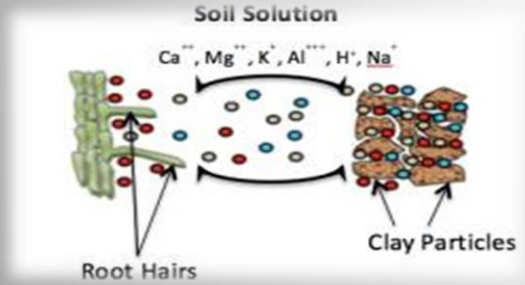
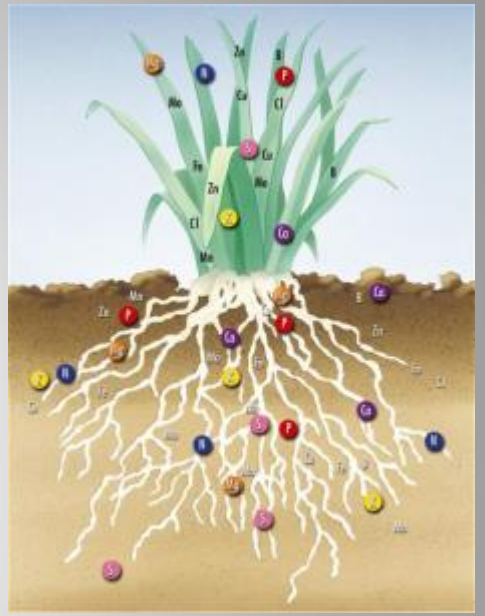
Essential Soil Nutrients for Plant Growth and Development



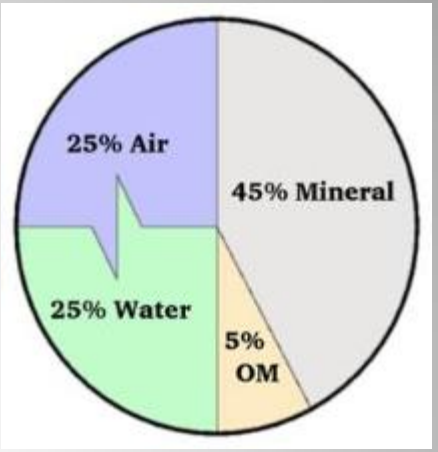
Essential nutrients required by plants

Role of nutrients within the plant

Symptoms of deficiencies/toxicities



The basic soil components are:
minerals,
organic matter,
water
and air.



Essential nutrients required by plants
(as listed by CCA training materials)

18

Structural

3

Mineral

15

Structural Nutrients

Obtained from the air (CO_2) and water (H_2O)

Carbon

Hydrogen

Oxygen

15 Mineral Nutrients
(Based on the National CCA Training Materials)

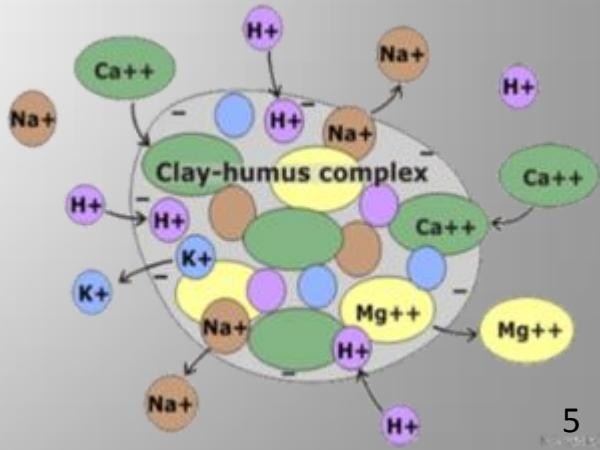
***Macro*-nutrients**

3 primary

3 secondary

***Micro*-nutrients**
(sometimes referred to as "trace" elements)

9



Macro-nutrients
Required in larger amounts

Primary

N	**Nitrogen**
P	**Phosphorus**
K	**Potassium**

Secondary

Ca	**Calcium**
Mg	**Magnesium**
S	**Sulfur**

Nitrogen (N)

- Often applied as NH_3 (ammonia)
  - The basic product producing nearly all other N sources
- Ammonia changes to:

  Step 1 (ammonium) $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

  Step 2 (nitrite) $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$

  Step 3 (nitrate) $2NO_2^- + O_2 \rightarrow 2NO_3^-$

- Protein builder
- Necessary for formation of amino acids
- Component of vitamins, enzymes, and chlorophyll
- Essential for plant cell division and plant growth
- Energy reactions within the plant
- Optimal tiller production

Nitrogen

Deficiencies made worse by:

- Low or high pH soils
- Low organic matter
- Drought conditions
- High rainfall or heavy irrigation (leaching)
- Sudden addition or high levels of non-decomposed organic matter/manure (eg. straw)

Nitrogen Deficiencies

- Because of its essential role in amino acids and proteins, deficient plants and grains will have low protein grain and yellowing of vegetation
- Excessive N inhibits uptake of K, Zn, Mn, and Cu
- *Mobile in plants.*

Nitrogen deficient small crop with light green upper (young) leaves and yellow older leaves.

Phosphorus (P)

- Major role in the energy system of plants
- Encourages early root formation and growth
- Increases water use efficiency
- Reduces winter plant stress (winter kill)
- Speeds crop maturity
- Improves quality of grain

Deficiencies made worse by:

- Acidic or very alkaline soils
- Low organic matter
- Cold or wet conditions
- Crops with a poorly developed root system (acidic soils)

Phosphorus Deficiencies

- Plants are stunted and show purple tints on their dark green leaves, veins and stems
- Older leaves affected first, often senesce prematurely
- Mobile in plant

Dark purple discoloration on the leaf tips, advancing down the leaf in a broad front (IPNI)

earlier maturing

Potassium (K)

- Major role in the plant metabolism and involved in photosynthesis
- Essential for protein synthesis, protein content
- Necessary for adaptations to stress
- Increases water use efficiency through regulation of water loss
- Increases drought tolerance
- Improves winter hardiness and disease resistance
- Important in grain formation and quality

Deficiencies made worse by:

- Acidic soils (low pH)
- Sandy or light soils (leaching)
- Drought conditions
- High rainfall or heavy irrigation (leaching)
- Heavy clay soils

Potassium Deficiencies

- Young leaves may be bluish green
- The older leaves show chlorotic tips and leaf margins, followed by necrosis
- Mobile in plant

Marginal chlorosis and necrosis on older leaves (IPNI).

Paul G. Carter

Calcium (Ca)

- Door keeper for all nutrient uptake by root hairs
- Cell division and formation
- Aids in translocation of photosynthesis from leaves to grain
- Increases grain set (yield)
- Stimulates microbial activity. Bacteria need calcium to perform at their highest levels. As calcium becomes unavailable or lacking, bacteria numbers will fall accordingly
- Essential for root health, growth of new roots and root hairs, and the development of leaves
- Reduces disease stresses

Deficiencies made worse by:

- Acidic soils
- Sandy or light soils (leaching)
- Soils high in sodium or aluminum
- Drought conditions

Calcium Deficiencies

- Flag leaf twisted/curled
- Leaf tip burn
- Wheat head trapped in flag leaf
- Stunted development
- Crop lodging (weakened stems)
- Blossom end rot (tomatoes and peppers) and bitter pit (apples)

Magnesium (Mg)

- Key component of chlorophyll and photosynthesis
- Aids in mobility of phosphorus in the plant
- Plant enzymes
- Earlier and uniform maturity
- Increase Iron utilization and aids nitrogen fixation in legume nodules

Deficiencies made worse by:

- Sandy soils
- Acidic soils
- Soils receiving high K applications
- Cold wet periods.

Magnesium Deficiencies

- Tillering is reduced, with extensive leaf and tiller death.
- Surviving plants produce fewer and smaller heads.
- Green yellow plants with yellow interveinal chlorosis turning to brown necrosis on the middle leaves.
- Often appears as patches of pale, floppy wheat in an otherwise green healthy crop
- Leaves often kink, collapse and eventually die.

Sulfur (S)

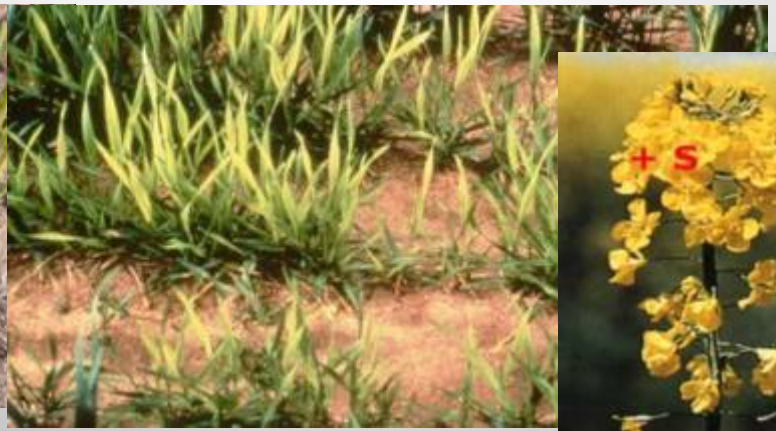
- Part of amino acids in plant proteins
- Involved in energy-producing processes in plants
- Helps develop enzymes and vitamins
- Nodule formation and seed production
- Leaches easily
- Nitrogen to Sulfur ratio, around 8 to 1

Deficiencies made worse by:

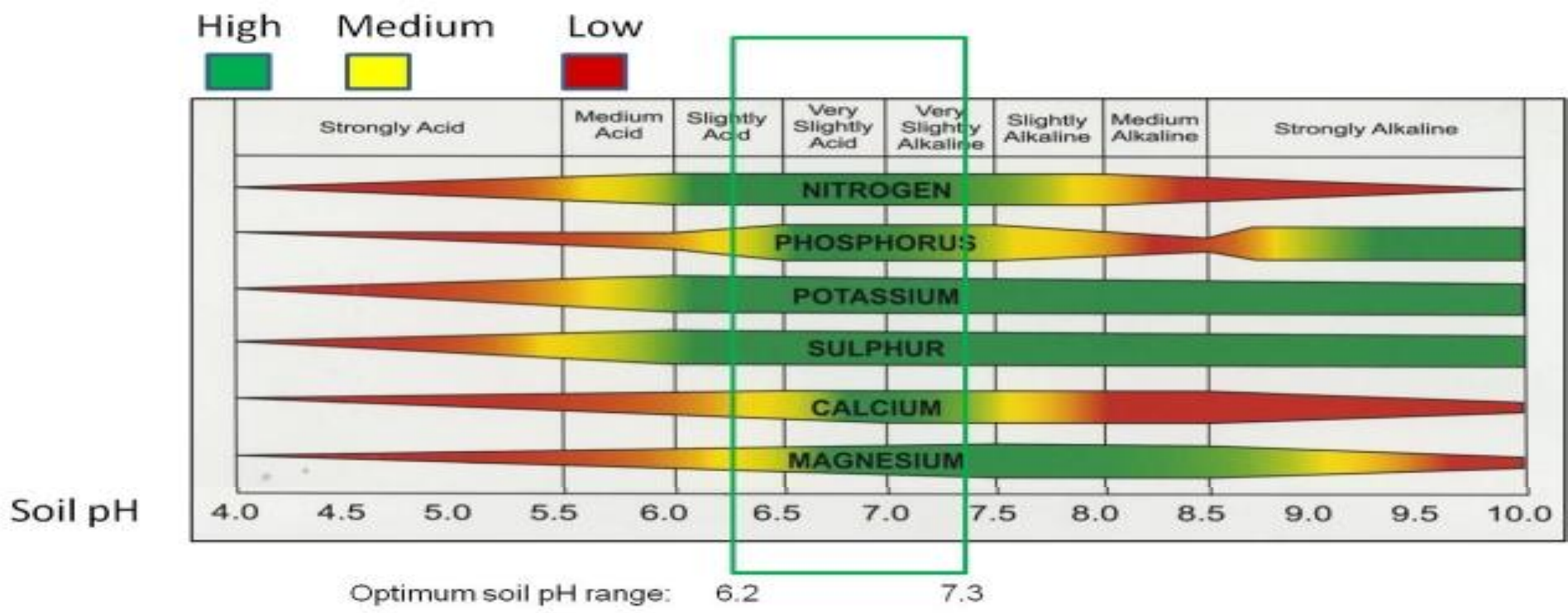
- Acidic soils
- Light, sandy soils (leaching)
- Low organic matter
- Poorly aerated soils (waterlogged soils)

Sulfur Deficiencies

- Plants show a bright chlorotic, yellow green color (younger leaves)
- Stunted growth
- The classic symptom, paleness of the younger foliage first
- Reduced number of grains sites and the size of grain
- Reduced bloom set (canola)
- Not mobile in plant



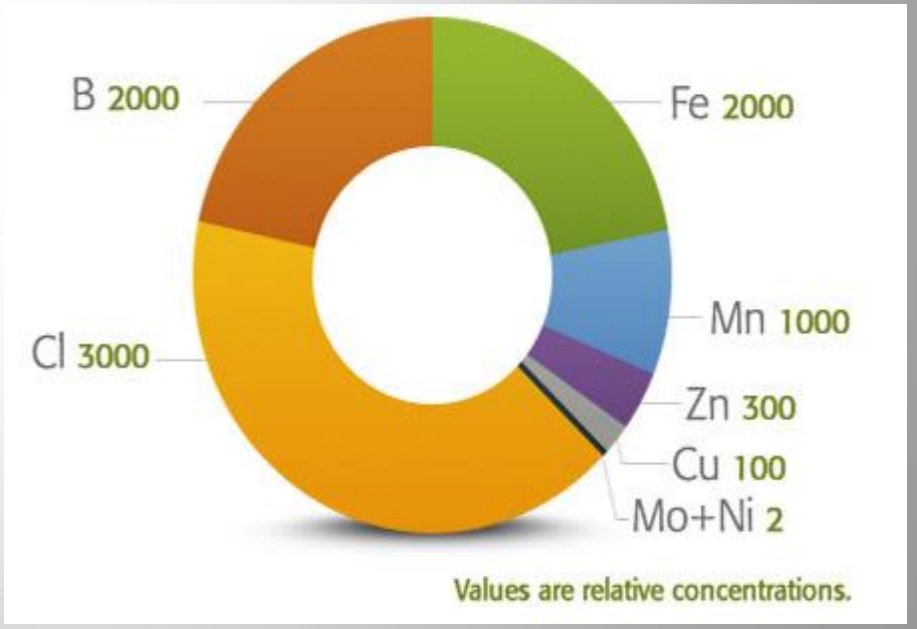
Soil pH Affects Availability of Plant *Macro*-nutrients



Micro-nutrients
(trace elements)
Required in smaller amounts

Considered the Enzyme nutrients

Cl	**chloride**
Fe	**iron**
B	**boron**
Mn	**manganese**
Zn	**zinc**
Cu	**copper**
Mo	**molybdenum**
Ni	**nickel**
Co	**cobalt**



Chloride (Cl)

- Photosynthesis and enzyme activation which affects germination and energy transfer.
- Aids in the transport of nutrients such as potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) since it acts as a counter-ion to maintain electrical balance.
- Water movement in cells
- Stomatal activity. Both K and Cl- are involved in the movement of guard cells that control the opening and closing of leaf pores or stomata.
- Water loss management

(photo courtesy of R. Engel)

Chloride Deficiencies

- Small, white necrotic spots along the plant's leaves
- Tips of leaves may curl or wilt

Physiological leaf spot

(photo courtesy of R. Engel)

Boron (B)

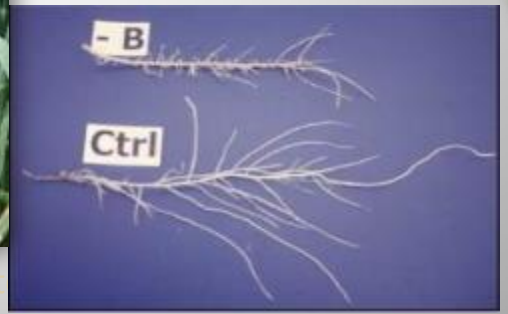
- Germination of pollen grains and fertilization
- Essential for seed set and yield
- Cell wall formation
- Promotes maturity
- Metabolism of phosphorous compounds

Deficiencies made worse by:

- Inhibited by high levels of N and Ca
- cold wet weather
- periods of drought

Boron Deficiencies

- Reduced flowering
- Thickened, curled, chlorotic leaves
- Stunted plant growth; growing point and younger leaves first
- Deficiency may reduce pollination and grain set



Zinc (Zn)

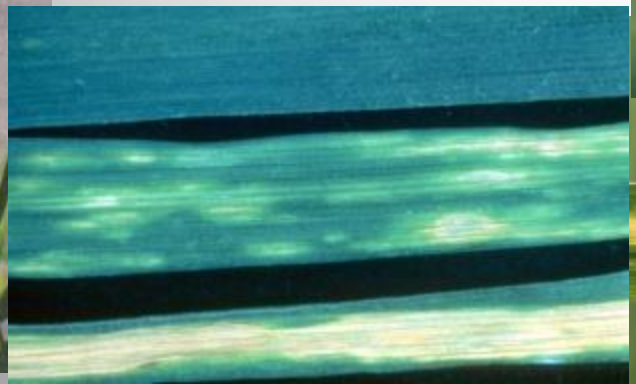
- Increased fertility (number of grains per head)
- Increased grain quality.
- Chlorophyll production
- Zinc is mostly immobile in the plant
- Zn applications can sometimes help with availability of P

Deficiencies made worse by:

- High soil pH
- low in organic matter
- Sandy soils

Zinc Deficiencies

- Symptoms usually appear first in the newly emerging leaves.
- Pale yellow linear chlorotic areas (interveinal chlorosis)
- A muddy grey-green region appears in the middle of leaf
- Yellow and brown necrotic patches gradually extend outwards towards the tip from the base of the leaf


Copper (Cu)

- Major function in photosynthesis
- An essential part of enzymes in plants
- Increased fertility (number of grains per head)
- Increased grain quality
- High pH inhibits Cu uptake
- Inhibited by excessive N and high pH

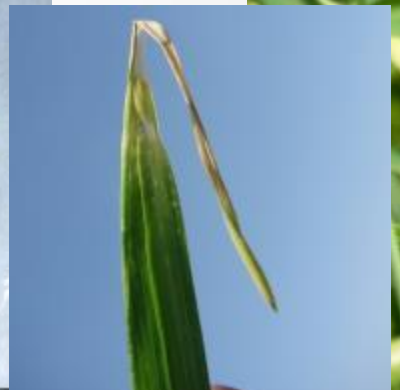
Deficiencies made worse by:

- High soil pH
- Excess potassium, phosphorus or other micronutrients can indirectly cause copper deficiency

Copper Deficiencies

- Weaken stalks (cell wall strength)
- Wheat crop lodging
- Plants show dry, white and twisted or curled leaf tips (white tip)
- Young leaves wilt and roll on their tips, whereas the basal leaves remain dark green
- Small grains may not head or form grain
- Not mobile






Molybdenum (Mo)

- Converts nitrates (NO3) into amino acids within the plant
- It is essential to the conversion of inorganic P into organic forms in the plant
- Required for synthesis and activity of the enzyme nitrate reductase
- Vital for N fixation by Rhizobia bacterial on legume root nodules
- Heavy P applications may increase Mo uptake
- Heavy S applications may inhibit Mo uptake
- Seed treatment is the most common way of correcting Mo deficiency because of the very small amounts of the nutrient required

Deficiencies made worse by:

- Leaching Soil Conditions: Available soil Mo is an anion, and is therefore leachable.
- Soil pH: Molybdenum is the only micronutrient that has increased availability as the pH increases. At a soil pH above 6.5

Molybdenum Deficiencies

- Show up as a general yellowing and stunting of the plant
- Marginal scorching and cupping or rolling of leaves
- Deficiencies more likely on low pH soils and can cause N deficiencies in legume crops
- Relatively rare in most agricultural cropping areas
- Poor grain or fruit set, due to less viable pollen

Manganese (Mn)

- Increases availability of P and K
- Chlorophyll synthesis
- Nitrate assimilation
- Part of certain enzymes
- Electron transport during photosynthesis
- Not mobile in plant

chlorosis due to a shortage of iron, manganese or molybdenum begins on the upper leaves.

Deficiencies or Toxicities made worse by:

- Can be in toxic amounts in very acid soils deficient in high pH soils
- High organic matter
- Can be deficient in sandy and highly alkaline soils
  - Toxicity is remedied with lime

Manganese Deficiencies

- Appear first on younger leaves
- Interveinal chlorosis (yellowing between the veins)
- Grayish areas appear at the base of young leaves
- Less available in high pH, waterlogged soils

Iron (Fe)

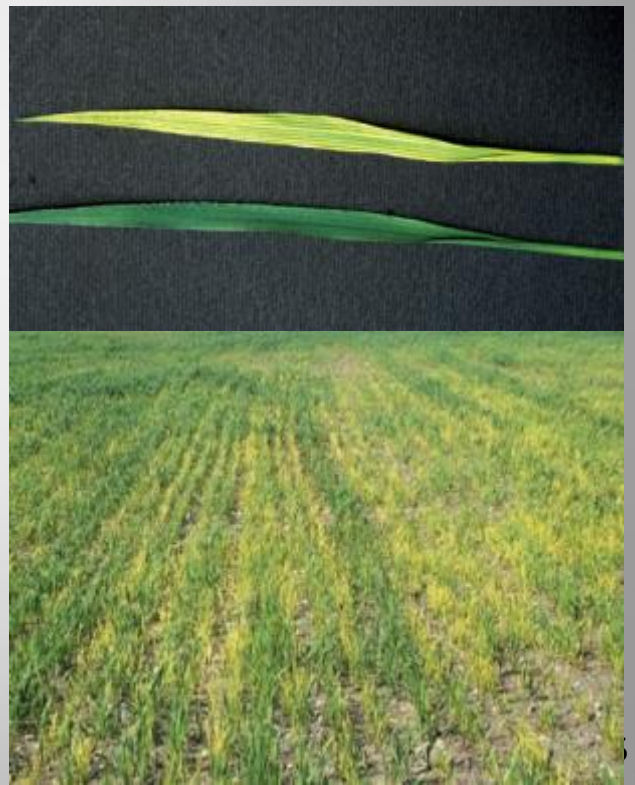
- Iron is a part of many compounds that regulate and promote growth
- Oxygen carrier
- Chlorophyll development and function
- It plays a role in energy transfer within the plant
- Iron functions in plant respiration and plant metabolism
- Involved in nitrogen fixation
- Immobile in plant

Deficiencies or Toxicities made worse by:

- Can be in toxic amounts in very acid soils deficient in high pH soils
- High organic matter
- Erosion or leaching
- Cool damp springs
- Can be deficient in sandy and highly alkaline soils
  - Toxicity is remedied with lime

Iron Deficiencies

- Deficiency symptoms include interveinal chlorosis of young leaves, often seen in high pH soils, toxicity in low pH soils
- Poor grain quality and quantity



Other nutrients

There are 2 other micronutrients not often addresses or recognized
Nickel and Cobalt

- Nickel – Nickel was long considered non-essential or toxic, but work on a variety of crops reveals it to be directly related to plant health. Ni, which is involved in symbiotic N fixation. Sprays with Ni salts are also effective against rust infection in cereals. Nickel deficiency can lead to the accumulation of urea, which causes necrotic spots on the leaves. Cereals show interveinal chlorosis in young leaves and stunted foliage.
- Cobalt – is seldom recognized but has proven to be beneficial to at least some plants although it does not appear to be essential for most species. Cobalt is necessary for *nitrogen* (N) fixation occurring within the nodules of legume plants.

Deficiency Chart of Micronutrients

Boron: Discoloration of leaf buds. Breaking and dropping of buds

Sulphur: Leaves light green. Veins pale green. No spots.

Manganese: Leaves pale in color. Veins and venules dark green and reticulated

Zinc: Leaves pale, narrow and short Veins dark green. Dark spots on leaves and edges.

Magnesium: Paleness from leaf edges. No spots Edges have cup shaped folds. Leaves die and drop in extreme deficiency.

Phosphorus: Plant short and dark green. In extreme deficiencies turn brown or black. Bronze colour under the leaf.

Calcium: Plant dark green. Tender leaves pale. Drying starts from the tips. Eventually leaf bunds die.

Iron: Leaves pale. No spots. Major veins green.

Copper: Pale pink between the veins. Wilt and drop.

Molybdenum: Leaves light green/ lemon yellow/ornge. Spots on whole leaf except veins. Sticky secretions from under the leaf.

Potassium: Small spots on the tips, edges of pale leaves. Spots turn rusty. Folds at tips.

Nitrogen: Stunted growth. Extremely pale color. Upright leaves with light green/yellowish.Appear burnt in extreme deficiency.

THE COLOUR REPRESENTED ARE INDICATIVE. THEY MAY VARY FROM PLANT TO PLANT

	FUNCTION	DEFICIENCY SYMPTOMS	MADE WORSE BY
N	• Primary building block for amino acids, protein, & protoplasm • Critical for flower differentiation, rapid shoot growth, bud vigor, & fruit set • Acts as a catalyst for other elements	• Foliage is yellowish green foliage yellowing first • Stunted plants • Smaller fruit, lower yields	• Extreme low or high pH • Fast growing crops
P	• Important for energy transfer & storage • Formation of nucleic acids • Promotes root, flower, & seed development	• Severe stunting, leaf die back • Leaves, stems, and veins dark green to purple • Delayed maturity • Poor seed development	• Very acidic or calcareous conditions • Cold conditions • Poorly developed root systems • Low Phosphorus, high Iron
K	• Necessary for the formation of sugars & starches • Essential for oil production • Enzyme activator • Improves cold weather tolerance	• Leaf distortion & curling • Marginal leaf scorch • Late season blotchy chlorosis • Poorly developed root system	• Acidic conditions • High Calcium and Magnesium nutrients
S	• Component of amino acids & proteins • Aids in nodule formation of sugars & starches • Stabilizes Nitrogen	• Leaves are light green/ yellow • Plants are stunted • Delayed maturity	• Acidic conditions • Poor aeration
Mn	• Necessary for the formation of sugars & starches • Aids in Nitrogen utilization & assimilation • Aids in chlorophyll synthesis	• Mottled chlorosis first on old leaves, moving to new growth • Crop stunting	• High pH • Organic conditions • Prolonged cold periods
Zn	• Synthesis of Auxins & protein • Needed for uniform maturity • Important for Calcium translocation	• Stunted growth, small malformed leaves • Interveinal chlorosis, striping in grasses • Twig die-back	• Organic conditions • High pH • High Phosphorus fertilization
Mg	• Enzyme activator • Chlorophyll synthesis • Aids in seed germination • Aids in the use of Phosphorus	• Interveinal chlorosis and necrosis especially on older leaf tips • Drooping leaves • Excessive premature fruit drops	• Very acidic conditions • High Potassium or Calcium
Ca	• Aids in cell wall structure • Necessary for early root growth • Regulates nutrient uptake and movement throughout the plant	• Poor root development • Premature shedding of blossoms and buds • Deformed terminal leaves/ dead terminal buds	• Acidic conditions • High Aluminum
B	• Pollen tube formation • Important for early growth • Necessary for cell division • Aids in Calcium translocation	• Death of terminal growth • Thick brittle leaves • Poor fruit set/ malformed fruit	• High Nitrogen or Calcium • High pH media • Alkaline conditions
Cu	• Critical for photosynthesis • Necessary for seed development • Component for several enzymes	• Marginal chlorosis • Shoot die back, stunted growth • Necrotic areas on terminal leaves	• Organic conditions • High Nitrogen application • Water stressed plants
Fe	• Chlorophyll formation • Activator for respiration • Enzyme activation	• Interveinal chlorosis, young leaves first • Stunted growth	• High pH • Water logged media • Calcareous conditions • High Copper, Manganese, Zinc
Mo	• Nitrogen fixation and metabolism • Iron and Phosphorus metabolism	• Reduced nodulation on legumes • Poor growth, pale leaves	• Low pH

Nutrient Availability Management

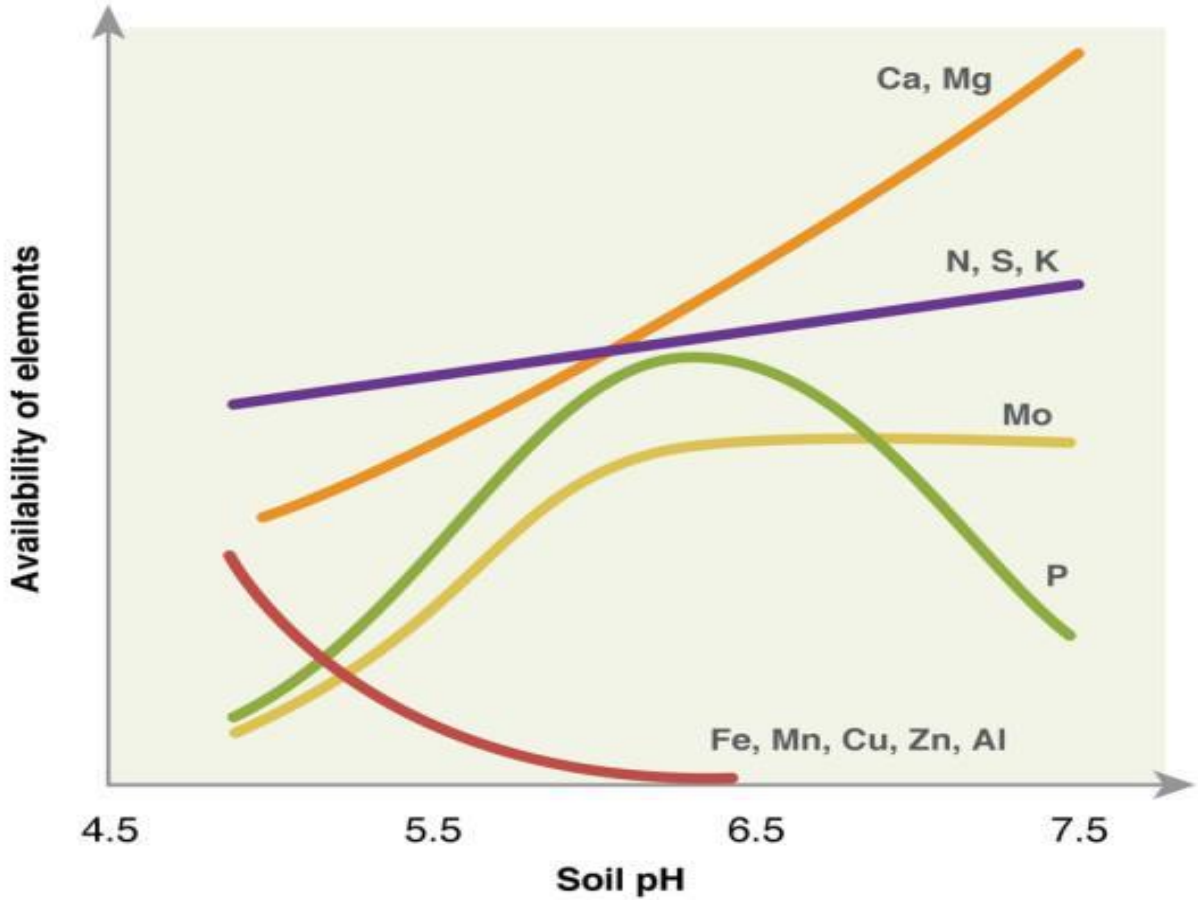
Acidic Soils

Less available nutrients

nitrogen, phosphorus, potassium, calcium, magnesium, sulfur

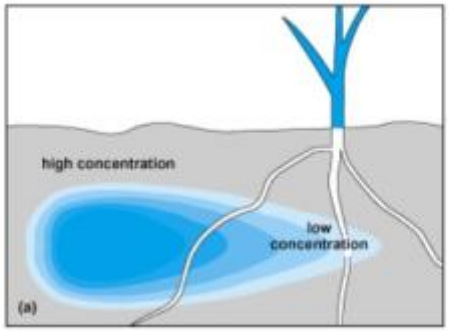
More available nutrients

in general the metal nutrients – iron, zinc, copper, manganese, aluminum

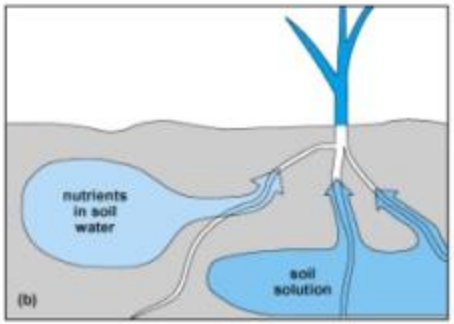

Availability of elements
Ca, Mg
N, S, K
Mo
P
Fe, Mn, Cu, Zn, Al
4.5
5.5
6.5
7.5
Soil pH

Plant root nutrient uptake

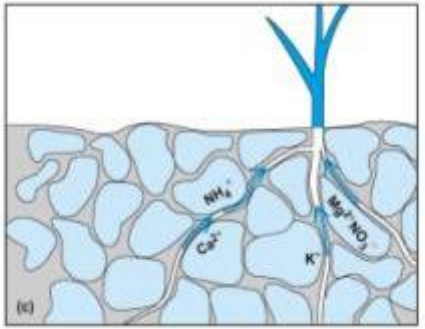
Diffusion – nutrients move from higher concentration in the bulk soil solution to lower concentration at the root;
-In the time it takes NO_3^- to diffuse 1 cm, K^+ diffuses 0.2 cm, and $H_2PO_4^-$ diffuses 0.02 cm



Mass flow – dissolved nutrients move to the root in soil water that is flowing towards the roots



Root interception – roots obtain nutrients by physically contacting nutrients in soil solution or on soil surfaces;
- roots contact ~1% of soil volume;
- mycorrhizal infection of root increase root-soil contact



Diffusion
Mass Flow
Root Intercept

TABLE 5.1
Adequate tissue levels of elements that may be required by plants (Part 1)

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

Source: Epstein 1972, 1999.

[a] The values for the nonmineral elements (H, C, O) and the macronutrients are percentages. The values for micronutrients are expressed in parts per million.

TABLE 5.1
Adequate tissue levels of elements that may be required by plants (Part 2)

Element	Chemical symbol	Concentration in dry matter (% or ppm)[a]	Relative number of atoms with respect to molybdenum
Obtained from the soil			
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

Source: Epstein 1972, 1999.

[a] The values for the nonmineral elements (H, C, O) and the macronutrients are percentages. The values for micronutrients are expressed in parts per million.

Why Proper Nutrient Levels

Reduced Nutrient availability reduces crop yield/quality and increases cropping system problems like soil compaction, water infiltration, drought, and crop lodging.

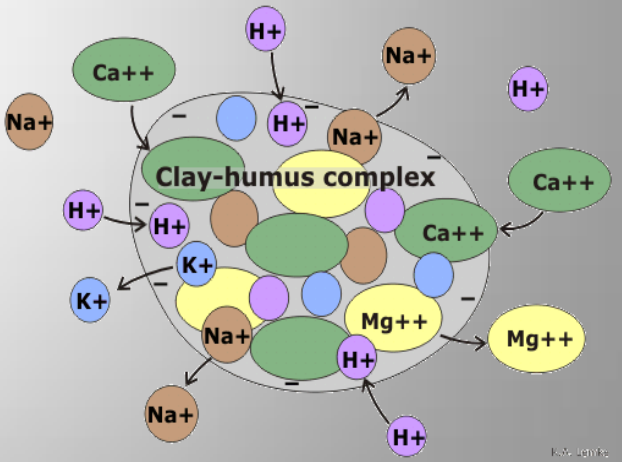
– Deficiencies of some nutrients (B, Zn, and Cu) reduce pollination, grain set and grain development

– An excess of a nutrient may cause a deficiency of another nutrient

Excessive N inhibits uptake of K, Zn, Mn, B, and Cu

- Low availability of SO_4^{2-} (sulfate S) can affect the uptake of NO_3^-(nitrate) and increase soil disease problems
- Low Ca and Cu can cause lodging problems - strength of cell walls

Questions



SUMMARY

- N - synthesis of proteins and part of chlorophyll molecule
- P - energy transfer
- K - carbohydrate metabolism, water relations
- Mg - chlorophyll molecule
- S - proteins
- Ca - strength of cell wall (one of the most important nutrients, should be 60-70% of base saturation)
- Micronutrients - enzyme activation

SUMMARY

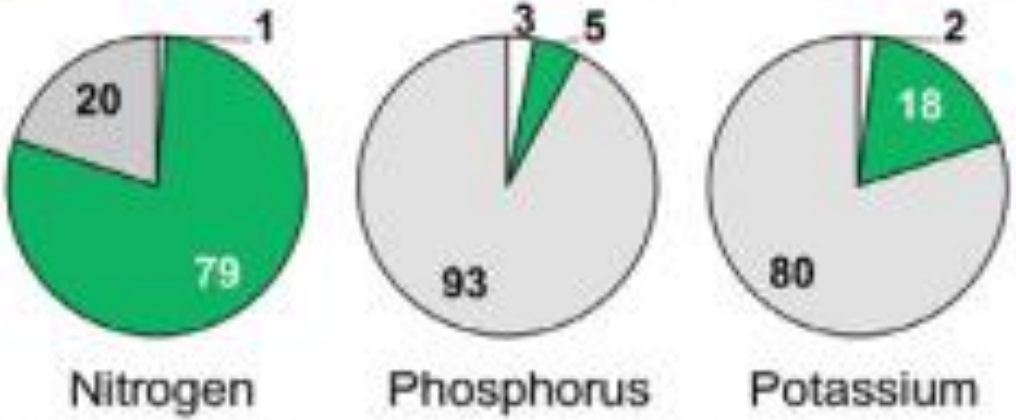
- Plants require essential nutrients to grow and survive
  - structural (C, H, O)
  - *macro*-nutrients
    - primary (N, P, K)
    - secondary (Ca, Mg, S)
  - *micro*-nutrients (B, Cu, Fe, Mn, Zn, Mo, Cl, Co, Ni)
- Nutrients may be mobile, somewhat mobile, or immobile in the plant and in the soil.
- Nutrient demands change throughout the life of the plant. In general increasing during vegetative growth and decreasing during reproductive development.
- Nutrient balance is critical to maximize plant development but can be very challenging

Root interception
(root grows into a nutrient location)

Mass flow
(nutrient moves with the water absorbed by a plant)

Diffusion
(nutrient moves from higher to lower concentration)

Relative contribution of each pathway for corn (



Barber, S.A. 1995. Soil nutrient bioavailability: A mechanistic approach. 2nd ed. John Wiley and Sons, New York, NY.