Plant Nutrition

1. **Plant Nutrients**
   - **Macronutrients**
   - **Micronutrients**
2. **Chemical Fertilizers**
   - **Commercial Analysis**
   - **Elemental Analysis**
3. **Fertilizer Concentration Calculations**
   - **ppm**
   - mM
   - Meq/liter
4. **Fertilizer Application**
   - **Preplant Application**
   - **Top Dressing**
   - **Liquid Feeding**

1. Essential Nutrietns of Plants

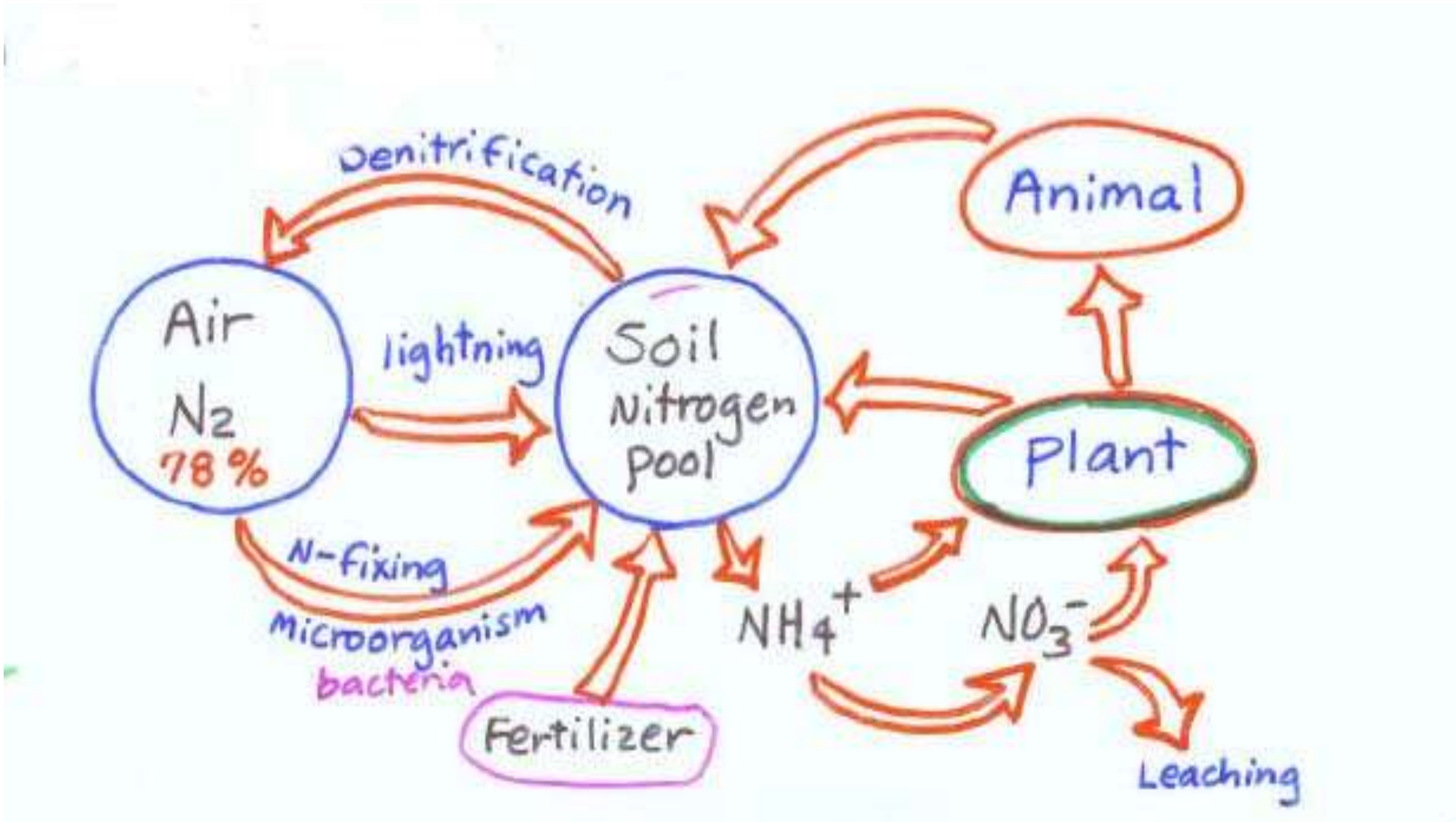
Element	Chemical symbol	Atomic weight	Ionic forms Absorbed by plants	Approximate dry concentration
Mccronutrients				
Nitrogen	N	14.01	NO_3^-, NH_4^+	4.0 %
Phosphorus	P	30.98	PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$	0.5 %
Potassium	K	39.10	K^+	4.0 %
Magnesium	Mg	24.32	Mg^{2+}	0.5 %
Sulfur	S	32.07	SO_4^{2-}	0.5 %
Calcium	Ca	40.08	Ca^{2+}	1.0 %
Micronutrients				
Iron	Fe	55.85	Fe^{2+}, Fe^{3+}	200 ppm
Manganese	Mn	54.94	Mn^{2+}	200 ppm
Zinc	Zn	65.38	Zn^{2+}	30 ppm
Copper	Cu	63.54	Cu_2^+	10 ppm
Boron	B	10.82	BO_3^{2-}, $B_4O_7^{2-}$	60 ppm
Molybdenum	Mo	95.95	MoO_4^{2-}	2 ppm
Chlorine	Cl	35.46	Cl^-	3000 ppm
Essential But Not Applied				
Carbon	C	12.01	CO_2	40 %
Hydrogen	H	1.01	H_2O	6 %
Oxygen	O	16.00	O_2, H_2O	40 %

Plant tissues also contain other elements (Na, Se, Co, Si, Rb, Sr, F, I) which are not needed for the normal growth and development.

2. Macronutrients

a. Nitrogen (N)

1) Soil Nitrogen Cycle



A. Nitrogen (N)

1) Soil Nitrogen Cycle

a) Nitrogen Fixation

-Transformation of atmospheric N to nitrogen forms available to plants

- Mediated by N-fixing bacteria:

Rhizobium (symbiotic) found in legumes (bean, soybean)
Azotobacter (non-symbiotic bacteria)

b) Soil Nitrification

- Decomposition of organic matter into ammonium and nitrate
- Mediated by ammonifying and nitrifying bacteria

Ammonifying bacteria (*Actinomycetes*) — Nitrifying bacteria (*Nitrosomonas*) (*Nitrobacter*)

Plant residue → NH_4^+ → NO_2 → NO_3^-

(Protein, aa, etc) — Ammonium — Nitrite — Nitrate

2) N Functions in Plants

- Component of proteins, enzymes, amino acids, nucleic acids, chlorophyll
- C/N ratio (Carbohydrate: Nitrogen ratio)
  High C/N ratio → Plants become more reproductive
  Low C/N ratio → Plants become more vegetative
- Transamination
  NO_3^- → NH_2 → Glutamic acid → Other amino acids (a.a.) → Protein
  Enzymes
- Essential for fast growth, green color

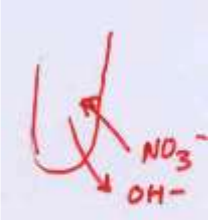
3) Deficiency and Toxicity Symptoms

Deficiency: - Reduced growth
- Yellowing of old leaves

Toxicity (excess): - Shoot elongation
- Dark leaves, succulence

4) Fertilizers

- Ammonium nitrate (NH_4NO_3)
  Calcium nitrate [$Ca(NO_3)_2$]
  Potassium nitrate (KNO_3)
  Urea [$CO(NH_2)_2$]
- Most plants prefer 50:50 NH_4^+ : NO_3^-



NH_4^+-form of N → lowers soil pH
NO_3^--form of N → raises soil pH

- Organic fertilizers (manure, plant residue) – slow acting
- N can be applied foliarly

Nitrogen (N) Deficiency Symptoms

Yellowing of mature lower leaves- nitrogen is highly mobile in plants

B. Phosphorus (P)

1) Soil Relations

- Mineral apatite [$Ca_5F(PO_4)_3$]
- Relatively stable in soil
- Has a low mobility (top dressing not effective)

2) Plant Functions

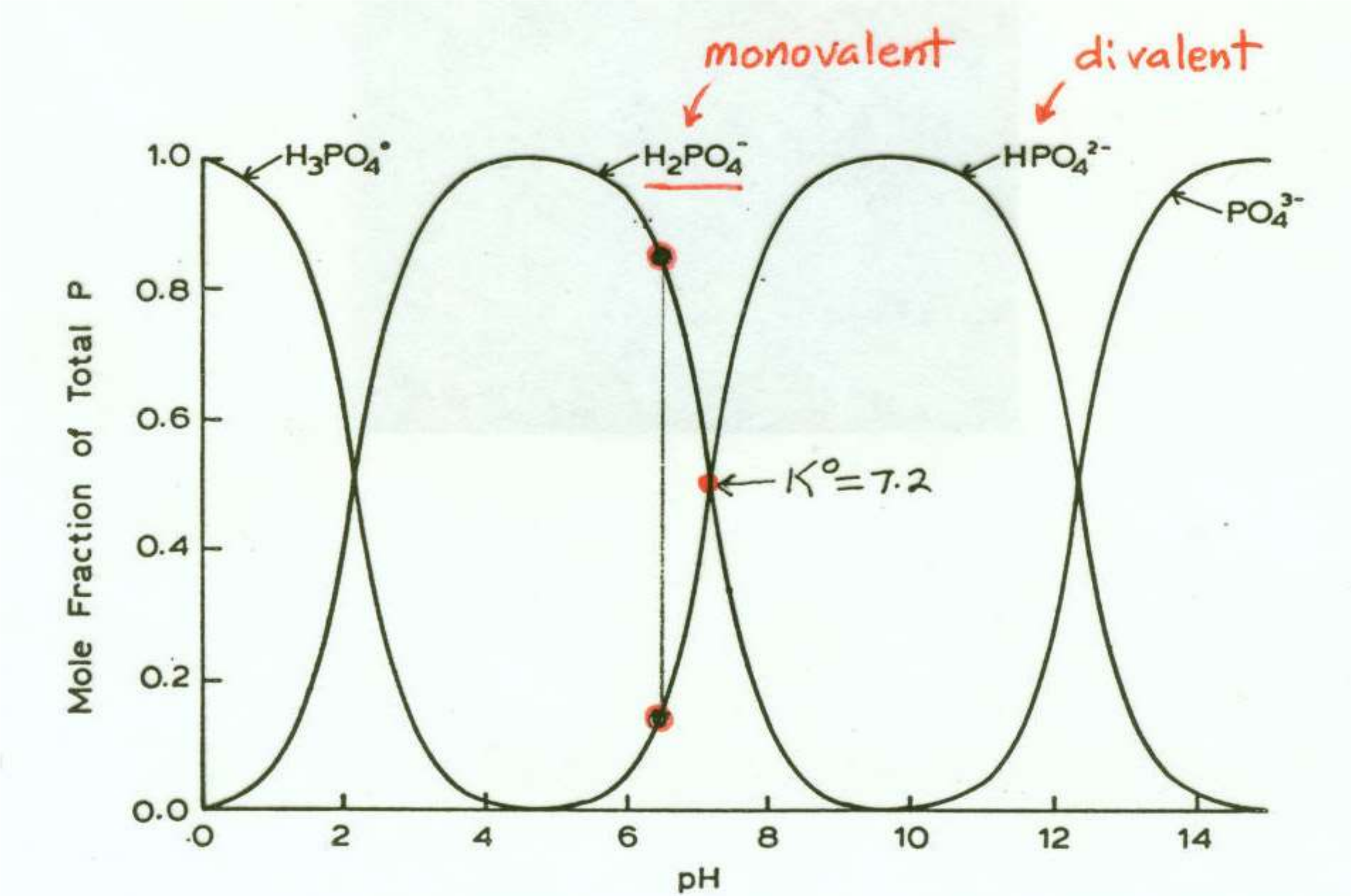
- Component of nucleic acid (DNA, RNA), phospholipids, coenzymes, high-energy phosphate bonds (ADP, ATP)
- Seeds are high in P

3) Deficiency and Toxicity

- P is mobile in plant tissues (Deficiency occurs in older leaves)
- Deficiency: dark, purplish color on older leaves
- Excess P: causes deficiency symptoms of Zn, Cu, Fe, Mn

4) Fertilizers

- Superphosphates (may contain F)
  - Single superphosphate (8.6% P): $CaH_4(PO_4)_2$
  - Triple superphosphate (20% P): $CaH_4(PO_4)_2$
- Ammonium phosphate: $(NH_4)_2PO_4$, NH_4HPO_4
- Bone meal
- Available forms: PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$
  - P absorption influenced by pH



Influence of pH on different forms of phosphorus (P)

C. Potassium (K)

1) Soil Relations

- Present in large amounts in mineral soil
- Low in organic soils

2) Plant Functions

- Activator of many enzymes
- Regulation of water movement across membranes and through stomata (Guard cell functions)

3) Deficiency and Toxicity

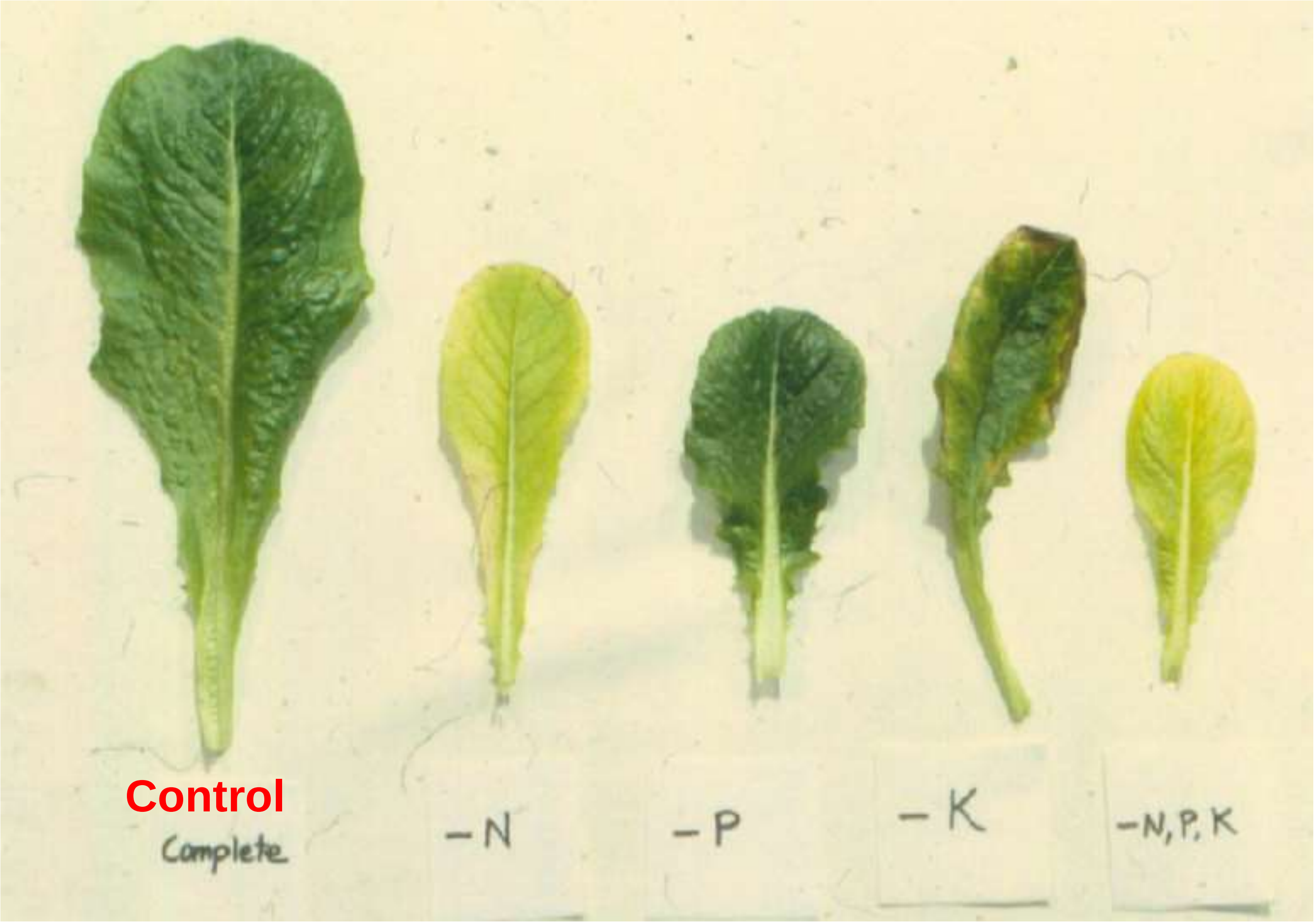
- Deficiency: Leaf margin necrosis and browning
  Older leaves are more affected
- Toxicity: Leaf tip and marginal necrosis

4) Fertilizers

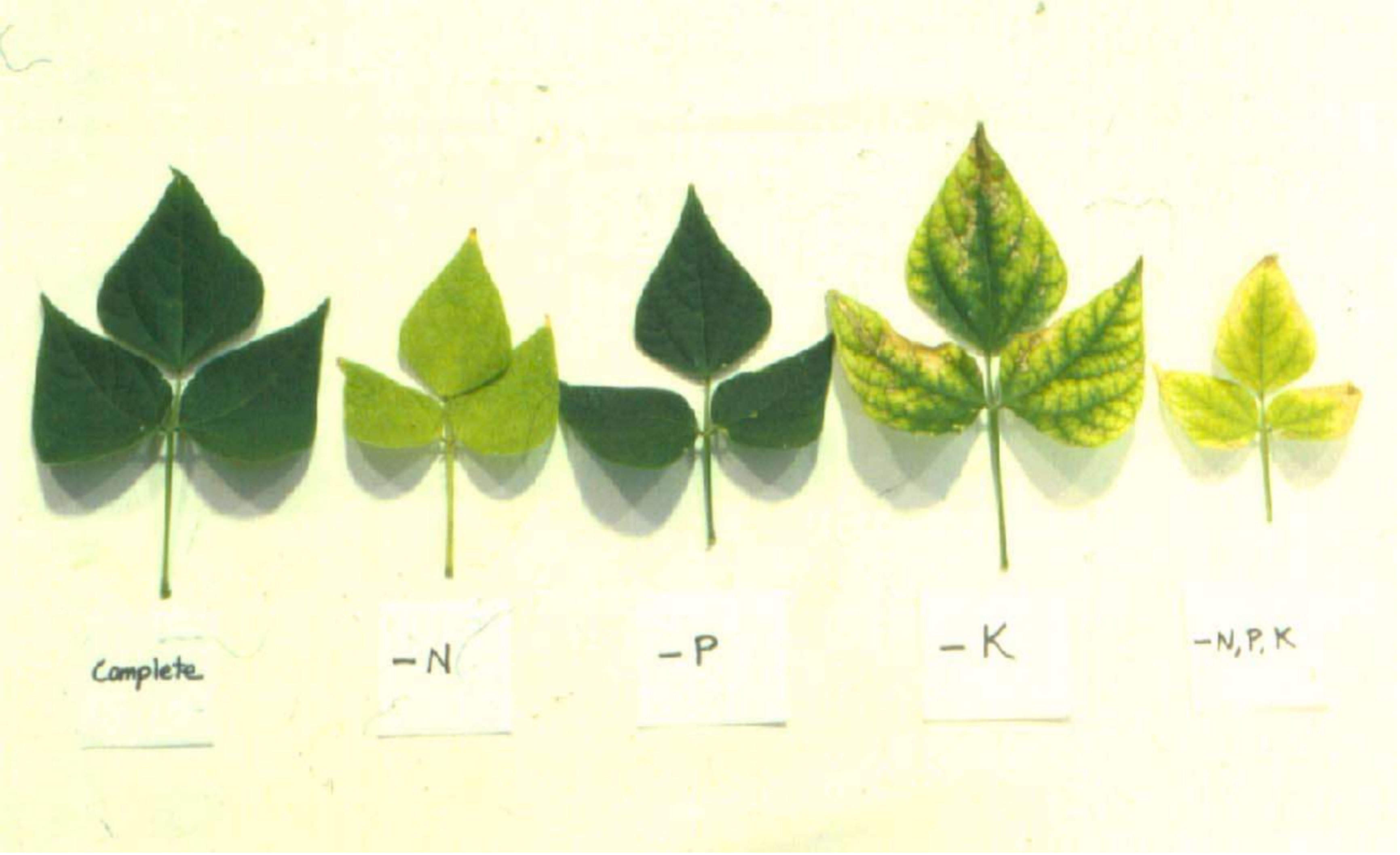
- Potassium chloride (KCl)- murate of potash
- Potassium sulfate (K_2SO_4)
- Potassium nitrate (KNO_3)

Leaf Margin Necrosis in Poinsettia
Potassium (K) Deficiency

Macronutrients N, P, K Deficiencies
Leaf Lettuce



Macronutrient Deficiencies
Beans



D. Calcium (Ca)

1) Soil Relations

- Present in large quantities in earth's surface (~1% in US top soils)
- Influences availability of other ions from soil

2) Plant Functions

- Component of cell wall
- Involved in cell membrane function
- Largely present as calcium pectate in meddle lamela

    Calcium pectate is immobile in plant tissues

3) Deficiency and Toxicity

- Deficiency symptoms in young leaves and new shoots (Ca is immobile)

    Stunted growth, leaf distortion, necrotic spots, shoot tip death

    Blossom-end rot in tomato

- No Ca toxicity symptoms have been observed

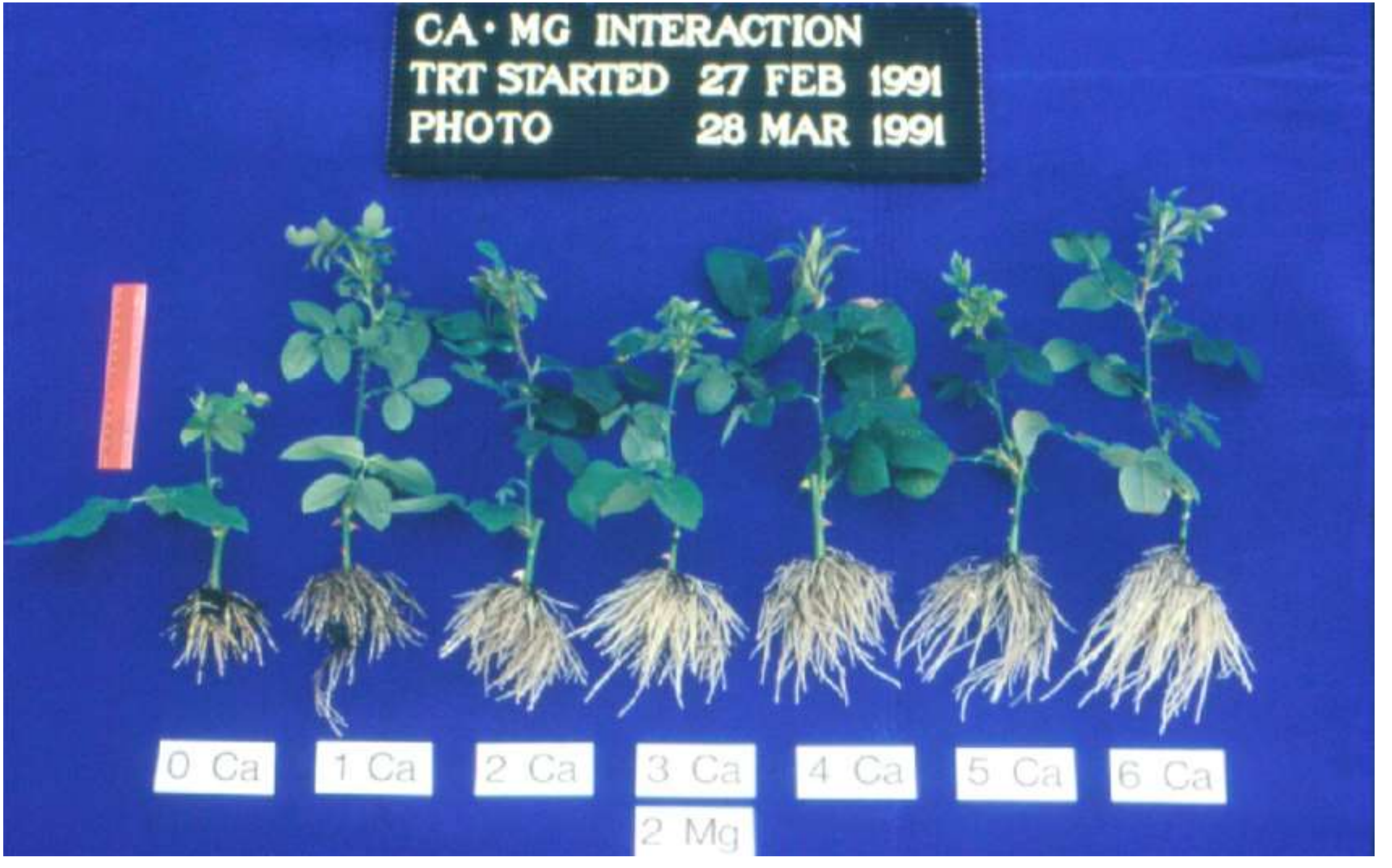
4) Fertilizers

- Agricultural meal (finely ground $CaCO_3 \cdot MgCO_3$)
- Lime ($CaCO_3$), Gypsum ($CaSO_4$)
- Superphosphate
- Bone meal-organic P source

Blossom End Rot of Tomato
Calcium Deficiency

Right-Hydroponic tomatoes grown in the greenhouse, Left-Blossom end rot of tomato fruits induced by calcium (Ca^{++}) deficiency

Influence of Calcium on Root Induction on Rose Cuttings



E. Sulfur (S)

1) Soil Relations

- Present in mineral pyrite (FeS_2, fool's gold), sulfides (S-mineral complex), sulfates (involving SO_4^{-2})
- Mostly contained in organic matter
- Acid rain provides sulfur

2) Plant Functions

- Component of amino acids (methionine, cysteine)
- Constituent of coenzymes and vitamins
- Responsible for pungency and flavbor (onion, garlic, mustard)

3) Deficiency and Toxicity

- Deficiency: light green or yellowing on new growth (S is immobile)
- Toxicity: not commonly seen

4) Fertilizers

- Gypsum ($CaSO_4$)
- Magnesium sulfate ($MgSO_4$)
- Ammonium sulfate [$(NH_4)_2SO_4$]
- Elemental sulfur (S)

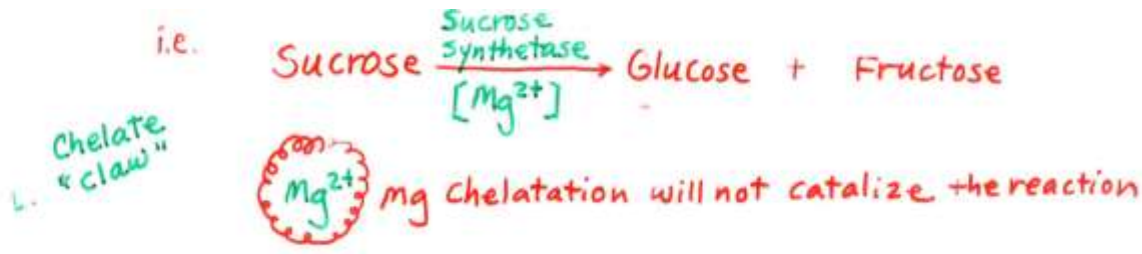
F. Magnesium (Mg)

1) Soil Relations

- Present in soil as an exchangeable cation (Mg^{2+})
- Similar to Ca^{2+} as a cation

2) Plant Functions

- Core component of chlorophyll molecule
- Catalyst for certain enzyme activity



3) Deficiency and Toxicity

- Deficiency: Interveinal chlorosis on mature leaves (Mg is highly mobile)
- Excess: Causes deficiency symptoms of Ca, K

4) Fertilizers

- Dolomite (mixture of $CaCO_3 \cdot MgCO_3$)
- Epsom salt ($MgSO_4$)
- Magnesium nitrate [$Mg(NO_3)_2$]
- Magnesium sulfate ($MgSO_4$)

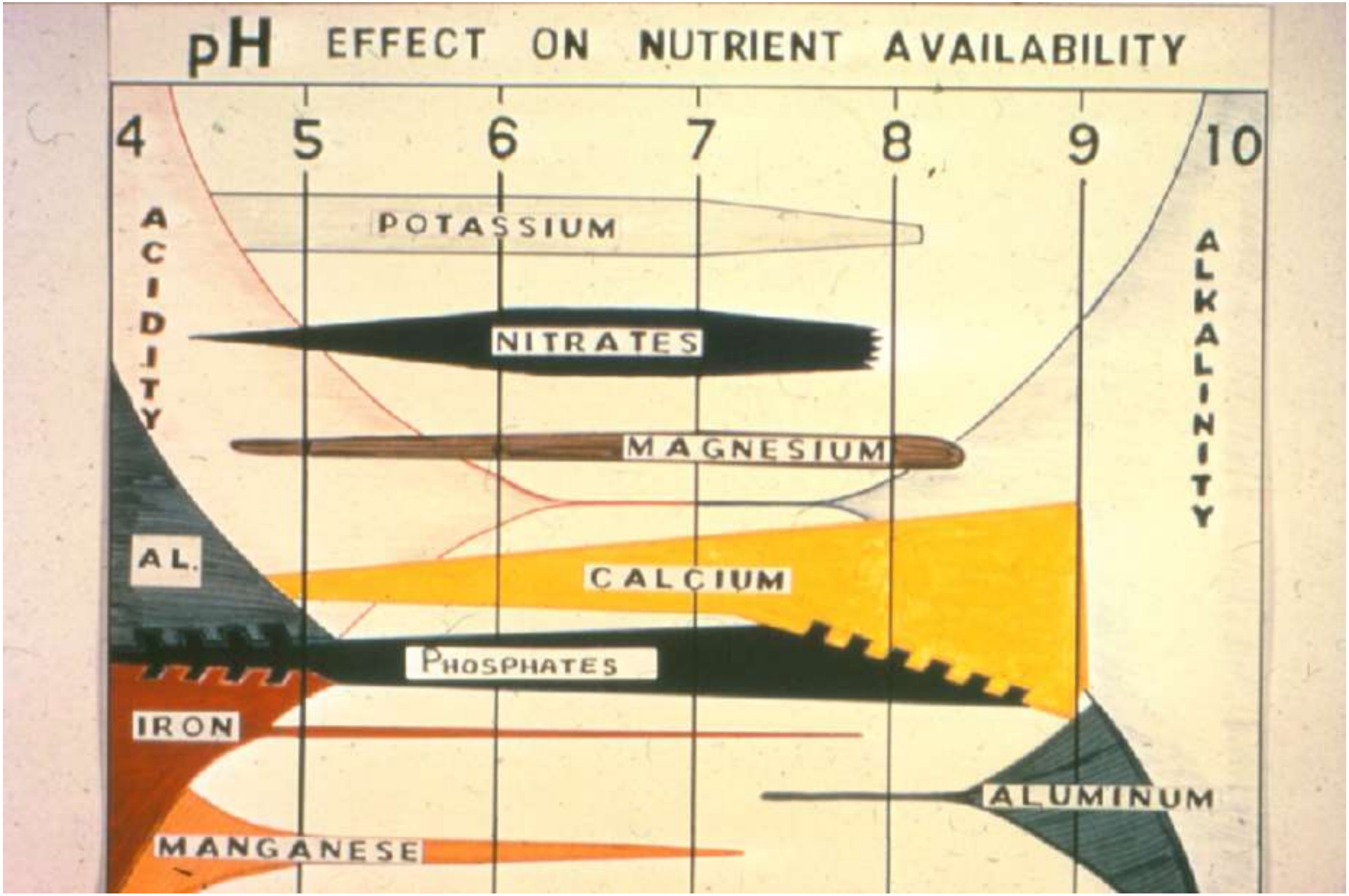
Magnesium (Mg) Deficiency on Poinsettia

Interveinal Chlorosis on Mature Leaves

Micronutrients

- **Micronutrient elements**
  - **Iron (Fe)**
  - **Manganese (Mn)**
  - **Boron (B)**
  - **Zinc (Zn)**
  - **Molybdenum (Mo)**
  - **Copper (Cu)**
  - **Chlorine (Cl)**
- **Usually supplied by irrigation water and soil**
- **Deficiency and toxicity occur at pH extremes**

Influence of pH on Nutrient Availability



3. Micronutrients

A. Iron (Fe)

- **Component of cytochromes (needed for photosynthesis)**
- **Essential for N fixation (nitrate reductase) and respiration**
- **Deficiency**

Symptom: Interveinal chlorosis on new growth

Fe is immobile

Iron chlorosis develops when soil pH is high

Remedy for iron chlorosis:

1) Use iron chelates

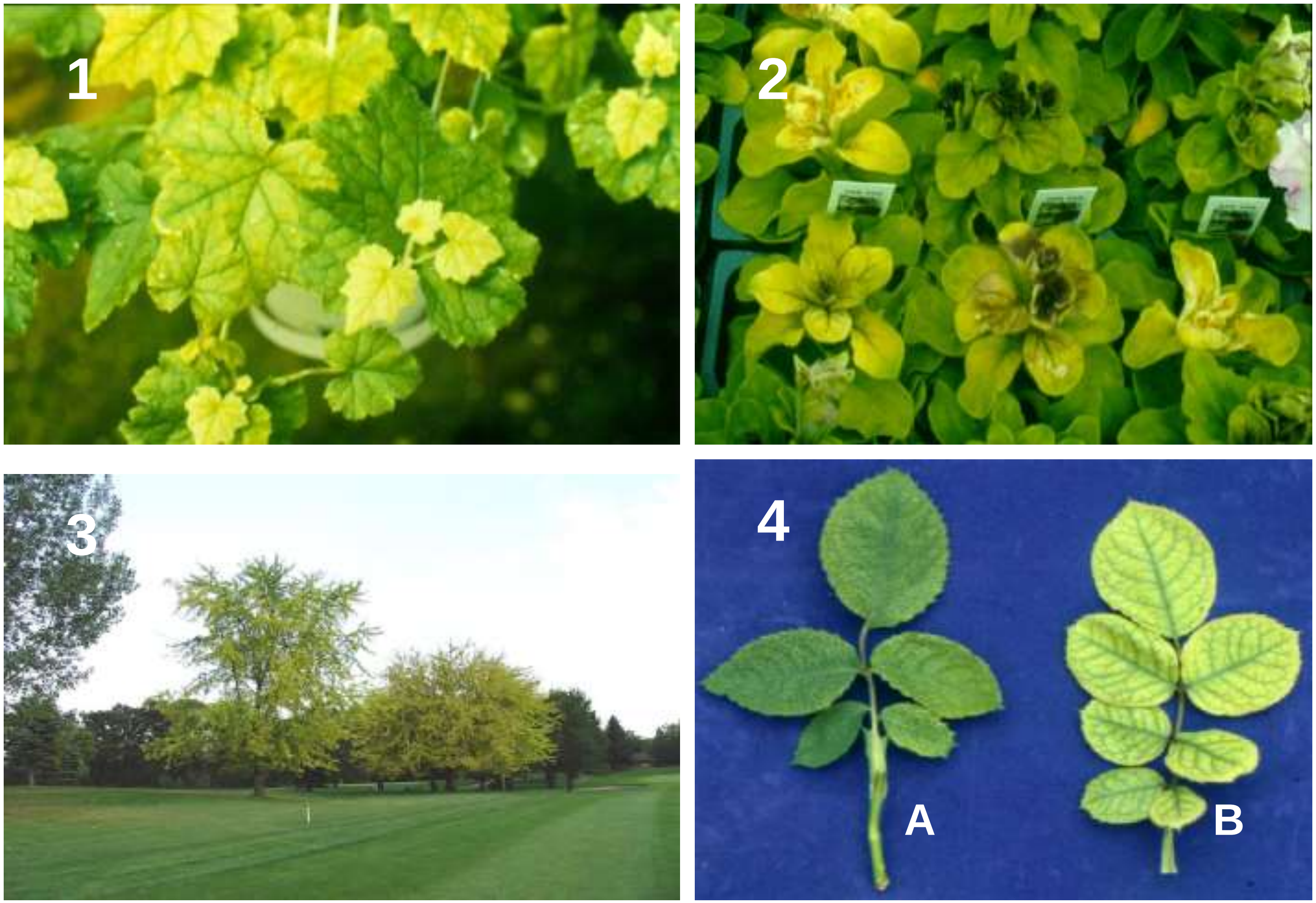
FeEDTA (Fe 330) – Stable at pH < 7.0

FeEDDHA (Fe 138) – Stable even when pH > 7.0

2) Lower soil pH

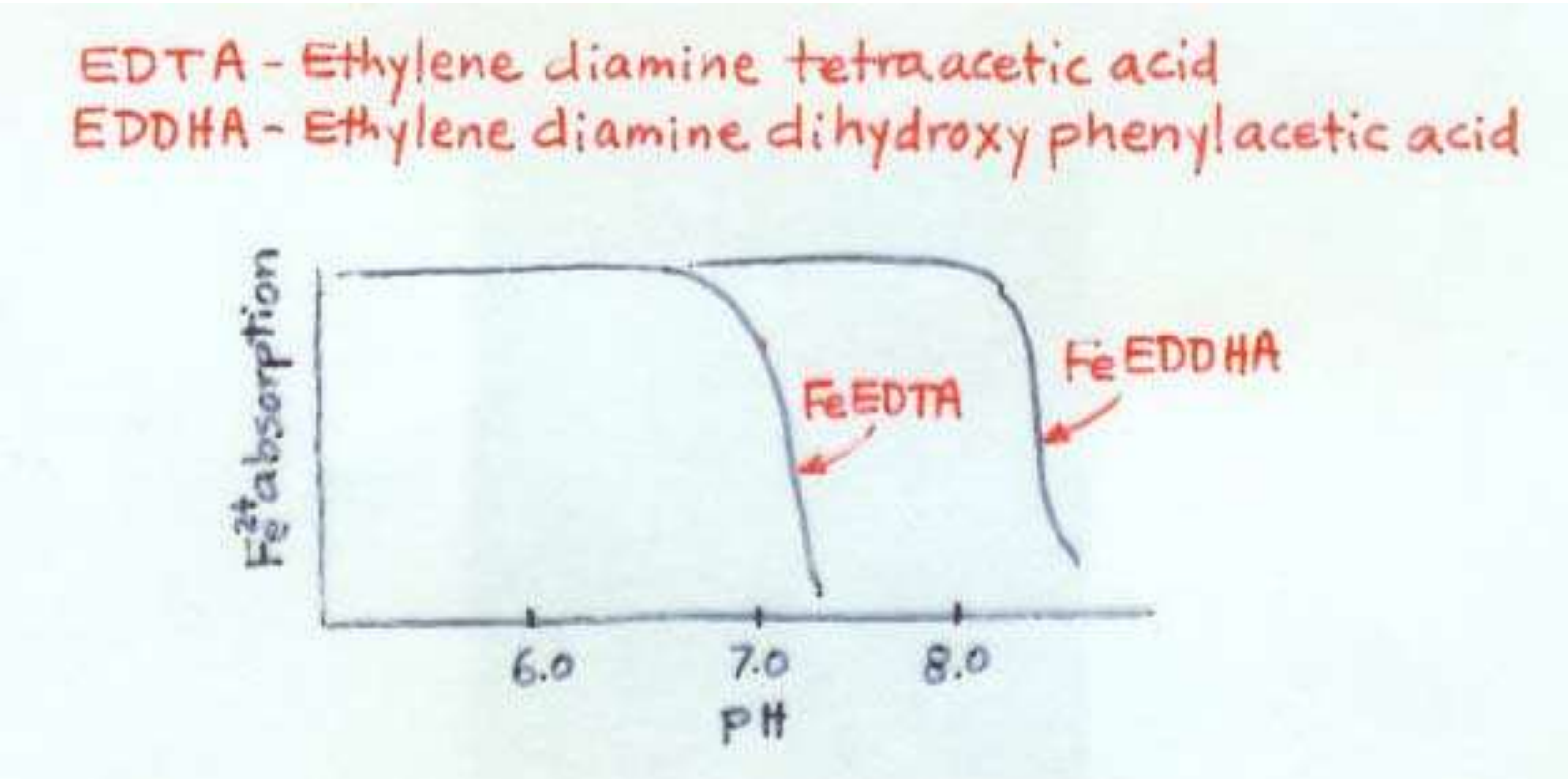
Iron is in more useful form (Fe^{2+})

Iron (Fe) Deficiency Symptoms

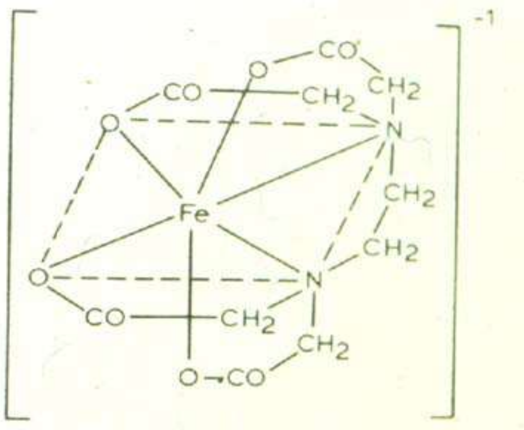


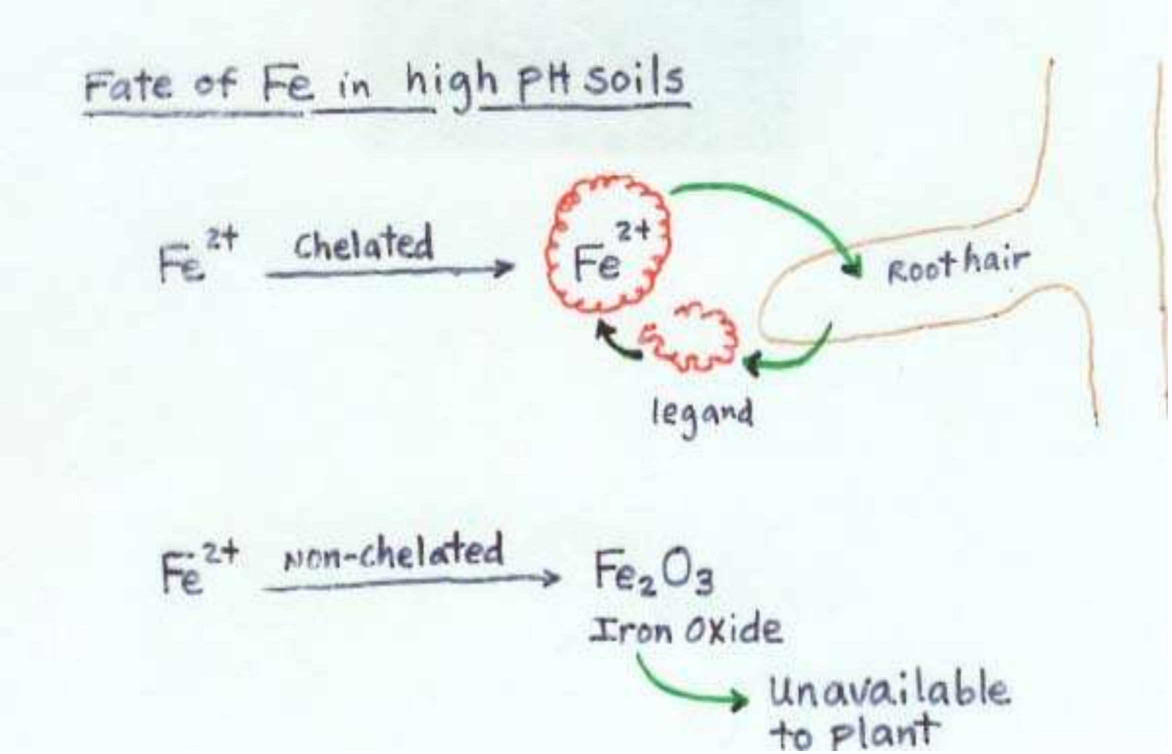
1-Piggyback Plant, 2- Petunia, 3-Silver Maple,
4-Rose (A-normal, B-Fe-deficient)

Iron Chelates



Iron (Fe) Absorption by Plants





B. Manganese (Mn)

- Required for chlorophyll synthesis, O_2 evolution during photoshynthesis
- Activates some enzyme systems
- Deficiency: Mottled chlorsis between main veins of new leaves (Mn is immobile), similar to Fe chlorosis
- Toxicity: Chlorosis on new growth with small, numerous dark spots

  Deficiency occurs at high pH

  Toxicity occurs at low pH
- Fertilizers: Manganese sulfate ($MnSO_4$)

  Mn EDTA (chelate) for high pH soils

C. Boron (B)

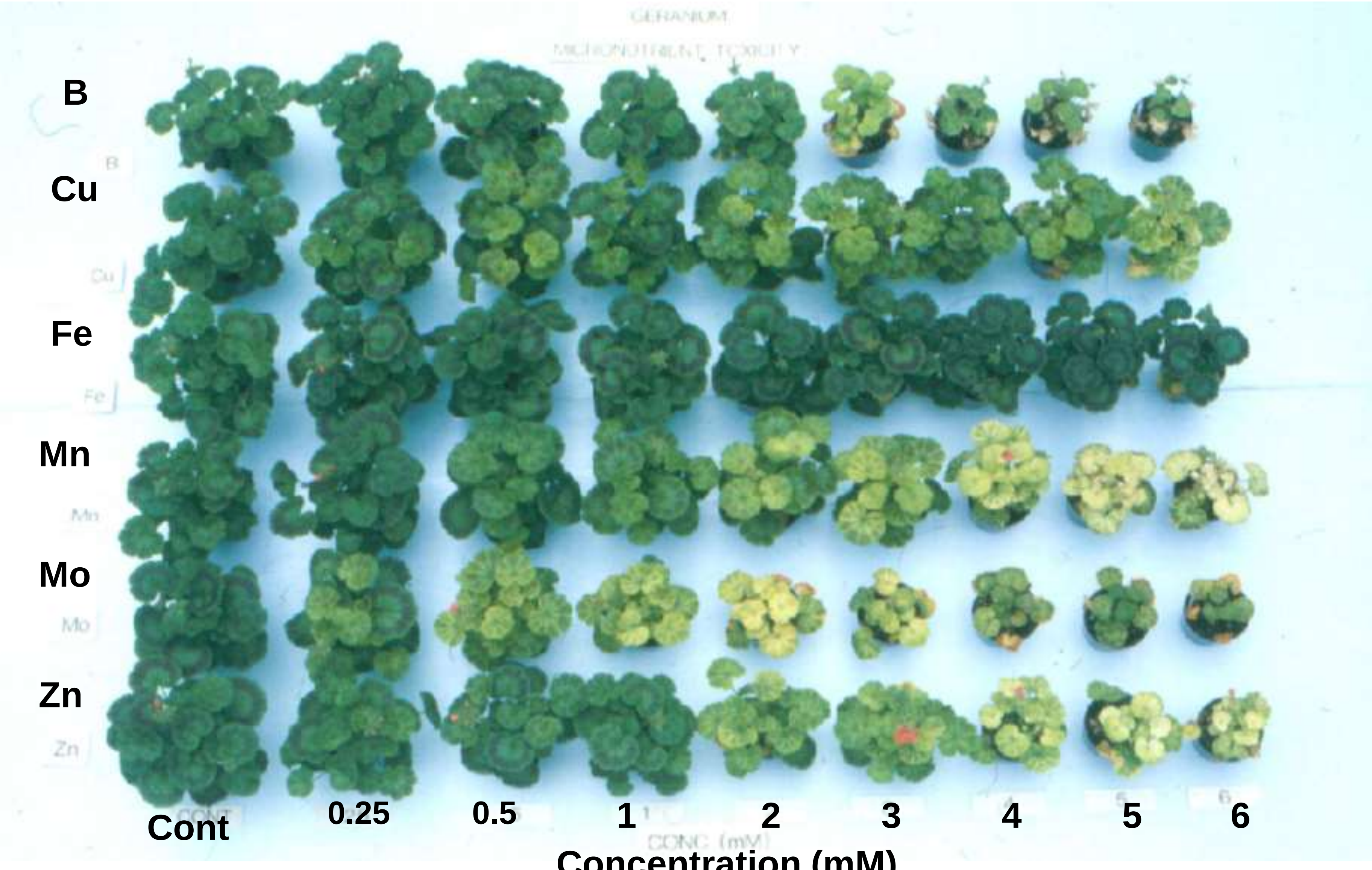
- Involved in carbohydrate metabolism
- Essential for flowering, pollen germination, N metabolism
- Deficiency: New growth distorted and malformed, flowering and fruitset depressed, roots tubers distorted
- Toxicity: Twig die back, fruit splitting, leaf edge burns
- Fertilizers: Borax ($Na_2B_4O_7 10H_2O$), calcium borate ($NaB_4O_7\ 4H_2O$)

D. Zinc (Zn)

- Involved in protein synthesis, IAA synthesis
- Deficiency: (occurs in calcarious soil and high pH)

  Growth suppression, reduced internode lengths, rosetting, interveinal chlorosis on young leaves (Zn is immobile in tissues)
- Toxicity: (occurs at low pH) Growth reduction, leaf chlorosis

Micronutrient Toxicity on Seed Geranium



E. Molybdenum (Mo)

- Required for nitrate reductase activity, vitamin synthesis

$$NO_3^- \xrightarrow[\text{Mo}]{\text{Nitrate reductase}} NH_2$$

Root-nodule bacteria also requires Mo

- Deficiency: Pale green, cupped young leaves (Mo is immobile)
  Strap leafe in broad leaf plants
  Occurs at low pH
- Toxicity: Chlorosis with orange color pigmentation
- Fertilizer: Sodium molybdate

F. Copper (Cu)

- Essential component of several enzymes of chlorophyll synthesis, carbohydrate metabolism
- Deficiency: Rosette or 'witch's broom'
- Toxicity: Chlorosis
- Fertilizers: Copper sulfate ($CuSO_4$)

G. Chlorine (Cl)

- Involved for photosynthetic oxygen revolution
- Deficiency: Normally not existing (Only experimentally induced)
- Toxicity: Leaf margin chlorosis, necrosis on all leaves
- Fertilizer: Never applied
  (Cl^- is ubiquitous!)

Molybdenum Deficiency on Poinsettia

Fertilizer Analysis

Commercial Analysis:

$N - P_2O_5 - K_2O$ (by % weight)

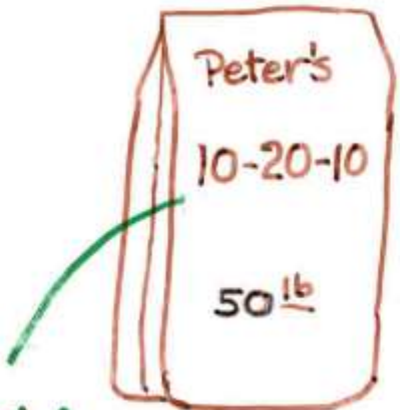
Elemental Analysis:

N - P - K (by % weight)

N -	**P_2O_5** -	**K_2O**
(10 lb)	*(10 lb)*	*(10 lb)*
N -	**P** -	**K**
(10 lb)	*(4.4 lb)*	*(8.3 lb)*

Commercial Analysis vs Elemental Analysis

Examples



Elemental
10 - 8.8 - 8.3

A 50 lb bag of a 10-20-10 Fertilizer contains:

$10\% = 0.1$

$$50^{lb} \times 0.1 = 5^{lb}\ N$$
$$50^{lb} \times 0.2 = 10^{lb}\ P_2O_5$$
$$50^{lb} \times 0.1 = 5^{lb}\ K_2O$$

} includes Oxides

Total 20 lb

conversion

$$5\ lb \times 1 = 5\ lb\ \ N$$
$$10\ lb \times 0.44 = 4.4\ lb\ \ P$$
$$5\ lb \times 0.83 = 4.15\ lb\ \ K$$

} Elemental

Total 13.55 lb

Fertilizer Rates and Concentrations

- **British System**
  - lb/1000 ft^2 (solid, field application)
  - 1b/acre (solid, field application)
  - oz/100 gallon (=75 ppm)
  - pint/gallon
- **Metric System**
  - kg/ha (solid, field application)
  - parts per million (**ppm**)
  - milli-molar (**mM**)
  - Milli-equivalent per liter (**meq/L**)

Molar (M) Concentrations

Weight

mole = molecular weight (g)

mmole = 0.001 mole = molecular wt (mg)

µmole = 0.000,001 mole = molecular wt (µg)

Concentration

molar (M) = mole/liter

milli-molar (mM) = mmole/liter

micro-molar (µM) = µmole/liter

To Make 50 gallon of 200 ppm N Solution

Concentration

1 ppm = 1 mg/liter

200 ppm = 200 mg/liter

Fertilizer Solution

Fertilizer: 20-20-20 $N\text{-}P_2O_5\text{-}K_2O$

Amount/liter = 200 mg x 1/0.2 =1,000 mg = 1g

Amount/50 gal

1 g/liter x 3.8 liter/gal x 50 gal = 190 g

Fertilizer Application

1. Preplant Application

   -Lime, sulfur, superphosphate, gypsum, dolomite

2. Dry Application

   - Fertilizers with solubility <20 g/100 ml
   - Top dressing
   - Do not apply lime with phosphorus

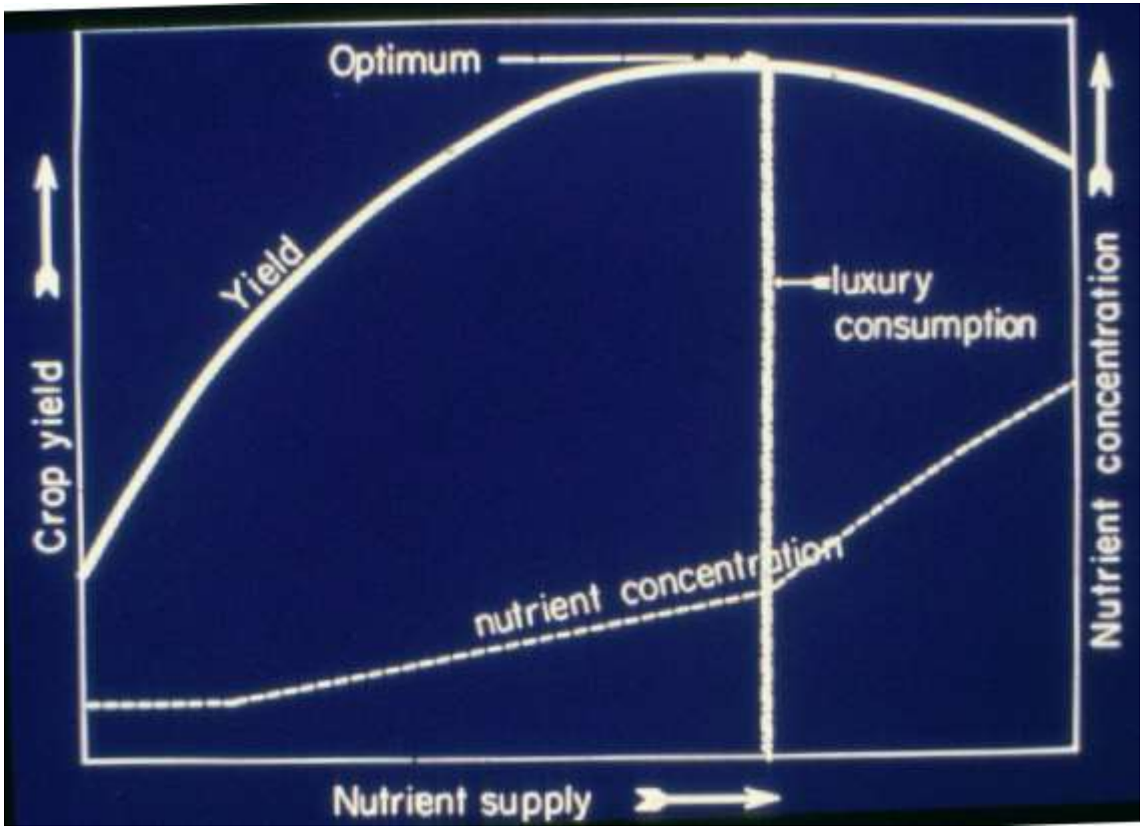
3. Liquid Feeding

   - Use soluble fertilizers
   - Constant feeding vs intermittent feeding

Fertilizer Application

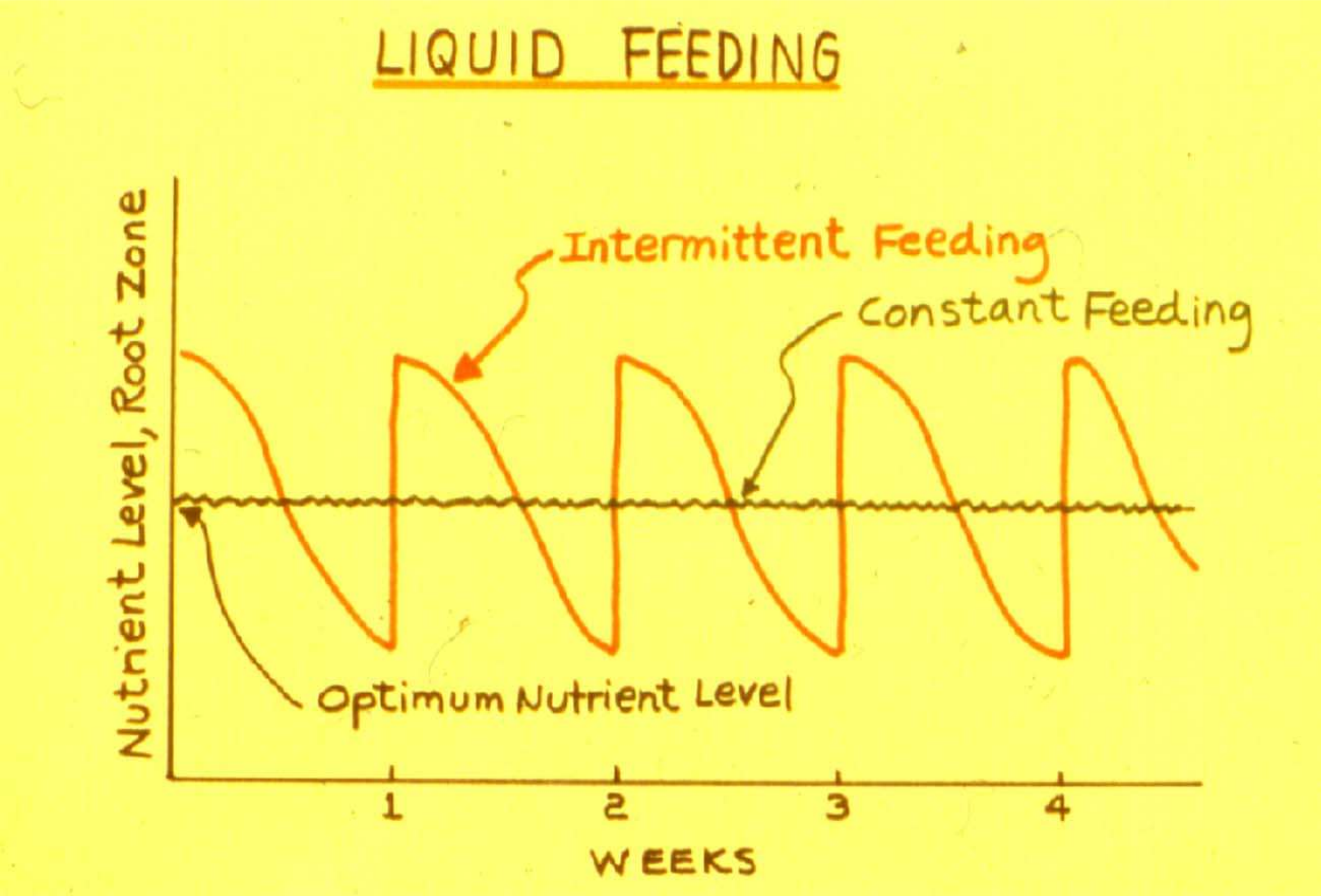
Plant growth in influenced by a nutrient at lowest concentration as a denominator

Amounts of Fertilizer Applied



Fertilizer Application

Liquid Feeding of Greenhouse Crops

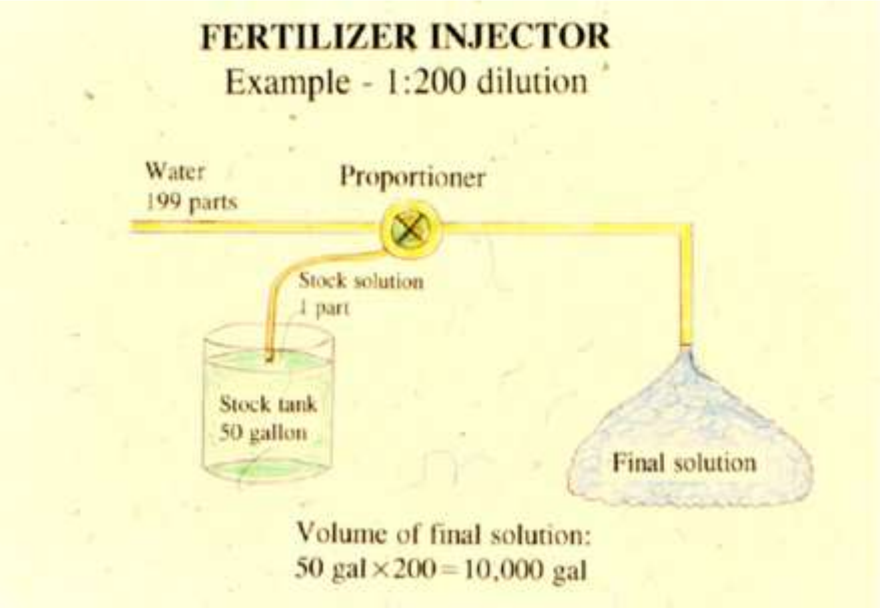


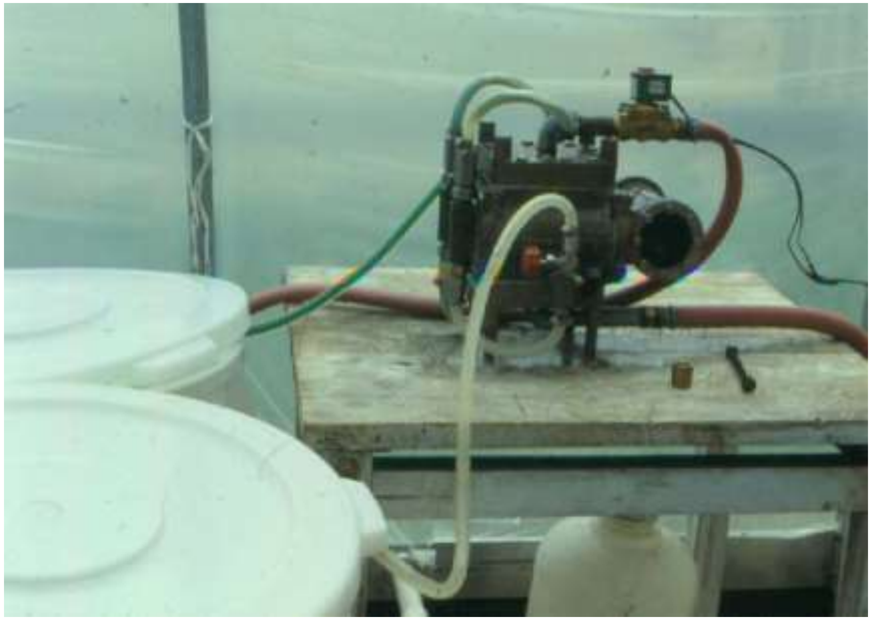
Use of Soluble Fertilizers

Peter's 20-20-20 soluble fertilizer

Lack of soluble fertilizer in Mexico lowers the quality of crops grown in greenhouses

Fertilizer Injector





A two-head Injector (proportioner) used for greenhouse crops

Purification of Water

- Filtration
- Reverse Osmosis (RO water)
- Distillation (DI water)

The Ebb-and-Flow System

The Floor Irrigation System
(Sub-irrigation)

Crops Grown with Sub-Irrigation System