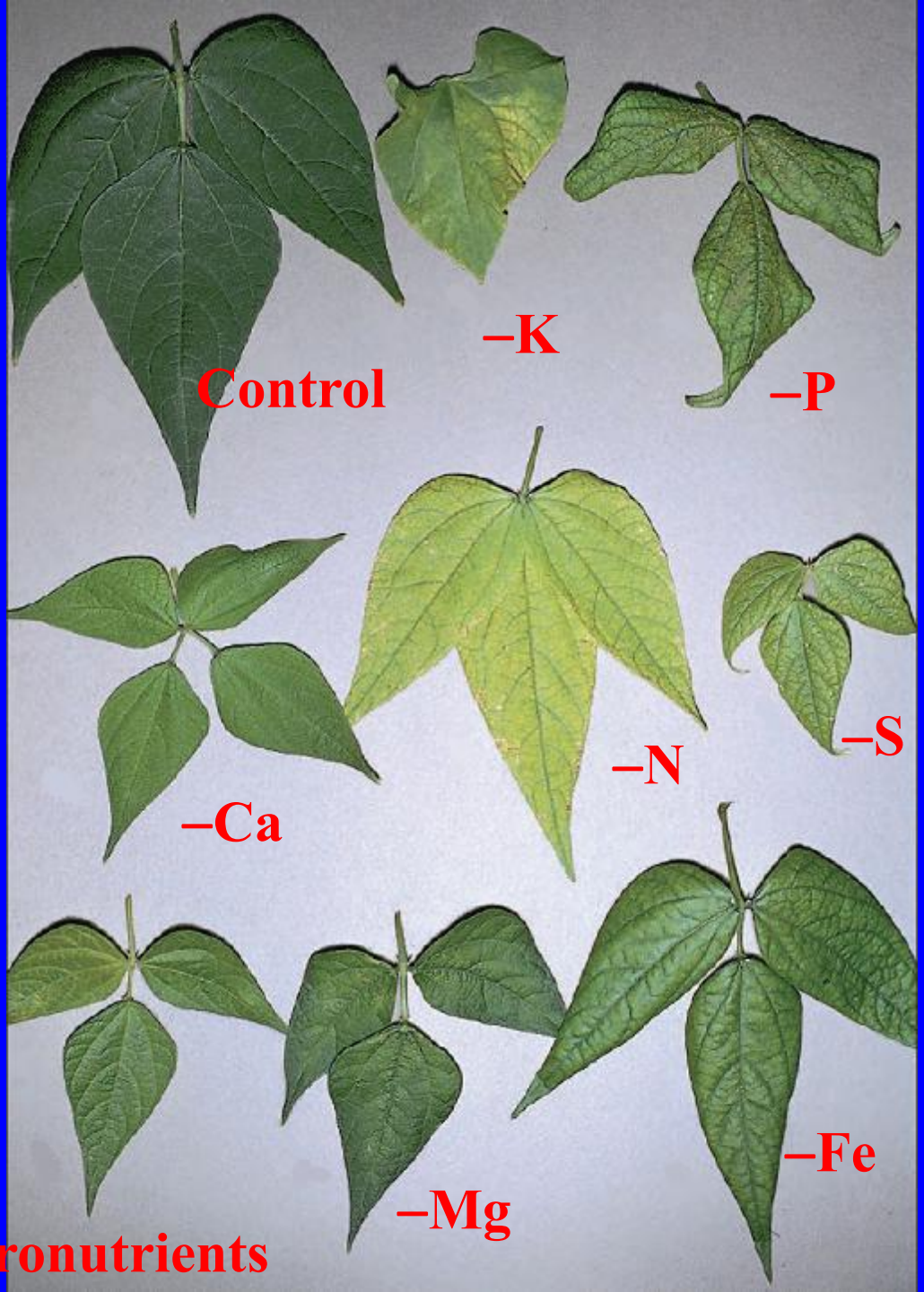
Leaves of bean plants grown in media deficient in various elements to show deficiency symptoms.



V. Diagnosis of Shortage of Mineral Elements in Crops

(I) Diagnostic method of chemical analysis

Leaf is used as a material to analyze the chemical composition of diseased plants. It is compared with the chemical composition of normal plants.

(II) Diagnostic method of symptoms

Different plants show different symptoms when an element is in shortage. The degree of manifestation varies with the extent of shortage. The interaction among different elements makes symptom diagnosis more complex. The plants are abnormal and also affected by diseases, pests and unfavorable environments.

(III) Diagnostic method of addition

After shortage of an element is preliminarily diagnosed, this element is added. If the symptoms disappear, pathogenesis can be determined.