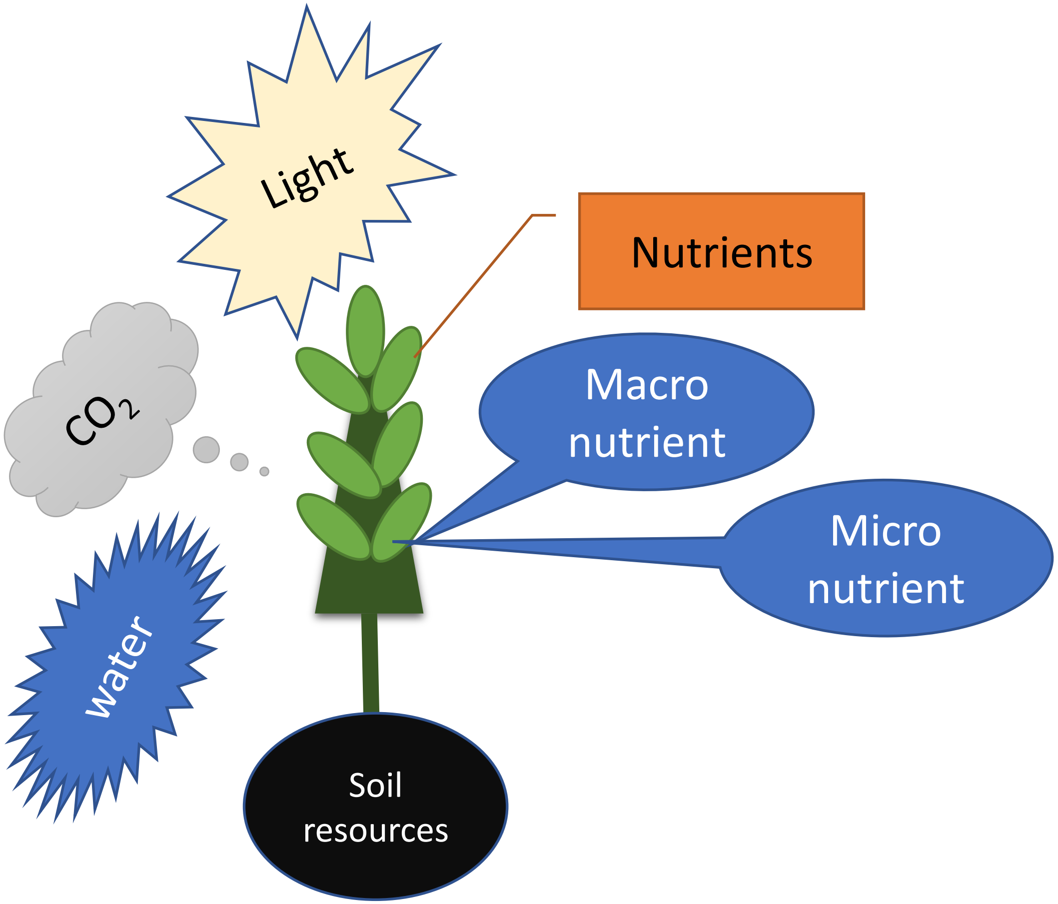
Daisy Myint (PhD.), LUD, DOA

သီးနှံပင်လိုအပ်သော အာဟာရဓာတ်များချို့တဲ့မှု လက္ခဏာနှင့် ကုစားနည်းများ

ဒေါက်တာဒေစီမြင့်
ဒုတိယဦးစီးမှူး
မြေအသုံးချရေးဌာနခွဲ

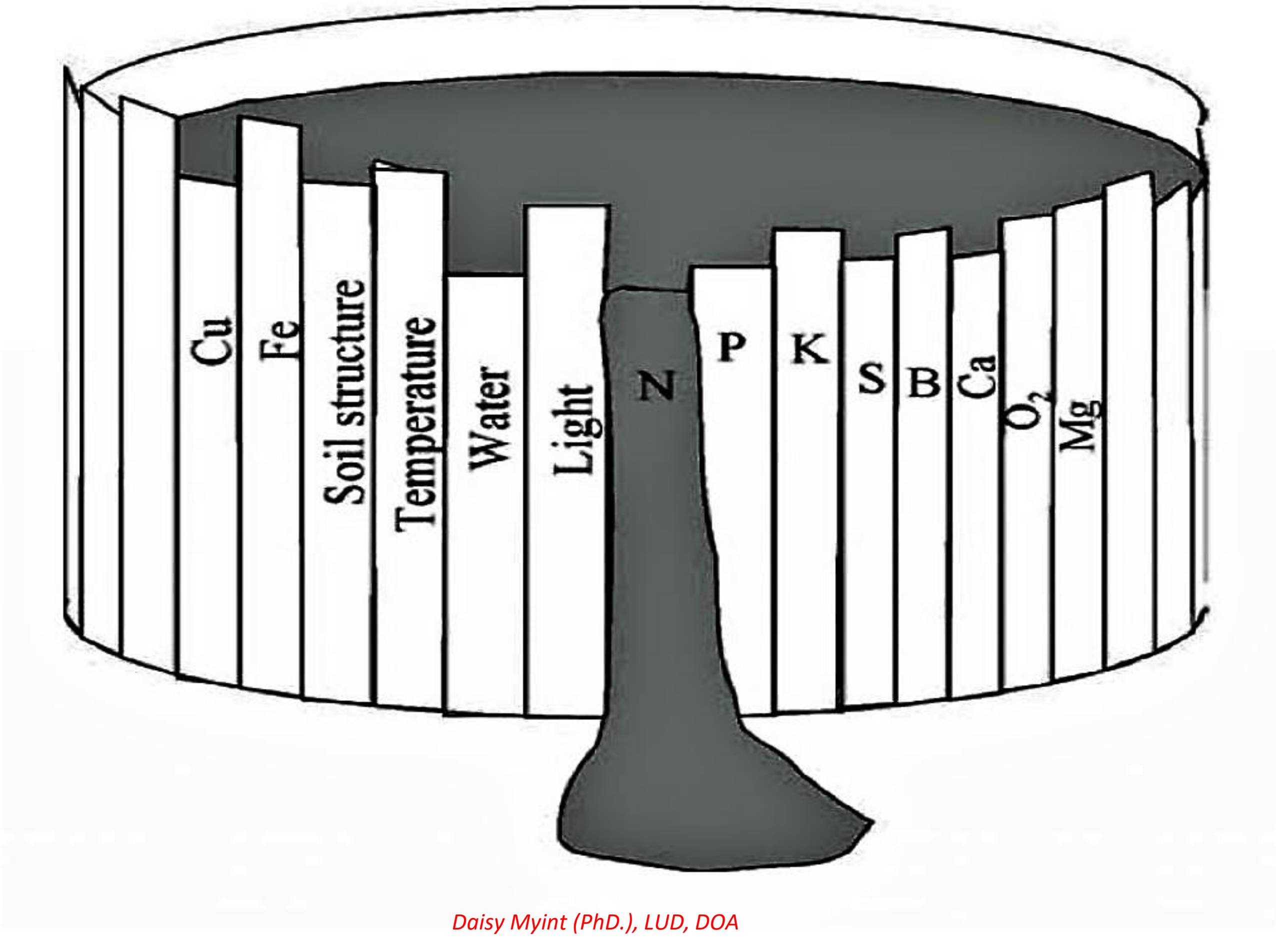
Plant Nutrition

- Plants meet their nutritional needs for growth by absorbing soil nutrients, water, and carbon dioxide, in addition to the required sunlight.



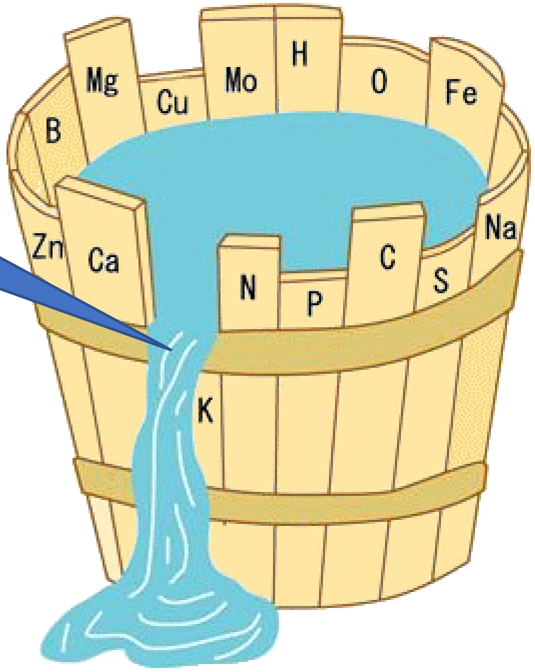
Limiting factor

No yield increase is to be expected when fertilising crops that are mainly limited by factors other than nutrient supply, e.g. water, light, pH, salinity, light or temperature, etc. (JOENSSEN et al. 2004).



Law of Minimum (Liebig’s Law

Plant growth is limited by the element in shortest supply, just as the level of water in the barrel is limited by the shortest stave.



Plant Nutrient

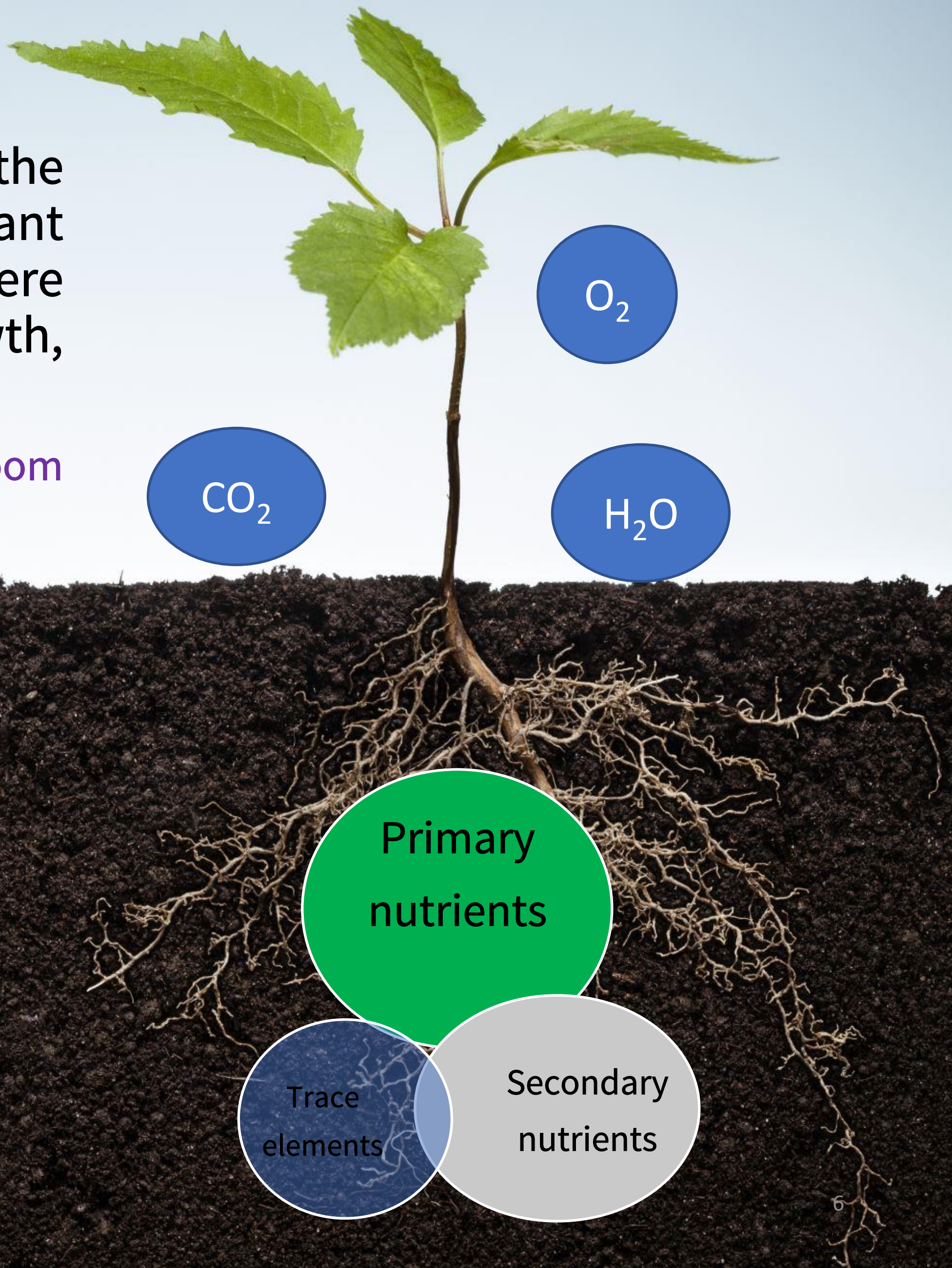
Plant Nutrient: Chemical element that is essential for plant growth and reproduction.

Essential element: A term used to identify a plant nutrient

Essential element

- An intrinsic component in the structure or metabolism of a plant or whose absence causes severe abnormalities in plant growth, development, or reproduction

(Arnon and Stout 1939, Epstein and Bloom 2005)



O_2

CO_2

H_2O

Primary nutrients

Trace elements

Secondary nutrients

Criteria For Essentiality

1. Omission of the element in question must result in abnormal growth, failure to complete the life cycle, or premature death of the plant.

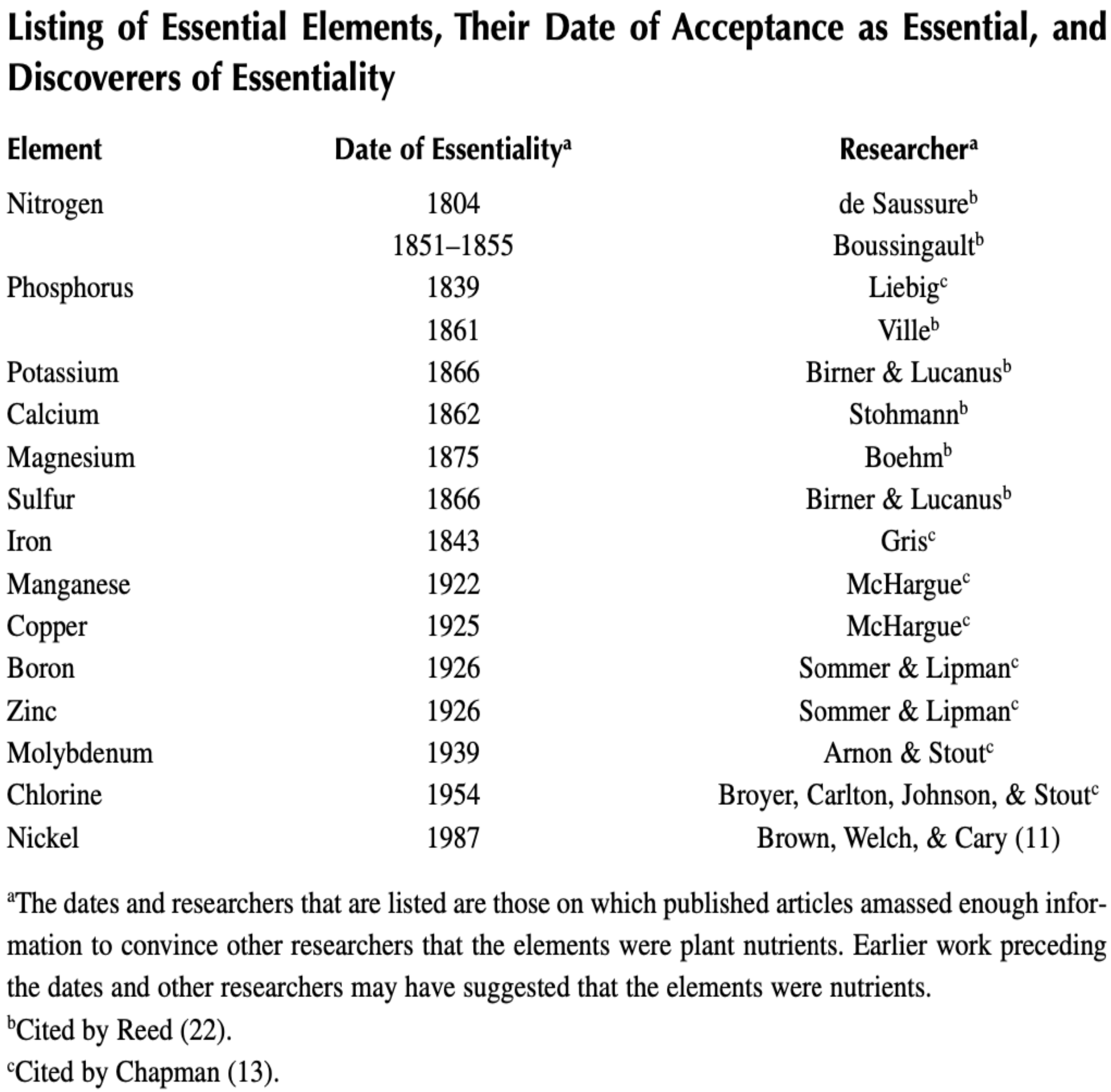
2. The element must be specific and not replaceable by another.

3. The element must exert its effect directly on growth or metabolism and not some indirect effect such as by antagonizing another element present at a toxic level

[Arnon and Stout (1939)]

Source: plant nutrition and soil fertility manual (2nd edition)

List of essential elements, their date of acceptance as essential and discoverers of essentiality



Listing of Essential Elements, Their Date of Acceptance as Essential, and Discoverers of Essentiality

Element	Date of Essentiality[a]	Researcher[a]
Nitrogen	1804	de Saussure[b]
	1851–1855	Boussingault[b]
Phosphorus	1839	Liebig[c]
	1861	Ville[b]
Potassium	1866	Birner & Lucanus[b]
Calcium	1862	Stohmann[b]
Magnesium	1875	Boehm[b]
Sulfur	1866	Birner & Lucanus[b]
Iron	1843	Gris[c]
Manganese	1922	McHargue[c]
Copper	1925	McHargue[c]
Boron	1926	Sommer & Lipman[c]
Zinc	1926	Sommer & Lipman[c]
Molybdenum	1939	Arnon & Stout[c]
Chlorine	1954	Broyer, Carlton, Johnson, & Stout[c]
Nickel	1987	Brown, Welch, & Cary (11)

[a] The dates and researchers that are listed are those on which published articles amassed enough information to convince other researchers that the elements were plant nutrients. Earlier work preceding the dates and other researchers may have suggested that the elements were nutrients.

[b] Cited by Reed (22).

[c] Cited by Chapman (13).

Source: plant nutrition and soil fertility manual (2nd edition)

Essential Elements–Macronutrients

- ❖ Mineral nutrients required for plants in concentration exceeding one part per million (ppm) or 1–150 g per kg of plant dry matter are called macronutrients

Carbon dioxide ($6CO_2$) + Water ($6H_2O$)

↓

(in the presence of light and chlorophyll)

↓

Carbohydrate ($C_6H_{12}O_6$) + Oxygen (O_2)

photosynthesis

•Plant must be fully turgid (not under water stress.

•Stomata must be open, which enhances gaseous exchange so that CO_2 can

•readily enter plant leaves.

•Leaf surface must be exposed to full sunlight.

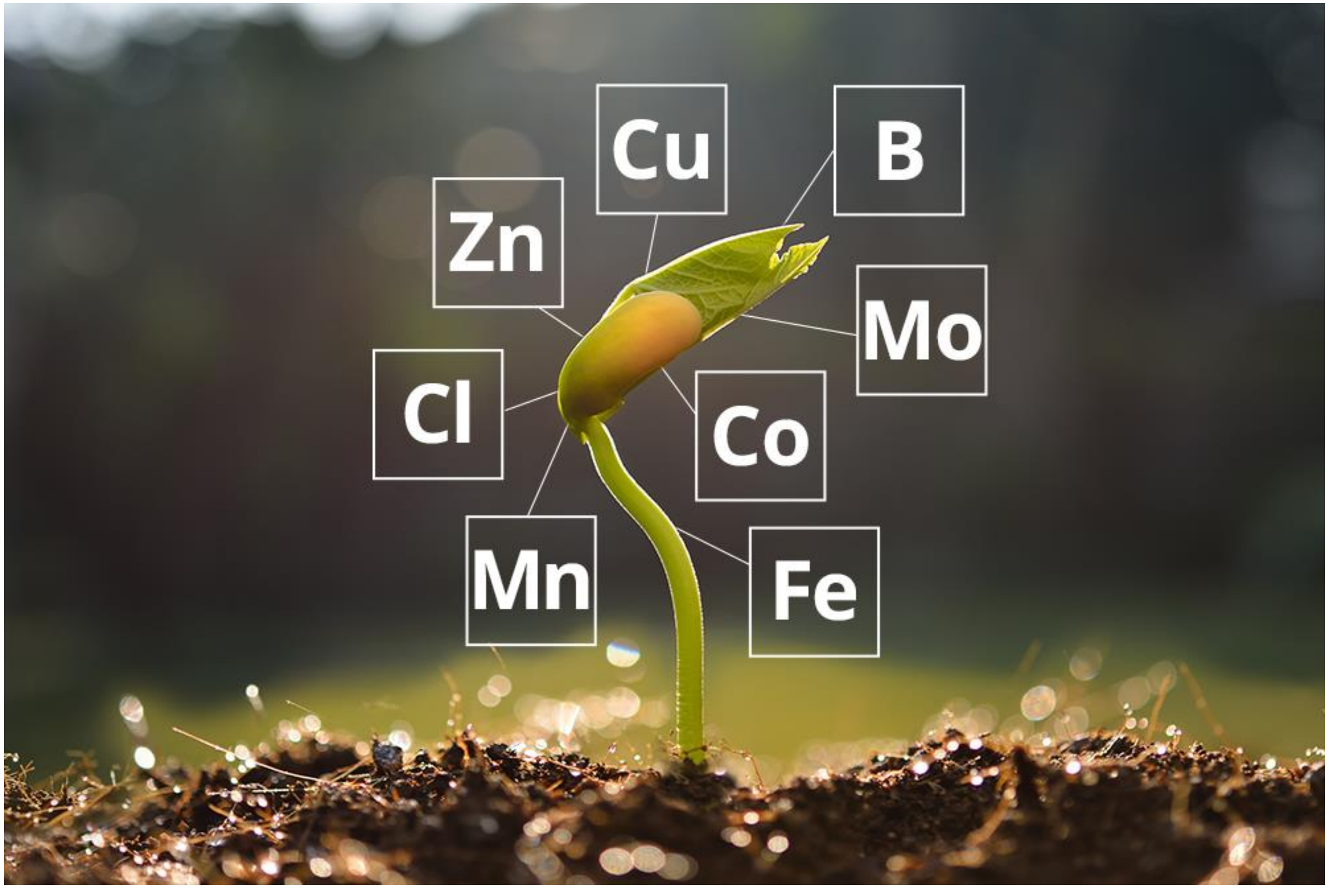
•Plant must be nutritionally sound.

List of Essential Elements, Their Status as Macronutrients Their Uptake Forms, and Their Plant Mobility

Nutrient	Macro/micro	Uptake form	Mobility in plant	Mobility in soil
Carbon	Macro	CO_2, H_2CO_3		
Hydrogen	Macro	H^+, OH^-,H_2O		
Nitrogen	Macro	NO^{3-}, NH^{4+}	Mobile	Mobile as NO–, immobile as NH4
Phosphorus	Macro	HPO_4^{2-}, H_2PO^{4-}	Somewhat mobile	Immobile
Potassium	Macro	K^+	Verry mobile	Somewhat mobile
Calcium	Macro	Ca^{2+}	Immobile	Somewhat mobile
Magnesium	Macro	Mg^{2+}	Somewhat mobile	Immobile
Sulfur	Macro	SO^{4-}	Mobile	Mobile

Micronutrients

- required in concentration below 1 ppm are micronutrients or 0.1–100 mg per kg of plant dry matter



List of Essential Elements, Their Status as Micronutrients, Their Uptake Forms, and Their Plant Mobility

Nutrient	Macro/micro	Uptake form	Mobility in plant	Mobility in soil
Boron	Micro	H_3BO_3,BO_3^-	Immobile	Very mobile
Copper	Micro	Cu^{2+}	Immobile	Immobile
Iron	Micro	Fe^{2+},Fe^{3+}	Immobile	Immobile
Manganese	Micro	Mn^{2+}	Immobile	Mobile
Zinc	Micro	Zn^{2+}	Immobile	Immobile
Molybdenum	Micro	MoO^{4-}	Immobile	Somewhat mobile
Chlorine	Micro	Cl^-	Mobile	Mobile
Cobalt	Micro	Co^{2+}	Immobile	Somewhat mobile
Nickel	Micro	Ni^{2+}	Mobile	Somewhat mobile

Classification of Plant 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, proteins, constituent of lipoic acid,coenzyme A, thiamine pyrophosphate, glutathione, biotin, adenosine–5’–phosphosulfate, 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. 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, cell walls, involved in cell elongation and nucleic acid metabolism

Classification of Plant Nutrients according to Biochemical Function

Mineral Nutrient	Functions
Group 3	**Nutrients that are part of carbon compounds**
K	Cofactor for more than 40 enzymes, cell turgor and maintain electroneutrality
Ca	Constituent of the middle lamella of cell walls, 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, peroxidases. Involved with other cations–activated enzymes and photosynthetic O_2 evolution
Na	Involved with the regeneration of phosphoenolpyruvate in C4 and CAM plants. Substitutes for potassium in some function.

Classification of Plant Nutrients according to Biochemical Function

Mineral Nutrient	Functions
Group 4	**Nutrients that are involved in redox reactions**
Fe	Constituent of cytochromes and nonheme iron proteins involved in photosynthesis, N_2 fixation, 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 Nitrogen fixing bacteria, constituent of hydrogenases.
Mo	Constituent of nitrogenase, nitrate reductase, xanthine dehydrogenase

Condition of nutrient deficiency

N ချို့တဲ့မှု အခြေအနေ

❖Sandy soils that have been leached by heavy rainfall or irrigation

❖Mineral soils low in organic matter content

❖Long history of crop–depleting N supply when applied N is less than that required by the planted crop(s)

ပဲပင်တွင် Nချို့တဲ့မှုလက္ခဏာ

ပြောင်းတွင် N ချို့တဲ့မှု လက္ခဏာ

ဂျုံတွင် N ချို့တဲ့မှု လက္ခဏာ

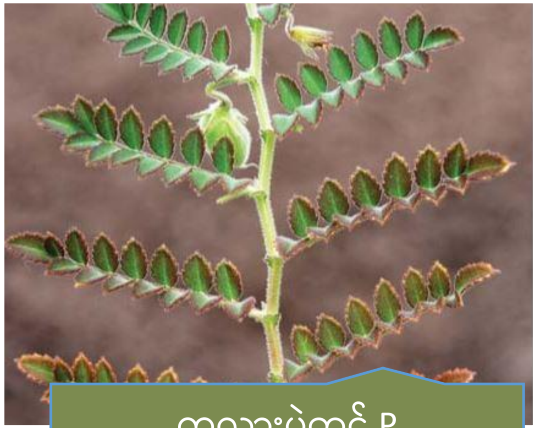
ငရုတ်တွင် N ချို့တဲ့မှု လက္ခဏာ

နေကြာတွင် N ချို့တဲ့မှုလက္ခဏာ

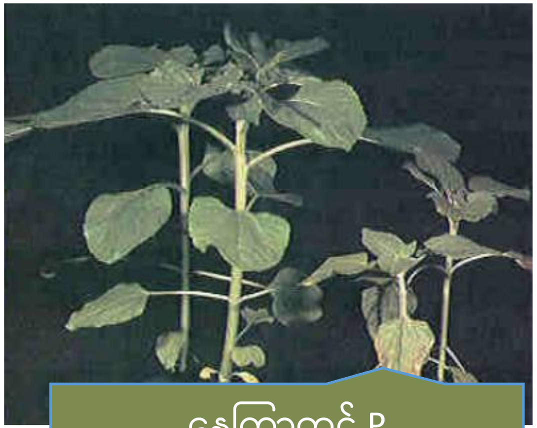
အာလူးတွင် N ချို့တဲ့မှုလက္ခဏာ

Condition of macronutrient deficiency

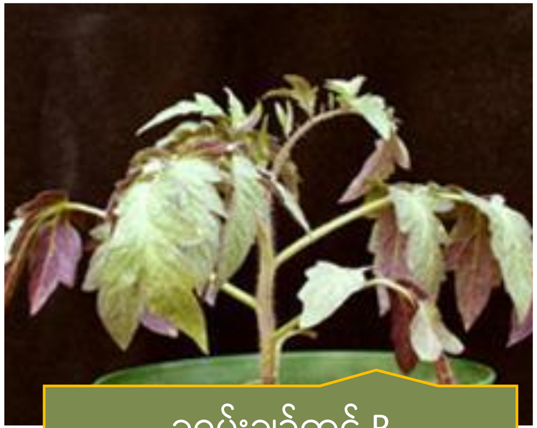
P ချို့တဲ့မှုလက္ခဏာများ



ကုလားပဲတွင် P ချို့တဲ့မှုလက္ခဏာ



နေကြာတွင် P ချို့တဲ့မှုလက္ခဏာ



ခရမ်းချဉ်တွင် P ချို့တဲ့မှုလက္ခဏာ

ပြောင်းတွင် P ချို့တဲ့မှုလက္ခဏာ

P ချို့တဲ့မှု အခြေအနေ

- Mineral soils low in organic matter content
- Long history of cropping without adequate P fertilization reducing the supply of P
- P–rich soils lost by erosion
- Calcareous soils where P availability is reduced by alkaline pH

Condition of macronutrient deficiency

K ချို့တဲ့မှုလက္ခဏာများ

စပါးတွင် K ချို့တဲ့မှုလက္ခဏာ

ပဲပုပ်တွင် K ချို့တဲ့မှုလက္ခဏာ

ပြောင်းတွင် K ချို့တဲ့မှုလက္ခဏာ

မြေပဲတွင် K ချို့တဲ့မှုလက္ခဏာ

K ချို့တဲ့မှု အခြေအနေ

- Mineral soils low in organic matter content
- Soils having a low cation–exchange capacity
- Long history of cropping without adequate K fertilization
- Sandy soils formed from low K–content parent material
- Sandy soils

Condition of macronutrient deficiency

Ca ချို့တဲ့မှုလက္ခဏာများ


စပါးတွင် Ca ချို့တဲ့မှုလက္ခဏာ


Cucurbits Ca ချို့တဲ့မှုလက္ခဏာ


ခရမ်းချဉ်တွင် Ca ချို့တဲ့မှုလက္ခဏာ


ဆေးရွက်ကြီးတွင် Ca ချို့တဲ့မှုလက္ခဏာ

Ca ချို့တဲ့မှု အခြေအနေ

- Acid sandy soils when Ca is lost by leaching from rainfall or irrigation
- Strongly acid peats
- Alkaline or sodic soils, high in pH and Na content
- Soils with high soluble Al, low exchangeable Ca content

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Condition of macronutrient deficiency

Mg ချို့တဲ့မှုလက္ခဏာများ

စပါးတွင် Mg ချို့တဲ့မှုလက္ခဏာ

ပဲ တွင် Mg ချို့တဲ့မှုလက္ခဏာ

ခရမ်းချဥ်တွင် Mg ချို့တဲ့မှုလက္ခဏာ

အာလူးတွင် Mg ချို့တဲ့မှုလက္ခဏာ

Mg ချို့တဲ့မှု အခြေအနေ

- Acid sandy soils when Mg is lost by leaching from rainfall or irrigation
- Acid soils with pH less than 5.4
- Strongly acid peat and muck soils
- Soils over–fertilized with either Ca and/or K

Condition of macronutrient deficiency

S ချို့တဲ့မှုလက္ခဏာများ

စပါးတွင် S ချို့တဲ့မှုလက္ခဏာ

အာလူးတွင် S ချို့တဲ့မှုလက္ခဏာ

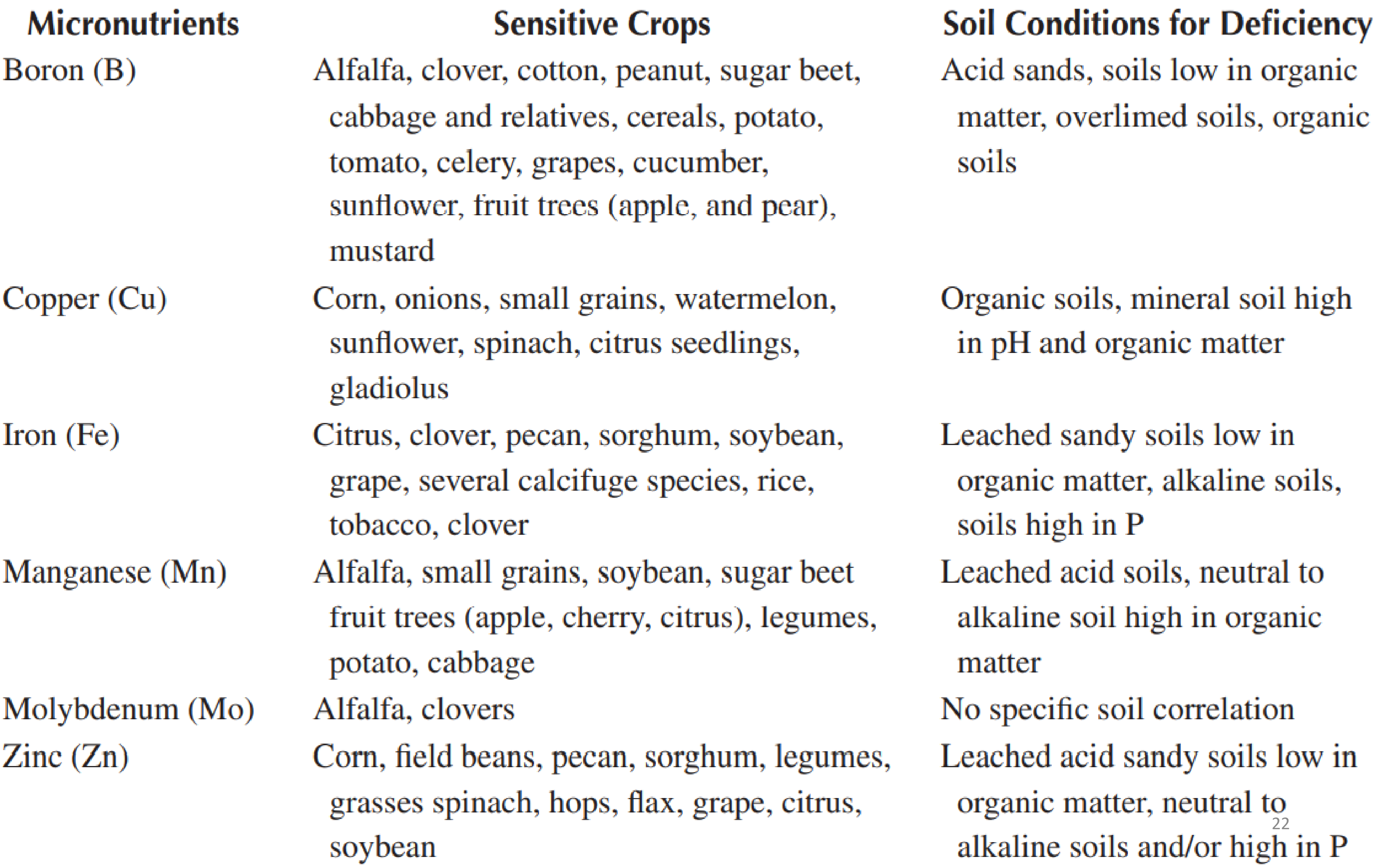
ငှက်ပျောတွင် S ချို့တဲ့မှုလက္ခဏာ

ပြောင်းတွင် S ချို့တဲ့မှုလက္ခဏာ

S ချို့တဲ့မှု အခြေအနေ

- Mineral soils low in organic matter
- Soils after years of cropping
- Acid sandy soils where sulfates have been leached by rainfall
- Soils formed from low S–containing parent material
- No substantial deposition of S by acid rainfall
- Use of low–S containing NPK fertilizers [i.e., substituting triple superphos–
- phate (0–46–0) for superphosphate (0–20–0)]

Condition of micronutrient deficiency



Micronutrients	Sensitive Crops	Soil Conditions for Deficiency
Boron (B)	Alfalfa, clover, cotton, peanut, sugar beet, cabbage and relatives, cereals, potato, tomato, celery, grapes, cucumber, sunflower, fruit trees (apple, and pear), mustard	Acid sands, soils low in organic matter, overlimed soils, organic soils
Copper (Cu)	Corn, onions, small grains, watermelon, sunflower, spinach, citrus seedlings, gladiolus	Organic soils, mineral soil high in pH and organic matter
Iron (Fe)	Citrus, clover, pecan, sorghum, soybean, grape, several calcifuge species, rice, tobacco, clover	Leached sandy soils low in organic matter, alkaline soils, soils high in P
Manganese (Mn)	Alfalfa, small grains, soybean, sugar beet fruit trees (apple, cherry, citrus), legumes, potato, cabbage	Leached acid soils, neutral to alkaline soil high in organic matter
Molybdenum (Mo)	Alfalfa, clovers	No specific soil correlation
Zinc (Zn)	Corn, field beans, pecan, sorghum, legumes, grasses spinach, hops, flax, grape, citrus, soybean	Leached acid sandy soils low in organic matter, neutral to alkaline soils and/or high in P

Condition of micronutrient deficiency

Micronutrients	Sensitive Crops	Soil Conditions for Deficiency
Boron (B)	Alfalfa, clover, cotton, peanut, sugar beet, cabbage and relatives, cereals, potato, tomato, celery, grapes, cucumber, sunflower, fruit trees (apple, and pear), mustard	Acid sands, soils low in organic matter, overlimed soils, organic soils
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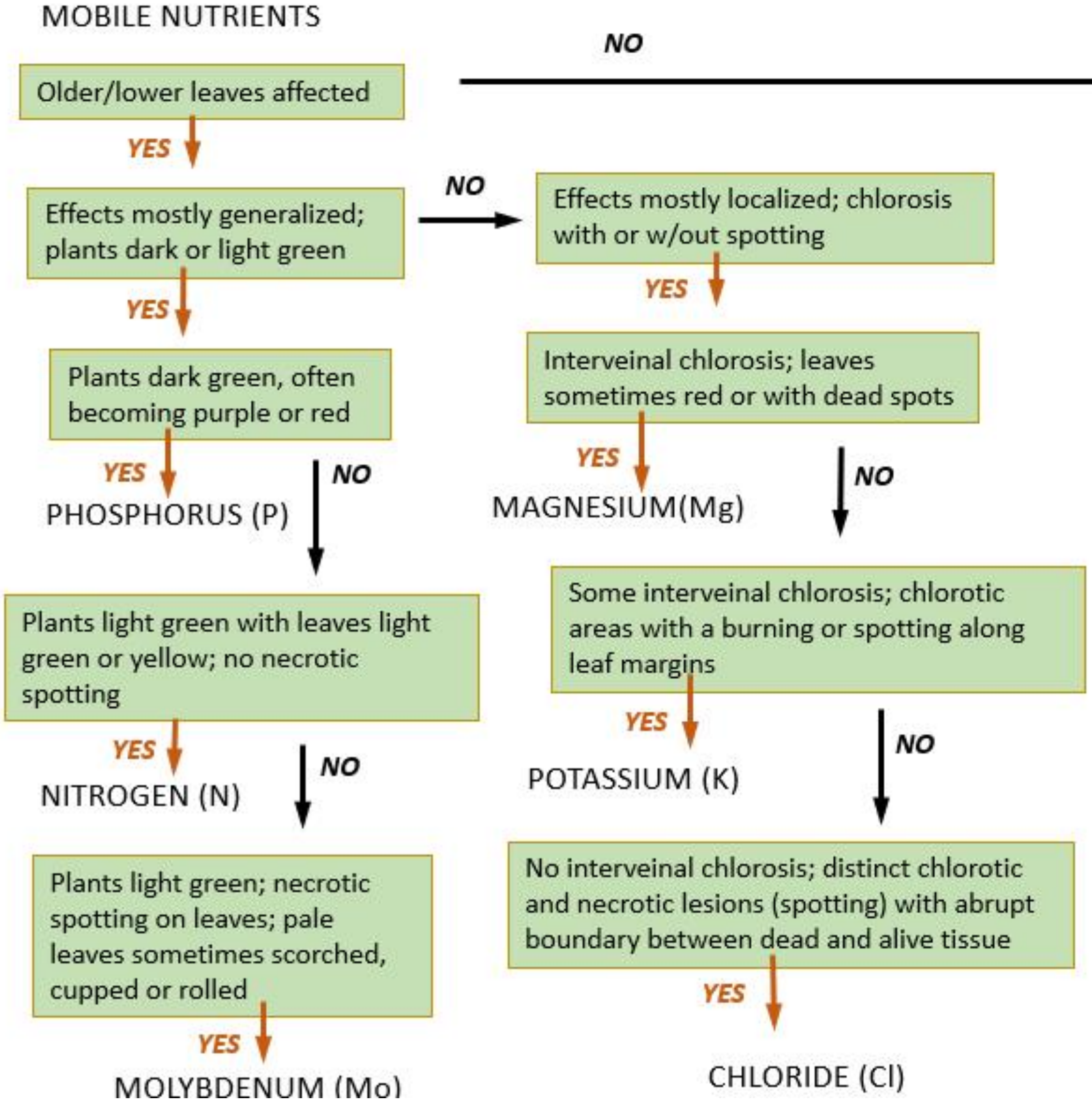
Visual tissue assessment



MOBILE NUTRIENTS

Older/lower leaves affected

NO

YES

Effects mostly generalized; plants dark or light green

NO

Effects mostly localized; chlorosis with or w/out spotting

YES

Plants dark green, often becoming purple or red

YES

PHOSPHORUS (P)

NO

Plants light green with leaves light green or yellow; no necrotic spotting

YES

NITROGEN (N)

NO

Plants light green; necrotic spotting on leaves; pale leaves sometimes scorched, cupped or rolled

YES

MOLYBDENUM (Mo)

YES

Interveinal chlorosis; leaves sometimes red or with dead spots

YES

MAGNESIUM(Mg)

NO

Some interveinal chlorosis; chlorotic areas with a burning or spotting along leaf margins

YES

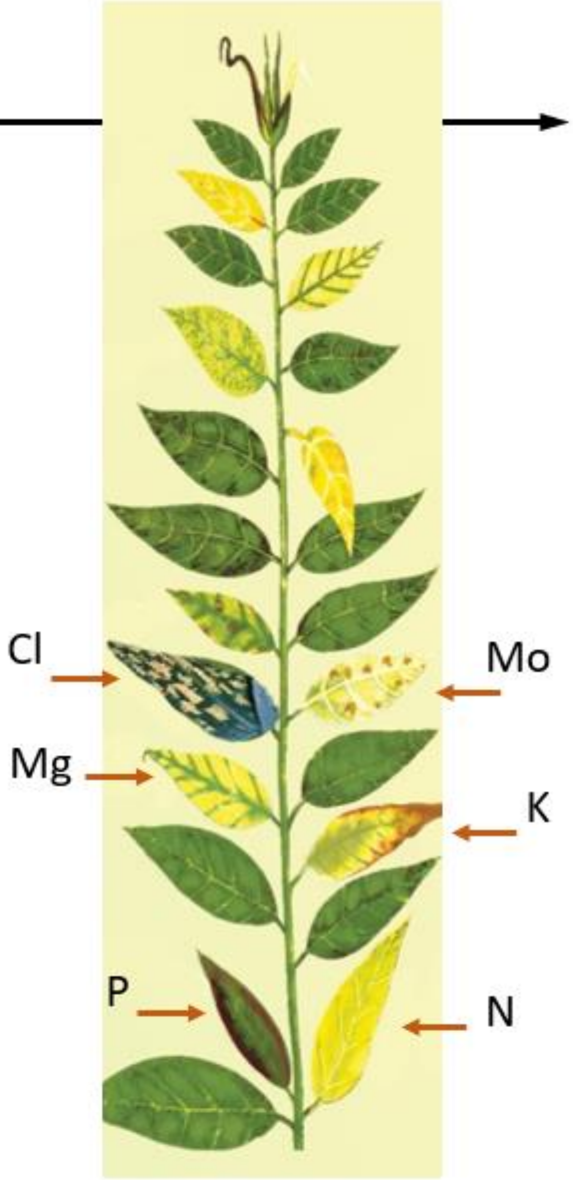
POTASSIUM (K)

NO

No interveinal chlorosis; distinct chlorotic and necrotic lesions (spotting) with abrupt boundary between dead and alive tissue

YES

CHLORIDE (Cl)



http://landresources.montana.edu/nm

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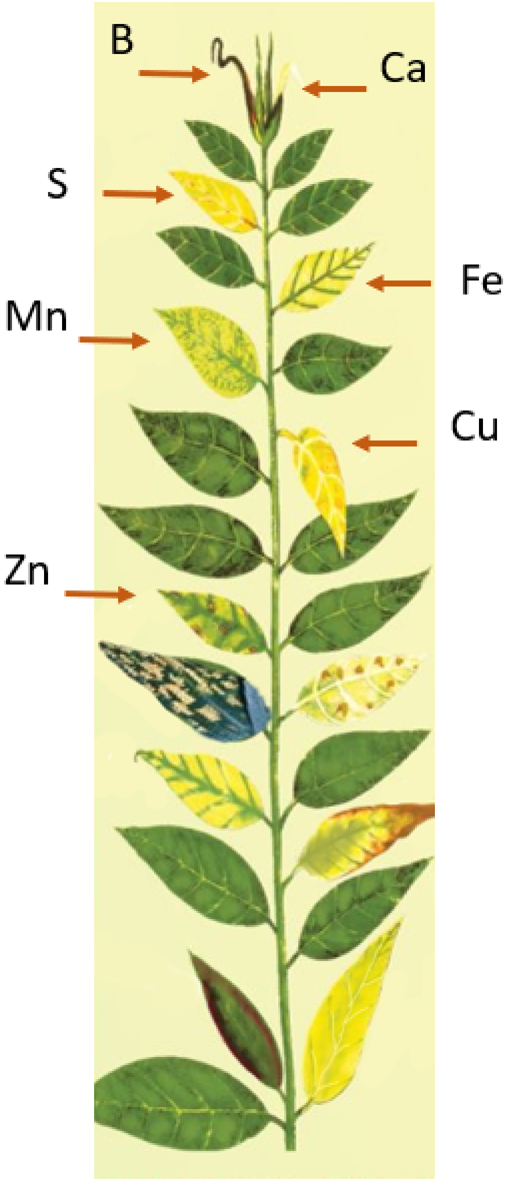
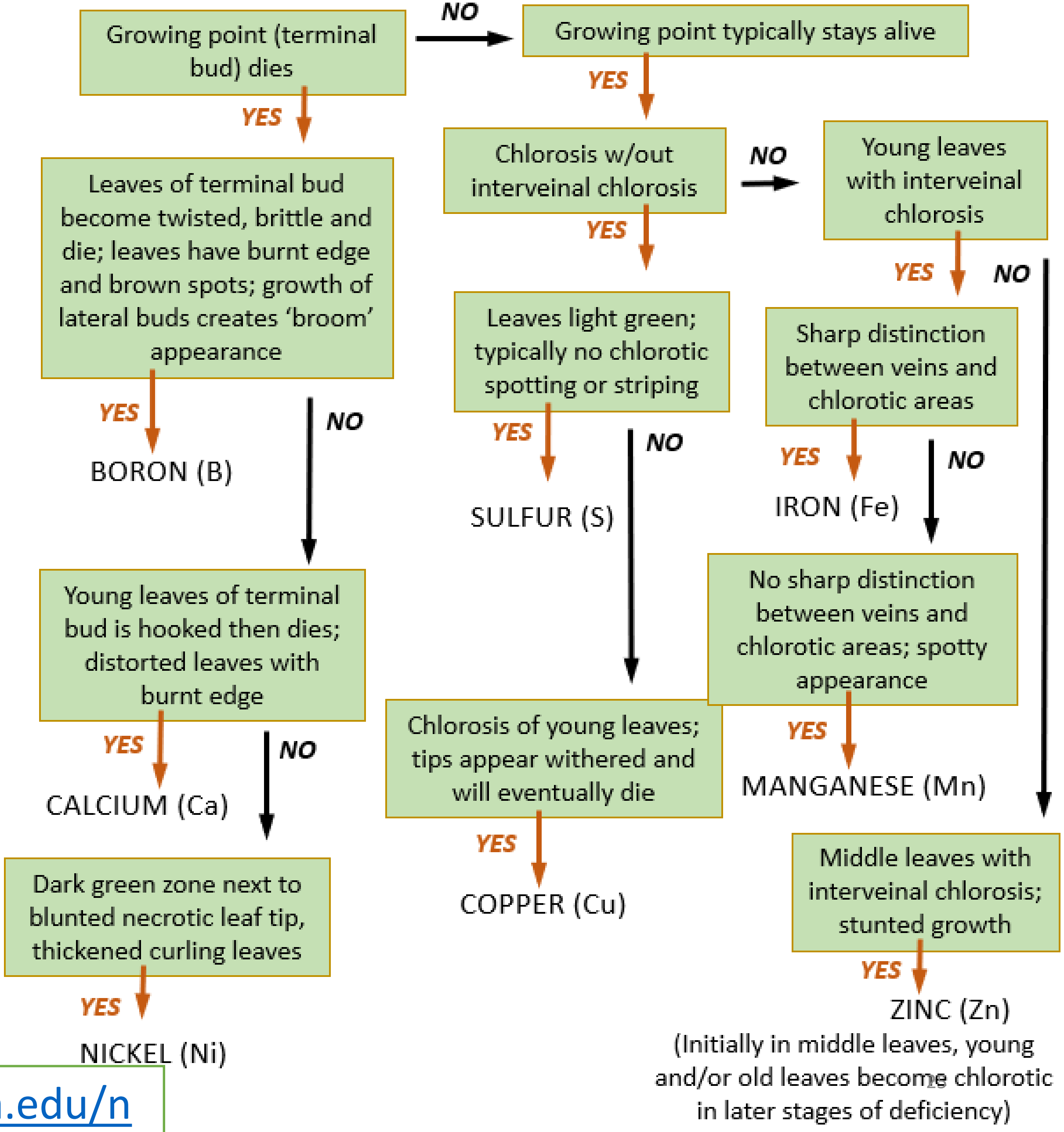
Newer or younger leaves

IMMOBILE NUTRIENTS





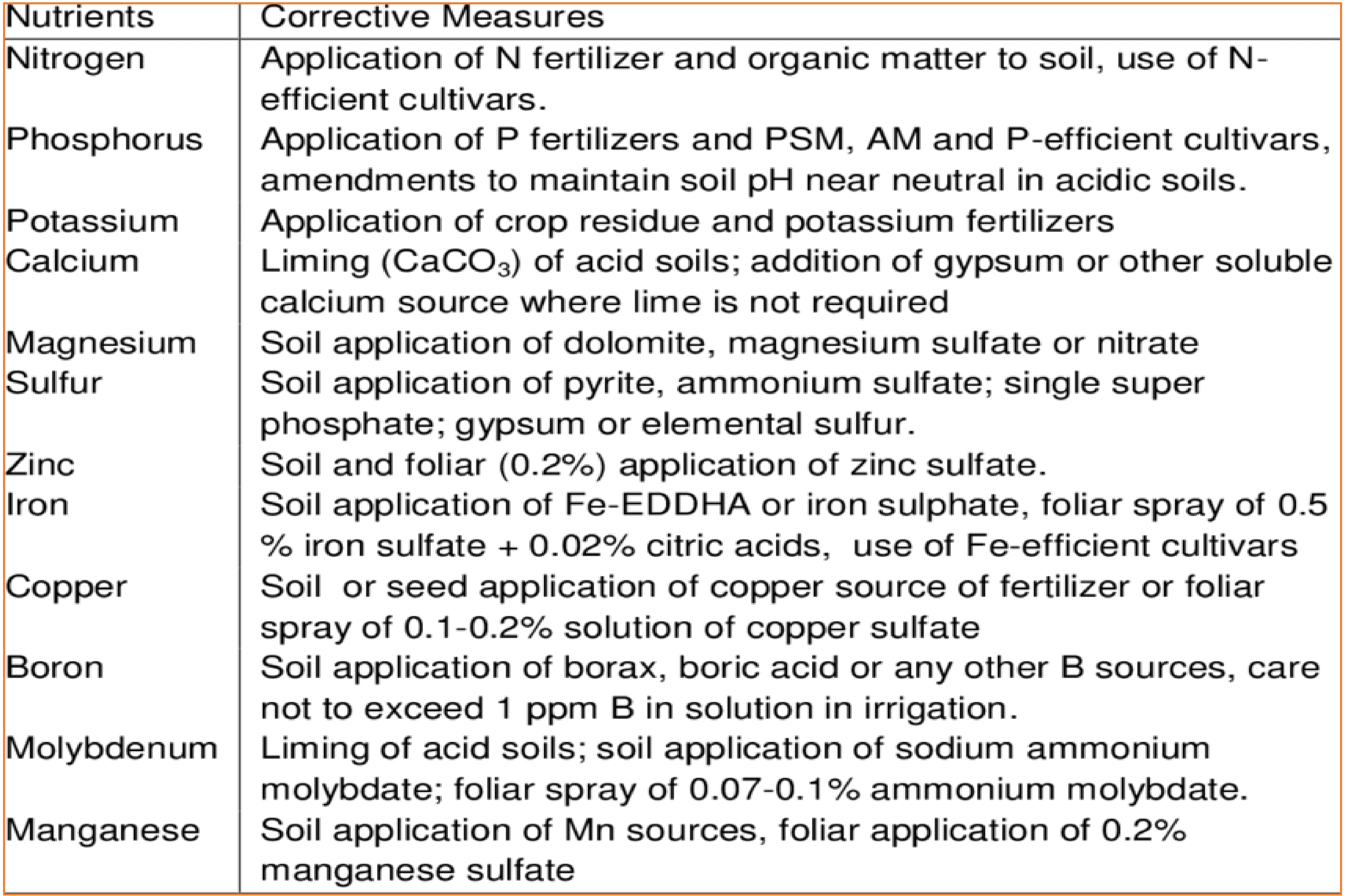
Growing point (terminal bud) dies

- **YES**: Leaves of terminal bud become twisted, brittle and die; leaves have burnt edge and brown spots; growth of lateral buds creates 'broom' appearance
  - **YES**: BORON (B)
  - **NO**: Young leaves of terminal bud is hooked then dies; distorted leaves with burnt edge
    - **YES**: CALCIUM (Ca)
    - **NO**: Dark green zone next to blunted necrotic leaf tip, thickened curling leaves
      - **YES**: NICKEL (Ni)
- **NO**: Growing point typically stays alive
  - **YES**: Chlorosis w/out interveinal chlorosis
    - **YES**: Leaves light green; typically no chlorotic spotting or striping
      - **YES**: SULFUR (S)
      - **NO**: Chlorosis of young leaves; tips appear withered and will eventually die
        - **YES**: COPPER (Cu)
    - **NO**: Young leaves with interveinal chlorosis
      - **YES**: Sharp distinction between veins and chlorotic areas
        - **YES**: IRON (Fe)
        - **NO**: No sharp distinction between veins and chlorotic areas; spotty appearance
          - **YES**: MANGANESE (Mn)
      - **NO**: Middle leaves with interveinal chlorosis; stunted growth
        - **YES**: ZINC (Zn)

(Initially in middle leaves, young and/or old leaves become chlorotic in later stages of deficiency)

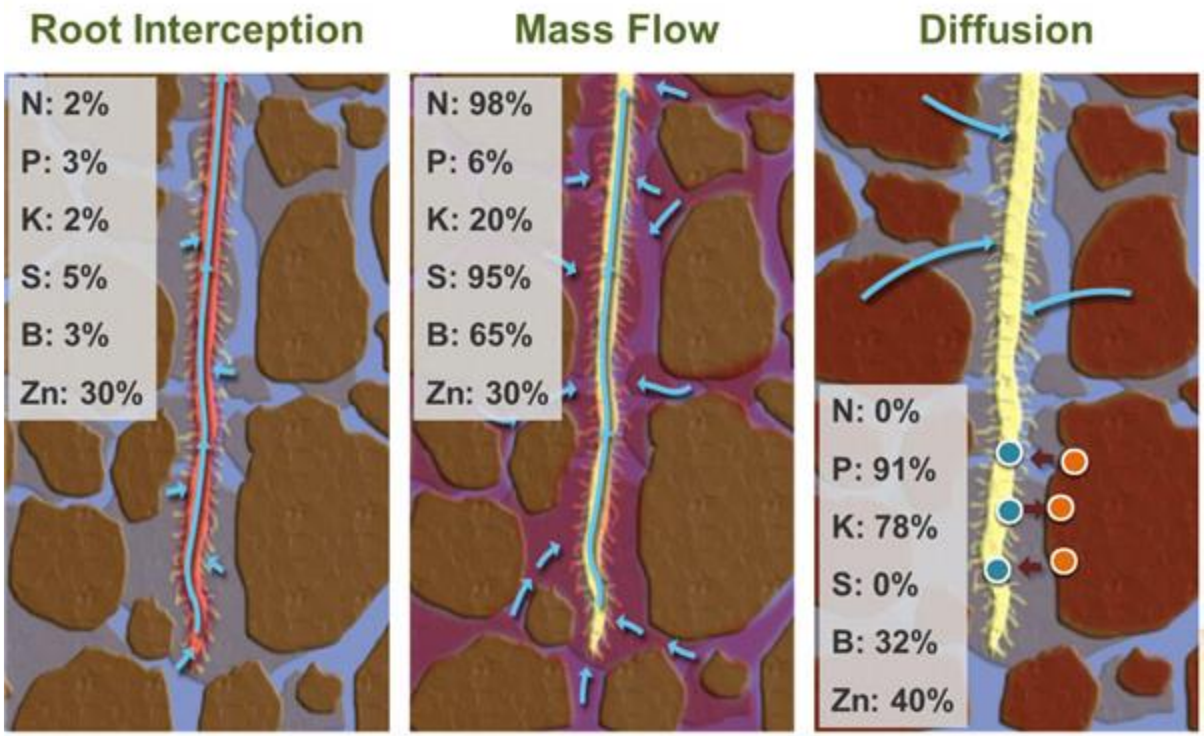
http://landresources.montana.edu/n

Corrective measures



Nutrients	Corrective Measures
Nitrogen	Application of N fertilizer and organic matter to soil, use of N-efficient cultivars.
Phosphorus	Application of P fertilizers and PSM, AM and P-efficient cultivars, amendments to maintain soil pH near neutral in acidic soils.
Potassium	Application of crop residue and potassium fertilizers
Calcium	Liming ($CaCO_3$) of acid soils; addition of gypsum or other soluble calcium source where lime is not required
Magnesium	Soil application of dolomite, magnesium sulfate or nitrate
Sulfur	Soil application of pyrite, ammonium sulfate; single super phosphate; gypsum or elemental sulfur.
Zinc	Soil and foliar (0.2%) application of zinc sulfate.
Iron	Soil application of Fe-EDDHA or iron sulphate, foliar spray of 0.5 % iron sulfate + 0.02% citric acids, use of Fe-efficient cultivars
Copper	Soil or seed application of copper source of fertilizer or foliar spray of 0.1-0.2% solution of copper sulfate
Boron	Soil application of borax, boric acid or any other B sources, care not to exceed 1 ppm B in solution in irrigation.
Molybdenum	Liming of acid soils; soil application of sodium ammonium molybdate; foliar spray of 0.07-0.1% ammonium molybdate.
Manganese	Soil application of Mn sources, foliar application of 0.2% manganese sulfate

Nutrient uptake



https://www.winfieldunited.com/news-and-insights/spring-nitrogen-strategies

Nickel

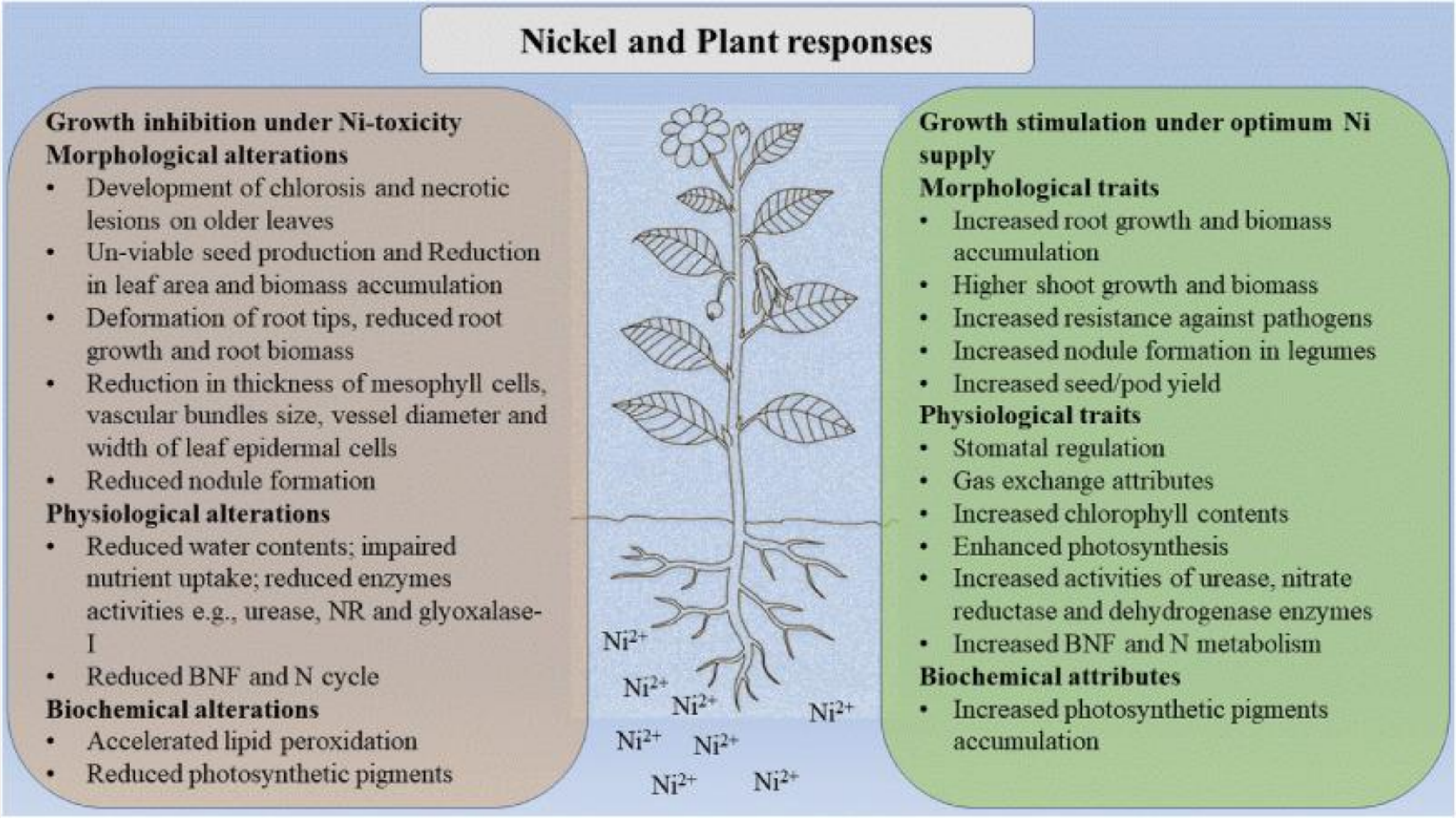
- **Nickel is considered an essential element for both legumes and small grains (e.g., barley)**(Brown, Welsh, and Cary (1987)
- Functions in plants: Component of plant urease,Benefits growth of N-fixing plant species, Barley seeds will not germinate when deficient in Ni.
- Content and distribution: • Adequate range between 0.084 and 0.22 ppm in leaf dry matter,

❖Essential for plants but the concentration in the majority of plant species is very low (0.05 – 10 mg/kg dry weight)

❖With increasing Ni pollution, excess Ni rather than a deficiency, is more commonly found in plants

❖Toxic effects of high concentrations of Ni in plants have been frequently reported

Effect of Nickel (Ni^{2+}) on plant



Nickel and Plant responses

Growth inhibition under Ni-toxicity

Morphological alterations

- Development of chlorosis and necrotic lesions on older leaves
- Un-viable seed production and Reduction in leaf area and biomass accumulation
- Deformation of root tips, reduced root growth and root biomass
- Reduction in thickness of mesophyll cells, vascular bundles size, vessel diameter and width of leaf epidermal cells
- Reduced nodule formation

Physiological alterations

- Reduced water contents; impaired nutrient uptake; reduced enzymes activities e.g., urease, NR and glyoxalase-I
- Reduced BNF and N cycle

Biochemical alterations

- Accelerated lipid peroxidation
- Reduced photosynthetic pigments

Growth stimulation under optimum Ni supply

Morphological traits

- Increased root growth and biomass accumulation
- Higher shoot growth and biomass
- Increased resistance against pathogens
- Increased nodule formation in legumes
- Increased seed/pod yield

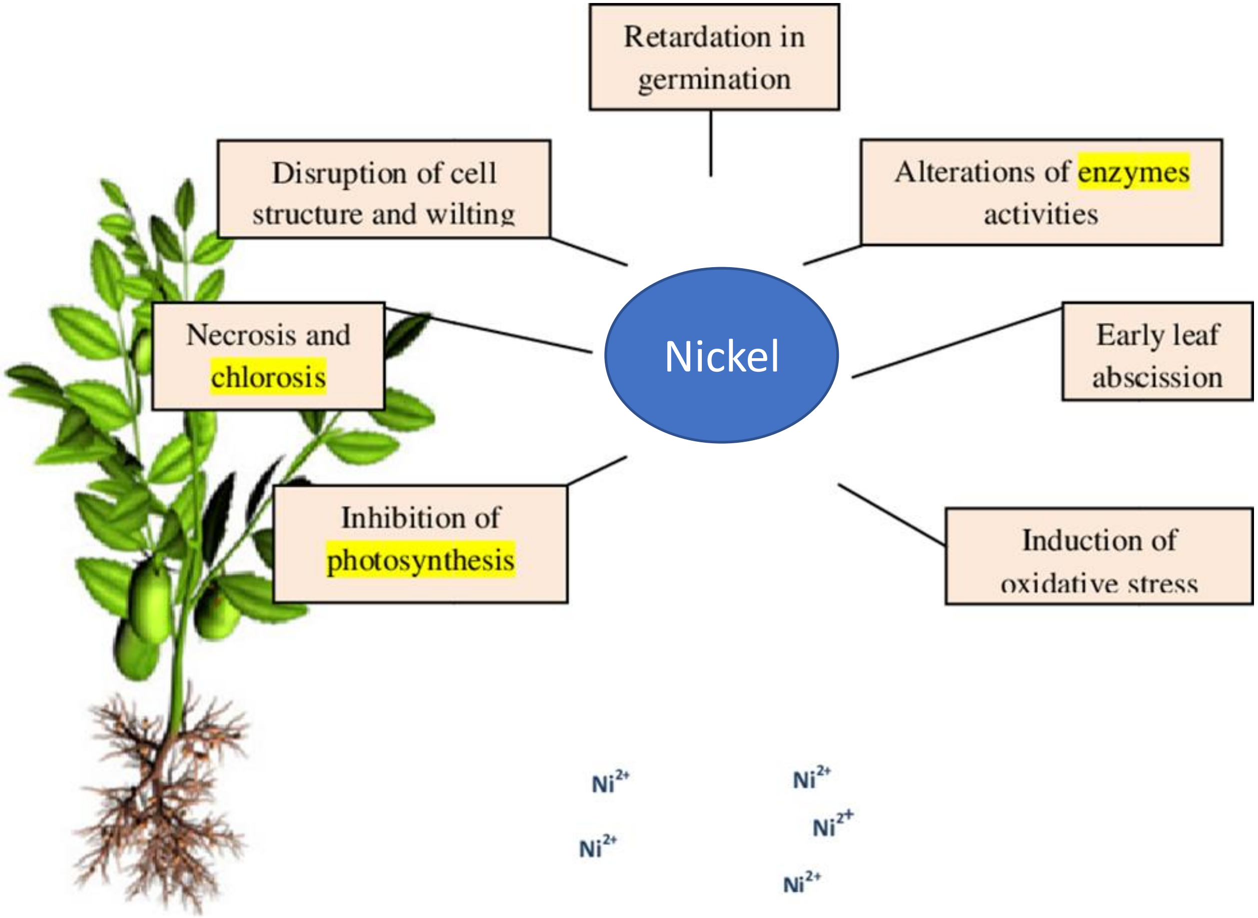
Physiological traits

- Stomatal regulation
- Gas exchange attributes
- Increased chlorophyll contents
- Enhanced photosynthesis
- Increased activities of urease, nitrate reductase and dehydrogenase enzymes
- Increased BNF and N metabolism

Biochemical attributes

- Increased photosynthetic pigments accumulation

Effect of Nickel (Ni^{2+}) on plant



Retardation in germination

Disruption of cell structure and wilting

Alterations of enzymes activities

Necrosis and chlorosis

Nickel

Early leaf abscission

Inhibition of photosynthesis

Induction of oxidative stress

Ni^{2+} Ni^{2+} Ni^{2+} Ni^{2+} Ni^{2+} Ni^{2+}

Figure 1. Severe leaflet tip necrosis due to nickel deficiency in nitrogen-fixing plants.
Credits: Patrick Brown, University of California, Davis

Figure 2. Nitrogen-fixing cowpea seedlings grown hydroponically with (left) or without (right) nickel and supplied with no inorganic nitrogen source. Without nickel, cowpea plants developed pronounced leaf tip necrosis and marked yellowing. These symptoms closely resemble those of nitrogen deficiency.
Credits: Patrick Brown, University of California, Davis

Nickel Fertilization

- As a micronutrient, also called a nanonutrient, Ni is required by plants at low concentration (Theuer 2009).
- Exists in most soils at sufficient levels to meet most crop requirements; therefore Ni is not generally applied as or with fertilizer.
- Availability is significantly reduced on high pH and lime content soils where soil fixation is likely to occur.
- Major source of Ni is sewage sludge.

- *Most annual plants have a requirement for Ni on the order of 0.5 lb per acre, compared with nitrogen (N) at 80–200 lb per acre.*

Nickel Fertilization

- Application of Ni fertilizers (Ni^{2+}) might be needed in the following growth conditions:
- (1) urea is the primary N source used for the crop production systems;
- (2) high applications of other metals, including Zn, Cu, Mn, iron (Fe), calcium (Ca), or magnesium (Mg), have been made for many years
- (3) leguminous crops are being grown in soils poor in mineral content or with a pH > 6.7. Soluble salts like nickel sulfate (NiSO4), which contains the Ni2+ ion, are suitable fertilizers to prevent or correct plant Ni deficiency.

Table. Adequacy ranges of nickel concentrations in plants tissues for selected vegetable and fruit crops.

	Ni concentration in plants(mg .kg)			
Plant Species	Deficient	Adequate	Toxic	Reference
Cowpea	0.01–0.14	0.22–10.3	TBE	Walker et al., 1985
Beans	TBE	TBE	10–83	Macnicol and Beckett 1985
Soybean	0.02–0.04	TBE	TBE	Eskew et al., 1984
Pecan	0.1	TBE	TBE	Wood et al.,2004

TBE= To be established
Source; Data from Brown (2006)

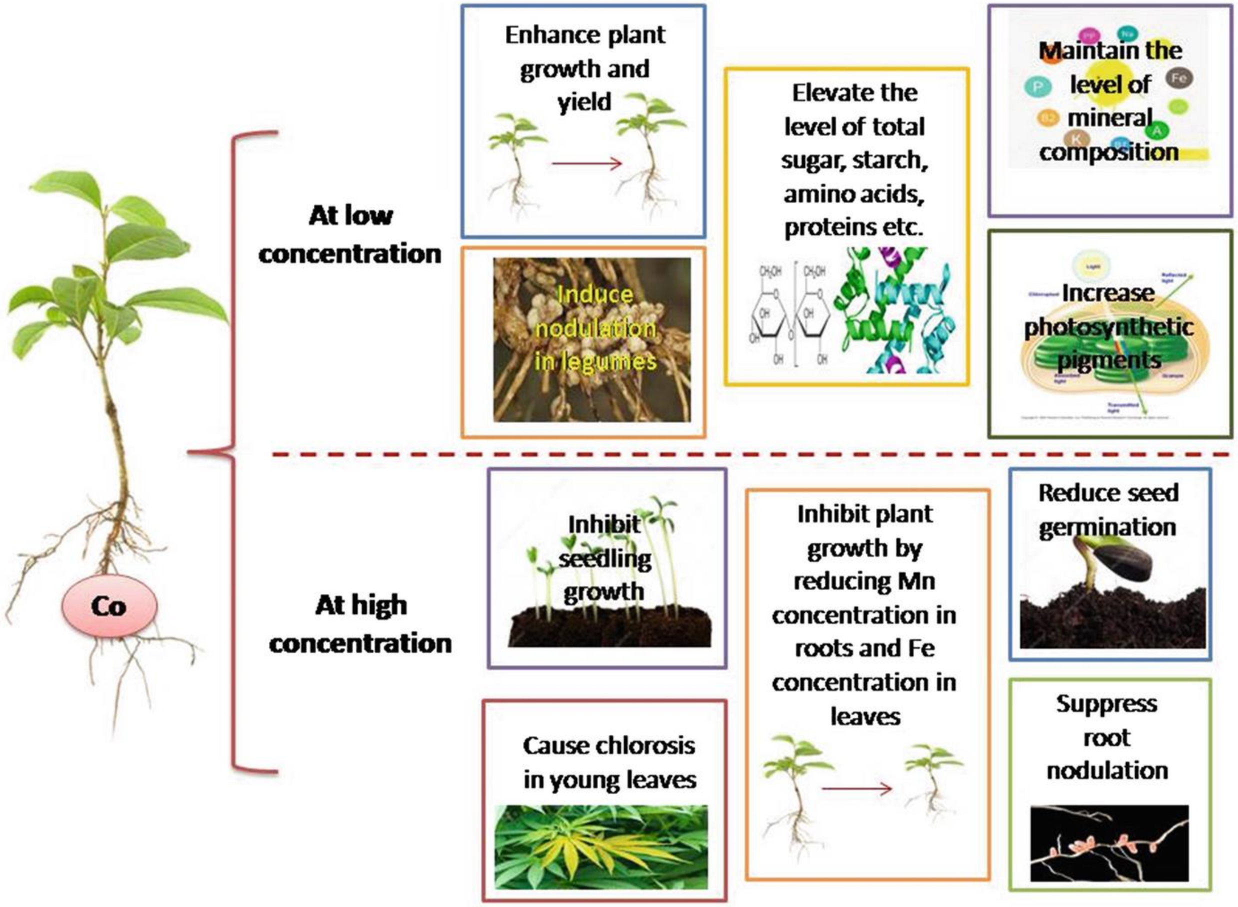
Table. Some Ni–containing fertilizers

Fertilizer	Formula or material	% Ni
Nickel sulfate (also called nickelous sulfate)	$NiSO_4 \bullet 6H_2O$	32.1
Anhydrous nickel sulfate	$NiSO_4$	37.5
Nickel nitrate	$Ni(NO_3)_2 \bullet 6H_2O$	20.2
Nickel chloride	$NiCl_2 \bullet 6H_2O$	37.2
Nickel(II) EDTA1 complex	$NiC_{10}H_{16}N_2O_8$	16.7
Nickel Plus2	Complex	5.4
Sewage sludge	Composite	2.4–5.3
1 EDTA = Ethylene Diamine Tetra-Acetate 2 Nickel Plus also contains N (5%) and S (3%)		

Cobalt(Co)

- Critical cobalamin component
- Needed for several enzyme and coenzyme operations
- Its role in accelerating the nitrogen fixation in legumes
- Rhizobia and other nitrogen (N)–fixation bacteria require Co and cobalamin
- To fix atmosphere dinitrogen (N2) into ammonia (NH3), providing plants with the essential macronutrient of N.
- Co – interaction with iron (Fe), nickel (Ni), and zinc (Zn) in maintaining cellular homeostasis
- Low concentrations of cobalt– promotes plant growth
- Higher concentrations– phytotoxicity
- Different from other beneficial elements, as plants do exhibit Co deficiency when grown in soils with limited supply

Effect of Cobalt on plants



At low concentration

- Enhance plant growth and yield
- Induce nodulation in legumes
- Elevate the level of total sugar, starch, amino acids, proteins etc.
- Maintain the level of mineral composition
- Increase photosynthetic pigments

At high concentration

- Inhibit seedling growth
- Cause chlorosis in young leaves
- Inhibit plant growth by reducing Mn concentration in roots and Fe concentration in leaves
- Reduce seed germination
- Suppress root nodulation

https://link.springer.com/chapter/10.1007/978-3-030-41552-5_17

Effect of Cobalt application on plant performance

Crops	Co application	Effects on plants	references
Groundnut	CoSO4 was mixed with soil at 0.21 kg/ha	10% higher kernel yield compared with control	Basu and Bhadoria, 2008
	Seedlings of groundnut at the true leaf stage were irrigated once with CoSO4 at 2.4.6.8 mg/l	Increased plant height, number of branches and leaf number, leaf area index, root length, shoot and root biomass, pod numbers, pods weight etc.,	Gad, 2012 a
Pigeon Pea	Seeds were treated with Co(NO3)2 at 500 mg/kg seed	Increased chlorophyll content, crop growth rate, relative growth rate, and net assimilation rate, resulting in increased plant height, number of branches, leaves, total dry matter, and yield	Raj, 1987
Coriander	Irrigated in the form of CoSO4 12.5 mg/L once	Increased coriander herb yield, mineral composition (except Fe), chemical constituents as well as essential oil components	Gad, 2012a
Soybean	Plants were grown in nutrient solutions containing 1 and 5 μg/L cobaltous chloride, inoculated with rhizobia in the absence of nitrogen	No N deficiency symptoms, and increased dry weight by 52% compared with the control treatments Ahmed and Evans	Ahmed and Evans, 1959
	Plants were grown in soil mixed with finely powdered (CoCl2) at the concentration of 50 mg/kg	Increased root and shoot length, leaf area, dry weight, yield, and yield components	Jayakumar et al., 2009
	Seeds were sown in soil mixed with finely powdered (CoCl2) at 50 mg/kg	Increased yield parameters, leaf area, shoot length, total dry weight as well as total phenol percentage	Vijayarengan et al., 2009

Effect of Cobalt application on plant performance

Crops	Co application	Effects on plants	references
Mango	Foliar spray with CoSO4 at 1,000 mg/L prior to flower bud differentiation in the first week of October	Reduced floral malformation by 65% and increased the fruit yield by 35%	Singh et al., 1994
Mungbean	Plants were treated with 50µM Co in sand culture	Improved plant growth by increasing leaf, stem, and total dry weight compared with the controls	Tewari et al., 2002
Cow Pea	Seedlings were applied with Co at 4, 6, and 8 mg/kg	Enhanced plant growth and yield and induced nodulation	Gad and Hassan, 2013
Rose	Cut flowers treated with 100 and 200 mg/L Co solutions	Inhibited vascular blockage in the stem of rose and maintained a high–water flow rate, leading to significantly water uptake by cut flowers	Aslmoshtaghi, 2014

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Cobalt: An Essential Micronutrient for Plant Growth?

Xiu Hu[1], Xiangying Wei[2], Jie Ling[3] and Jianjun Chen[4*]*

[1] College of Horticulture and Landscape Architecture, Zhongkai University of Agriculture and Engineering, Guangzhou, China, [2] Institute of Oceanography, Minjiang University, Fuzhou, China, [3] He Xiangning College of Art and Design, Zhongkai University of Agriculture and Engineering, Guangzhou, China, [4] Department of Environmental Horticulture and Mid-Florida Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, Apopka, FL, United States

Diagnostic criteria

Visual diagnosis

Plant Analysis

Quantitative Analysis

Tissue Testing

Biochemical Tests

Soil Tests

Factors Affecting Essential Nutrient Element Concentrations in Plants

- Soil physical factors: soil tilth, structure, compaction, soil surface conditions
- Soil chemical factors: organic matter content, water pH, level of essential elements
- Crop factors: previous crop, date of planting, hybrid or variety, stage of growth
- Treatment factors: applied manures and composts; fertilizer placement; time, kind, and amount
- Weather factors: air temperature, rainfall (amount and time), solar light conditions, wind
- Pest factors: weeds and insect

Principles of soil fertility and plant nutrition

Management Requirements

Productivity Factors

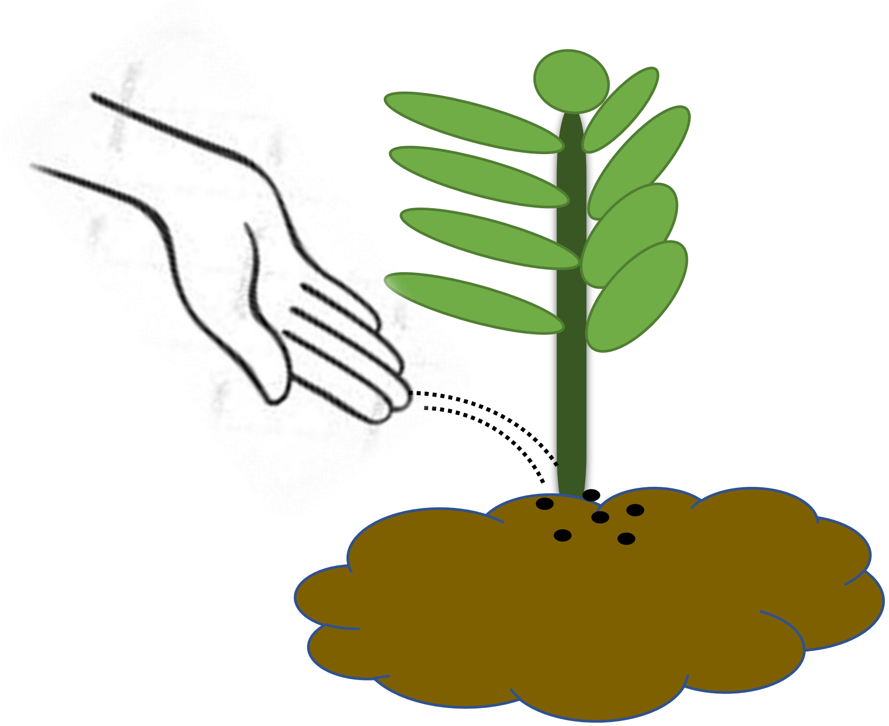
Climatic Factors

Moving Up The Yield Scale

Productivity Quality

Thank you

The best fertilizer is the foot print of the farmer (grower) in his field — Chinese Proverb



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