Nutrients & Diagnosing Nutrient Needs

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Sources of nutrients available for plant uptake

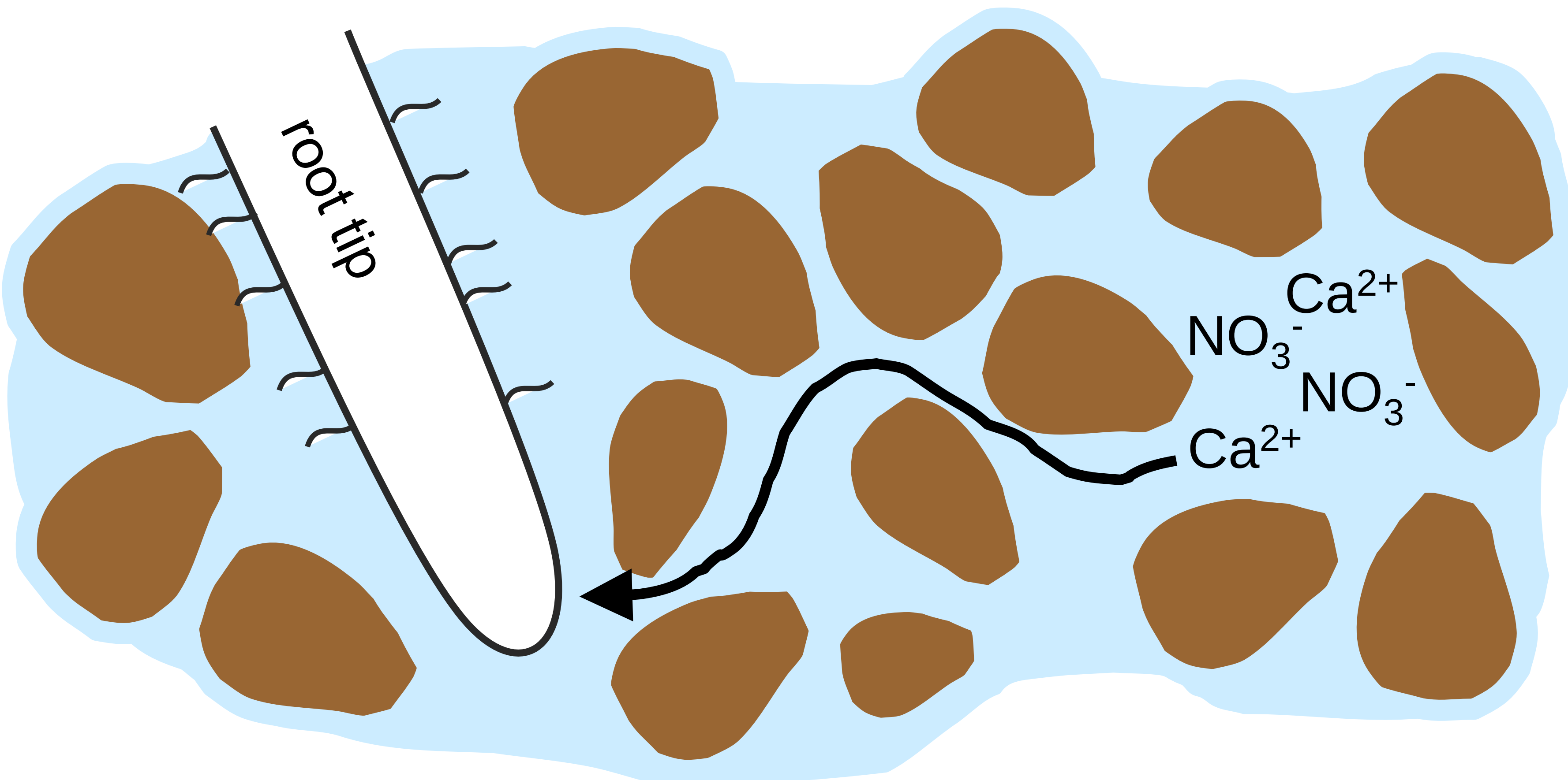
- Nutrients in the soil solution are:
  - In ionic form
  - At low concentration
  - Highly buffered

- Contributors to soil solution:
  - Exchange sites on clay and organic matter
  - Organic matter decomposition
  - Weathering of soil minerals and rocks
  - Atmosphere & precipitation
  - Organic and inorganic additions

Movement of nutrients to roots

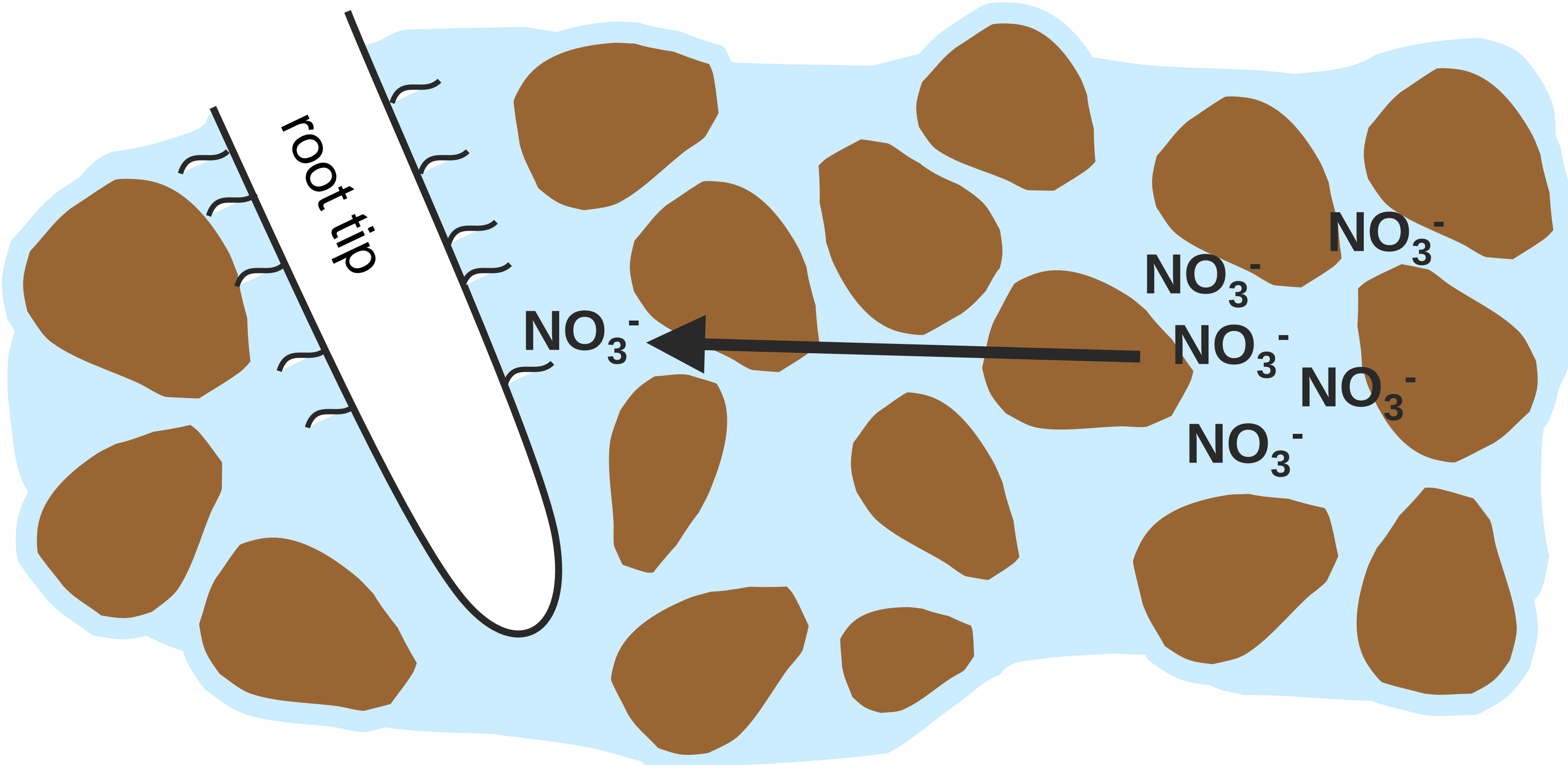
- Mass flow
- Diffusion
- Root interception

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



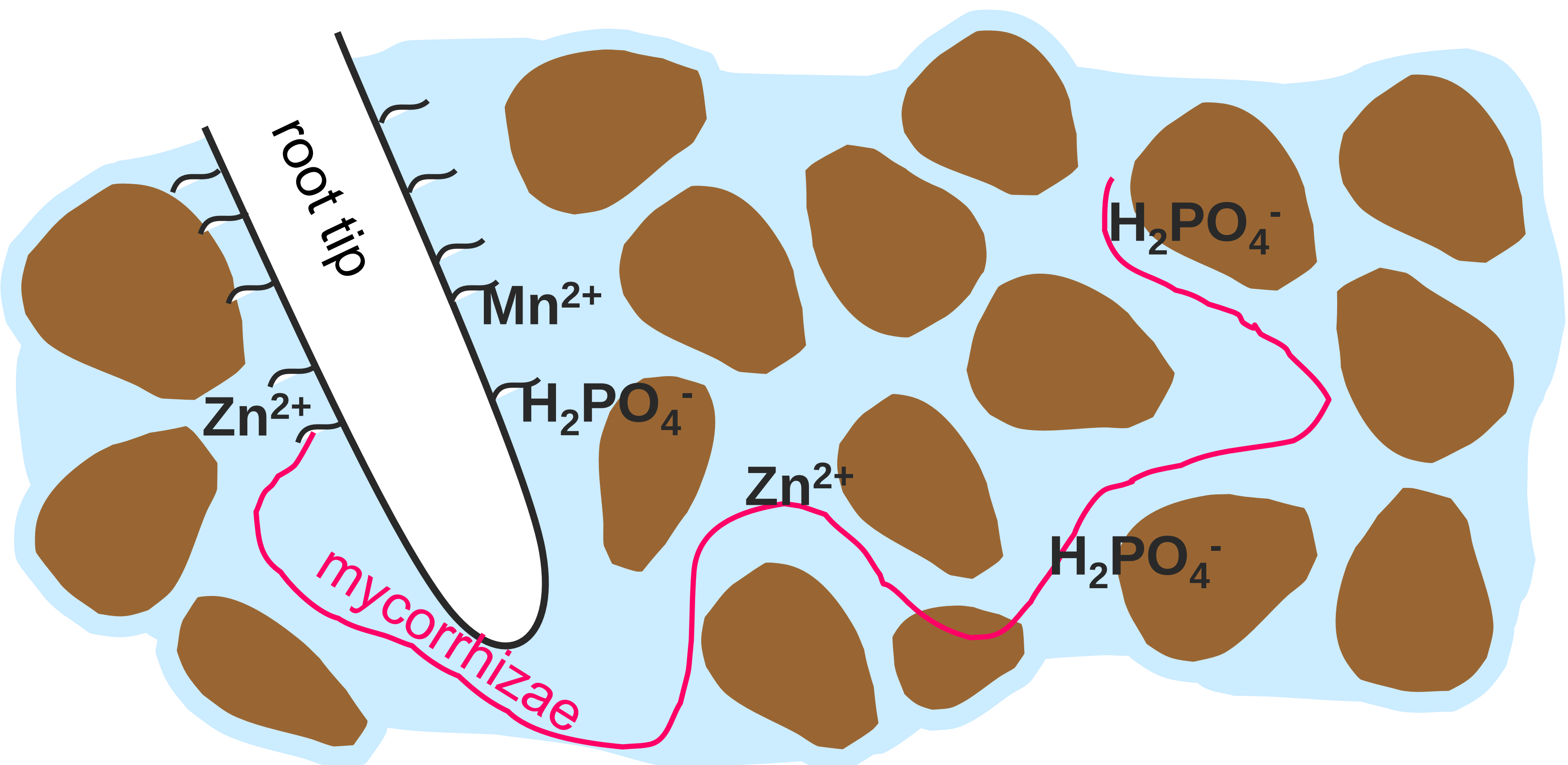
Diffusion – nutrients move from higher concentration in the bulk soil solution to lower concentration at the root;

-In the time it takes NO_3^- to diffuse 1 cm, K^+ diffuses 0.2 cm, and $H_2PO_4^-$ diffuses 0.02 cm



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



Principal ways in which ions move from soil to the roots of corn

Nutrient	Amount of Nutrient Required for 150 bu/a of Corn (lb/a)	-------- Percentage Supplied by --------		
		Root Interception	Mass Flow	Diffusion
N	170	1	99	0
P	35	3	6	94
K	175	2	20	78
Ca	35	171	429	0
Mg	40	38	250	0
S	20	5	95	0
Cu	0.1	10	400	0
Zn	0.3	33	33	33
B	0.2	10	350	0
Fe	1.9	11	53	37
Mn	0.3	33	133	0
Mo	0.01	10	200	0

Barber, *Soil Bionutrient Availability*, (1984). Diffusion estimated be difference between total nutrient need and nutrient supply by root interception & mass flow.

Ion absorption by plants:

- Passive uptake
  - Simple diffusion – small nonpolar molecules (O_2, CO_2)
  - Facilitated diffusion – small polar species (H_2O, ions, amino acids)
  - Transporter proteins
    - Energy required is obtained from electrical/chemical gradient, not plant
- Active uptake
  - Larger, more charged molecules (sugars, phosphate/ions, DNA, proteins, etc.)
  - Selectively permeable membrane requires plant to expend energy to transport ions against a concentration gradient

Nutrient Availability

- Macronutrients
  - Structural: C, O, H
  - Primary: N, P, K
  - Secondary: Ca, Mg, S
- Micronutrients
  - B, Mn, Zn
  - Cu, Fe, Mo, Cl, Ni

Macronutrients – Structural

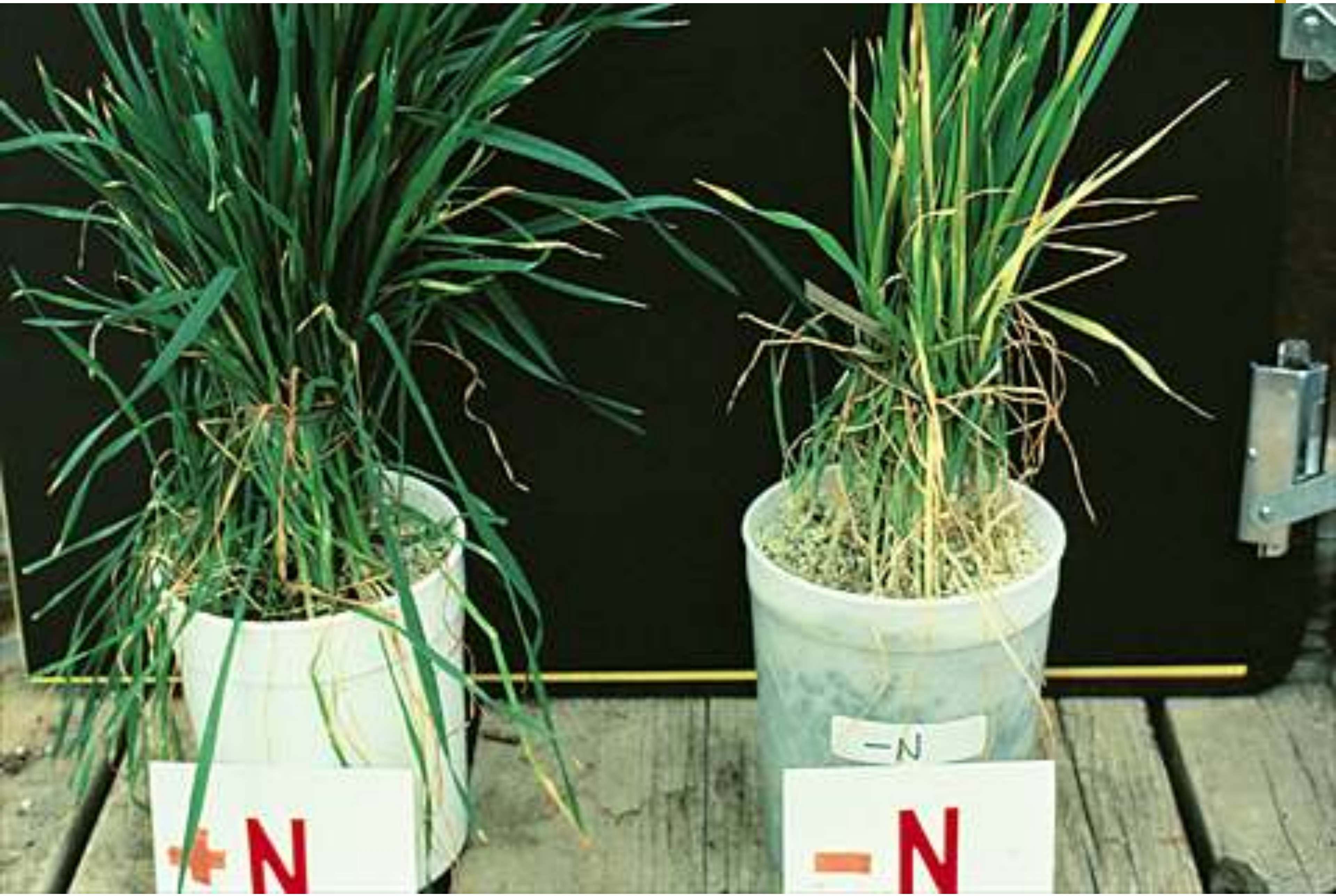
Element	Main Function	Primary Source	Approx. Concentration in Plants
Carbon (C)	Part of all organic compounds	Carbon dioxide in air	45%
Hydrogen (H)	Forms main structural components	Water	6%
Oxygen (O)	Forms main structural components	Water, air	43%

Macronutrients – Primary

Element	Main Function	Primary Source	Approx. Conc. in Plants
Nitrogen (N)	Component of proteins, chlorophyll, nucleic acids	Soil OM; fixation of atmospheric N (legumes)	1-6%
Phosphorus (P)	Energy transfer; metabolism, nucleic acids, nucleoproteins	Soil organic matter soil minerals	0.05-1%
Potassium (K)	Protein synthesis; translocation of carbohydrates; enzyme activation	Soil minerals	0.3-6%

Nitrogen

- NO_3^- and NH_4^+ taken up by roots
- NO_3^- mobile in the soil
  - Leaches readily
- NH_4^+ held to soil cation exchange
- Most N is in organic forms
  - Undergoes many transformations


+N
-N
-N

Phosphorus

- Is taken up by roots as $H_2PO_4^-$ or HPO_4^{2-}

- Generally not mobile in soil
  - Except under conditions of high soil test levels
- Plants get P by root interception

- Most available at $5.5 < pH < 7.2$
- Cycles between organic and inorganic forms

Potassium

- Moderately mobile in the soil
- Plants obtain K mainly by diffusion
- Is held on the cation exchange
  - Greater CEC results in greater availability

- Natively K comes from soil minerals
  - Slow process of mineral weathering
  - Added K can be fixed in these minerals


POTASSIUM DEFICIENCY
CHLOROSIS
&
MARGINAL
NECROSIS

Macronutrients – Secondary

Element	Main Function	Primary Source	Approx. Conc. in Plants
Calcium (Ca)	Structural component of cell walls; cell elongation; affects cell permeability	Soil minerals, limestone	0.1-3%
Magnesium (Mg)	Component of chlorophyll; enzyme activator; cell division	Soil minerals, dolomitic limestone	0.05-1%
Sulfur (S)	Constituent of proteins; involved in respiration and nodule formation	Soil organic matter, rainwater	0.05-1.5%

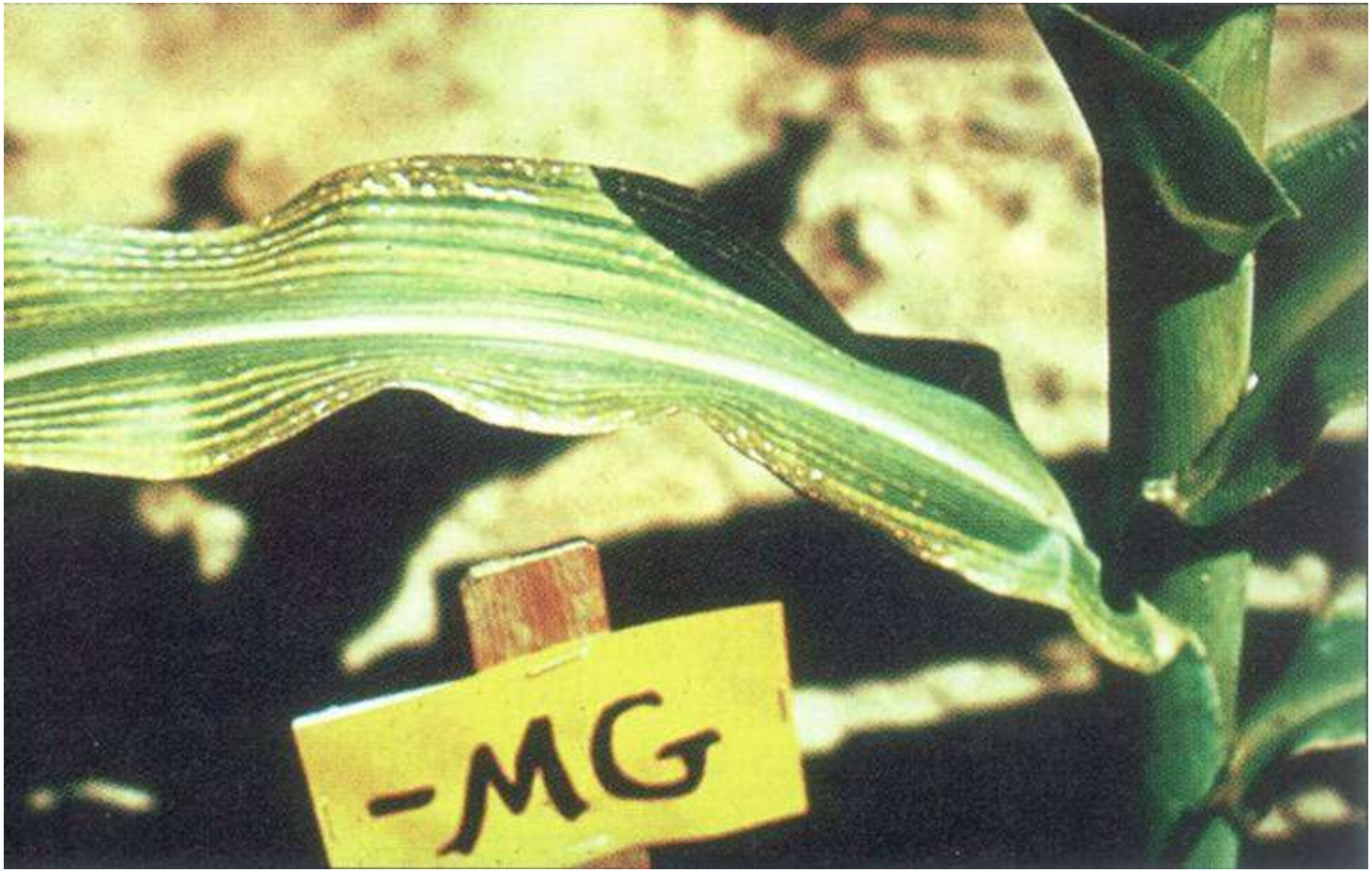
Calcium

- Is mobile in the soil
  - Moves to root by mass flow
  - Can be leached – particularly sandy soils
  - Deficiency sometimes seen in dry soils when there isn't enough water to transport Ca

- Is held on the cation exchange
- Low pH soils likely to be low in Ca

Magnesium

- Moves to root via mass flow & diffusion
  - Leaches somewhat more than Ca
- Held on the cation exchange
- Deficiency occurs in low pH soils

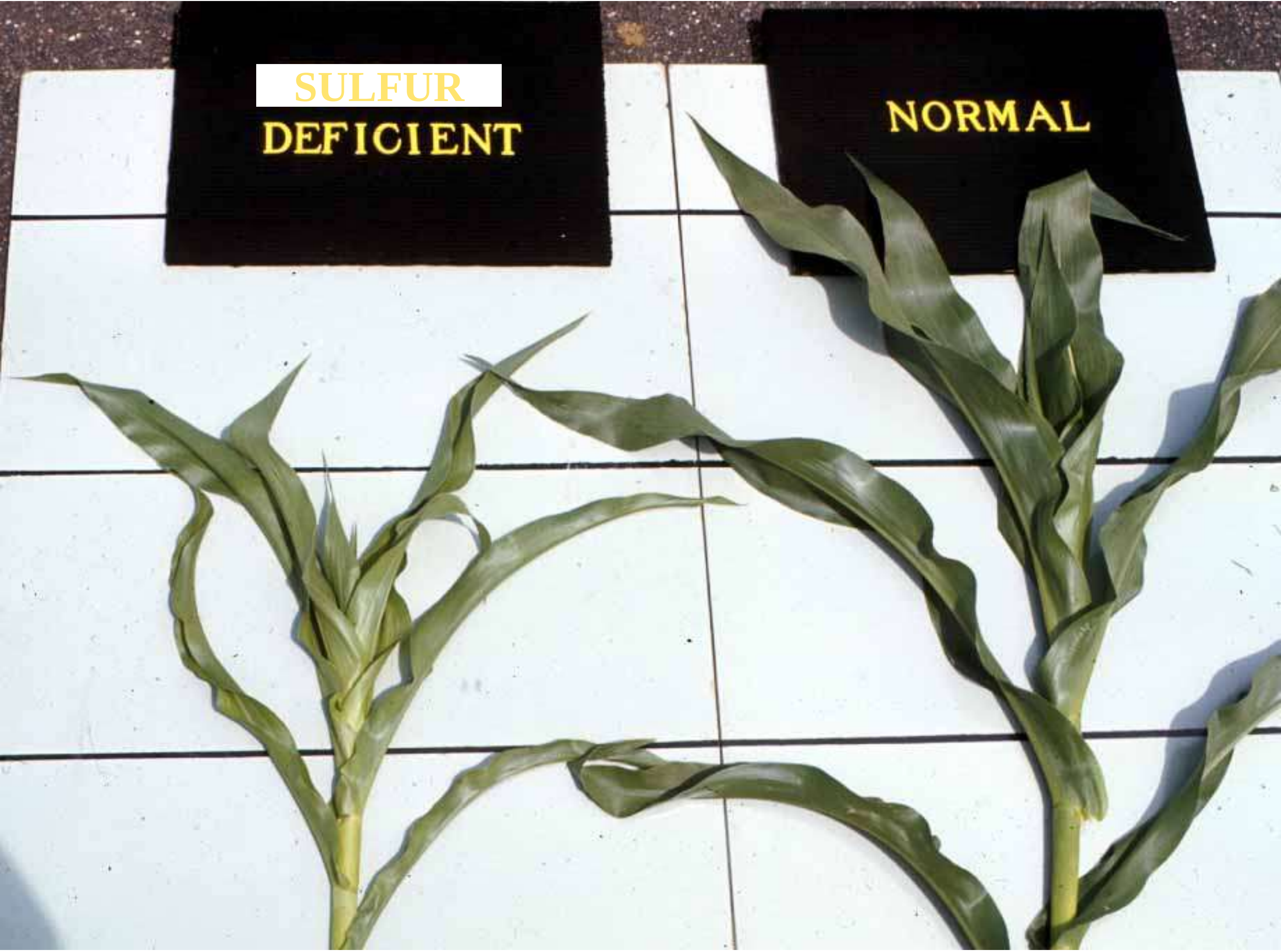

-MG

Sulfur

- Is mobile in soil; SO_4^{2-}
- Mass flow and diffusion supply roots

- Availability dependant on amount of OM
  - Undergoes transformations similar to N

- More deficiencies are occurring because
  - Less atmospheric deposition
  - N-P-K fertilizer are purer contain less S


SULFUR
DEFICIENT
NORMAL

Micronutrients

Element	Main Function	Primary Source	Approx. Conc. in Plants
Iron (Fe)	Chlorophyll synthesis; oxidation-reduction reactions; enzyme activator	Soil minerals	10-1000 ppm
Manganese (Mn)	Oxidation-reduction reactions; nitrate reduction; enzyme activator	Soil minerals	5-500 ppm
Copper (Cu)	Enzyme activator; nitrate reduction; respiration	Soil minerals; soil organic matter	2-50 ppm
Zinc (Z)	Enzyme activator; regulates pH of cell sap	Soil minerals; soil organic matter	5-100 ppm
Boron (B)	Cell maturation and differentiation; translocation of carbohydrates	Soil organic matter; tourmaline	2-75 ppm

Iron

- Deficiency not observed on field or vegetable crops in WI

- Turfgrass, pin oak, some ornamentals
  - Deficiency on soils with pH > 7.5

Manganese

- Immobile in the soil
- Exists in mineral & organic forms
  - Held by clays and OM

- Availability influenced by:
  - pH: most available $5.0 < pH < 6.5$
  - OM: high OM decreases availability
  - Acidifying fertilizers increase Mn^{2+} uptake


Copper

- Ususally only seen on very acid soils
  - Particularly mucks
- Not easily leached
- Not easily fixed in unavailable forms
- Thus, repeated application not necessary
- Toxicities reported at high levels of use

Zinc

- Immobile in the soil
- Is held on clay, OM, & carbonates
- pH induced deficiencies $6 < pH < 8$

- Deficiency more likely on:
  - Severely eroded soils
  - Sands/loamy sands
  - Muck soils

Boron

- Highly mobile in soil
  - Can leach; sandy soils with low OM

- Bound to clay and OM
- Availability decreases at pH > 6.5

- Boron can injure sensitive crops
  - Dry bean, soybean, corn, & small grains


BORON DEF

Micronutrients

Element	Main Function	Primary Source	Approx. Conc. in Plants
Molybdenum (Mo)	Nitrate reduction; fixation of atmospheric nitrogen by legumes	Soil organic matter; soil minerals	0.01-10 ppm
Chlorine (Cl)	Photochemical reactions in photosynthesis	Rainwater	0.05-3%
Nickel (Ni)	Enzyme activation (urease), N metabolism	Soil Minerals	0.01-10 ppm

Molybdenum

- Only micronutrient where availability increases as soil pH increases

- Liming soils to optimal pH levels usually eliminates deficiencies

Chlorine

- Deficiency never observed in WI
- Crop only needs small amount
- Often applied in fertilizer salts (KCl), manure, rainwater

Nickel

- Most recent nutrient considered to be essential (1987)
- Needed in very small amount
- Deficiency not observed in WI

Beneficial/Enhancing Nutrients

Element	Main Function	Primary Source	Approx. Conc. in Plants
Sodium (Na)	K substitution, flavor enhancer, ionic balance	Soil minerals	0.3-3%
Silicon (Si)	Strengthen cell walls, reduces micronutrient toxicity	Soil minerals	0.5-15%
Cobalt (Co)	N2 fixation, enzyme activity	Soil minerals	0.3-4 ppm
Selenium (Se)	Sulfur substitution "white muscle disease" reproductive disorder	Soil minerals	1-1000 ppm
Aluminum (Al)	Stimulate root growth	Soil minerals	20-2000 ppm

Plant Analysis

Plant Analysis Uses

- Identify deficiency symptoms
  - Determine nutrient shortages before they appear as symptoms
- Aid in determining nutrient supplying capacity of the soil
  - Need soil test and field history
- Aid in determining effect of nutrient addition on the nutrient supply in the plant
- Study the relationship between nutrient status of plant and crop performance

Types of Plant Analysis

- Cell sap tests
  - Usually in-field, quick tests, semiquantitative

- Total analysis
  - Lab tests on whole plant or specific part
    - Sampled part may be dependent on growth stage
  - Provides an indicator of plant nutritional status
  - Assumes nutritional status is related to soil nutrient availability

Tissue Sampling

- What to sample
- When to sample
- Sample handling
  - Refrigerated (kept cold)
  - Removal of contaminants (soil, dust, fertilizer)
- Interpretation

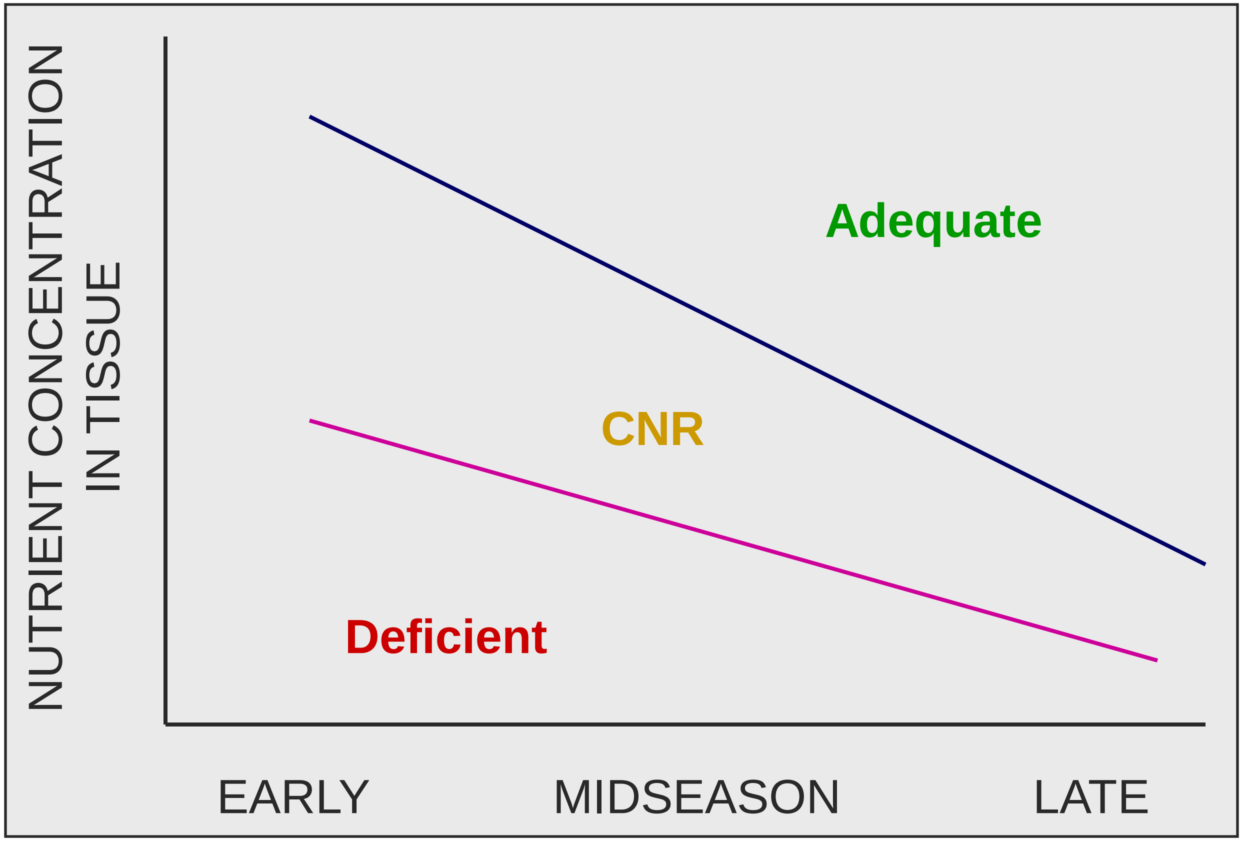
What & When to Sample

Table 12-13. Proper plant sampling for diagnostic plant analysis

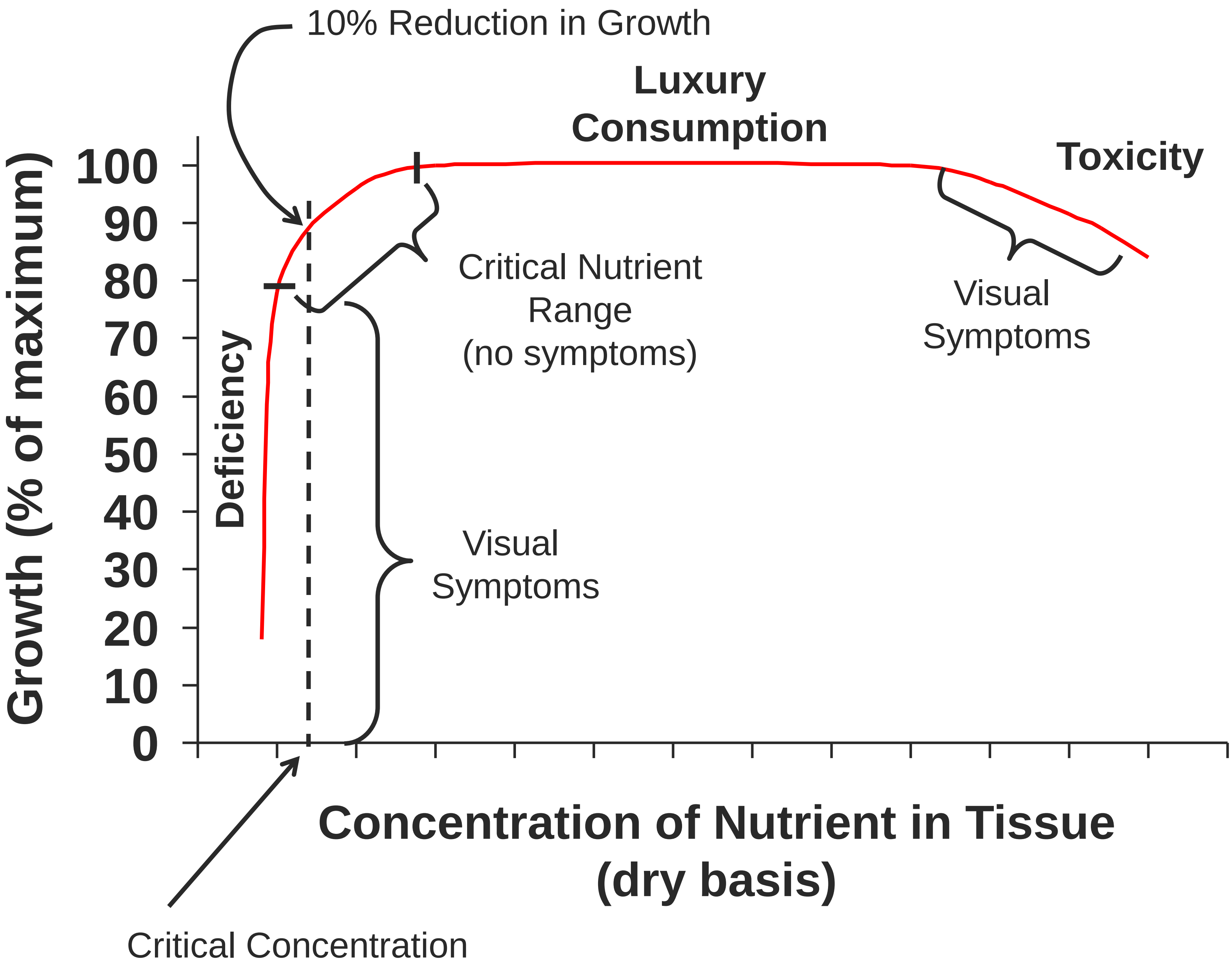
Crop	Stage of growth	Plant part	Number of plants to sample
Alfalfa, birdsfoot trefoil, clover	Prior to flowering	Top 6 inches	35
Asparagus, onion	Boot	Top 6 inches	20
Bean, pea	Prior to or at initial flowering	Newest fully developed leaf	25
Beets, broccoli, brussels sprouts, cabbage, carrot, cauliflower, celery, lettuce, radish, spinach, tobacco	Midseason	Upper mature leaves	20
Corn	a) Seedling to 20 inches high b) 20 inches high to flag leaf c) Tasseling to silking	Whole plant above ground Newest fully developed leaf Earleaf or opposite & below	20 15 15
Cucumber, melon, pumpkin, squash	Prior to or at initial flowering	Newest fully developed leaf	25
Forage (grasses, grains)	Prior to heading	Newest fully developed leaf	50
Mint	Boot	Whole plant	20
Pepper, potato, tomato	Prior to or at initial flowering	Newest petiole and leaflet	40
Sorghum (grain, sudan)	Prior to heading	Second fully developed leaf	20
Apple, cherry, pear, plum	Current season's shoots taken July 1–15	Fully developed leaf at midpoint of new shoots	4 leaves from each of 10 trees
Grape	Bearing primary shoots	Petioles from newest leaves	5 petioles from each of 10 vines
Strawberry	Current season's shoots	New petioles and leaves	5 parts from each of 10 plants

Table 12-13 in Management of WI Soils (A3588)

Relationship between nutrient concentration in leaves over the growing season



Redrawn from Havlin et al., 2005



Redrawn from Havlin et al., 1999

Tissue Test Interpretation

- Critical nutrient concentration ranges (sufficiency ranges)
  - Using Plant Analysis as a Diagnostic Tool

    see New Horizons in Soil Science 2000

    http://www.soils.wisc.edu/extension/publications/horizons/index.htm
- DRIS (Diagnostic & Recommendation Integrated System)
- PASS (Plant Analysis with Standardized Scores)

Correction of deficiencies identified with tissues tests may not be feasible because:

- Deficiency may have already caused yield loss
- Crop may not respond at the growth stage tested
- Crop may be too large for nutrient application
- Weather may be unfavorable for fertilization and/or for crop to benefit

From Havlin et al., 2005

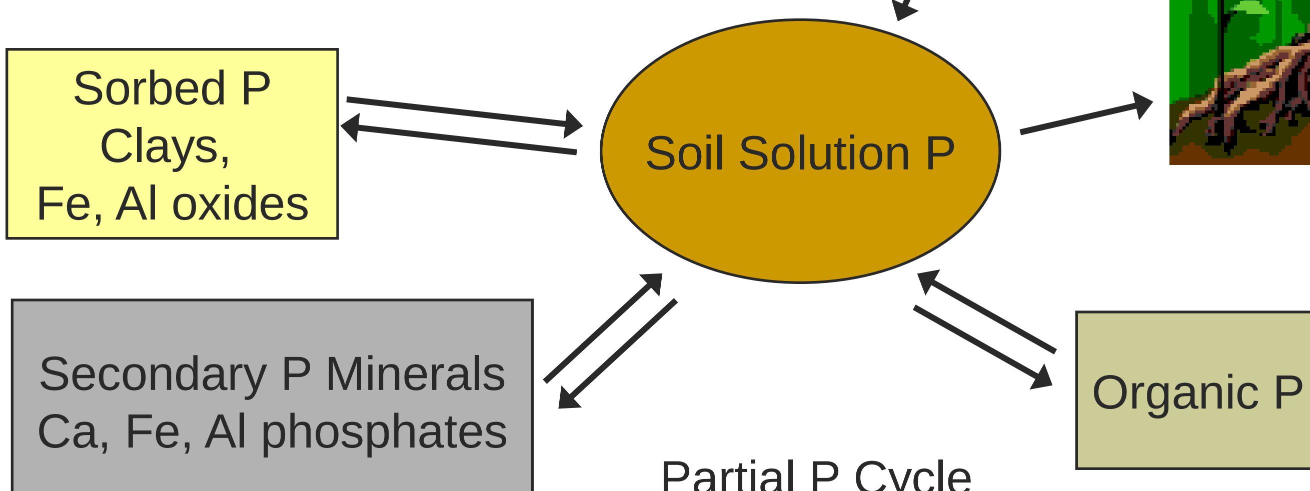
Using plant analysis to help diagnose a field problem

- **<u>Not a clear cut tool</u>**
- Need to collect all the evidence:
  - Nutrient deficiency symptoms
  - Root growth patterns
  - Weather
  - Current field conditions
  - Field history
  - Tissue analysis
  - Soil analysis

Soil Testing & Nutrient Recommendations

Objectives of Soil Tests

1. Provide an index of nutrient availability (or supply) in a given soil
   - A soil test measures a portion of a nutrient from a "pool" that is used by plants
   - Calibration



Partial P Cycle

Objectives of Soil Tests

2. Predict the probability of obtaining a profitable response to lime and fertilizer
   - On low testing soils, a response to applied nutrients may not always be obtained because of other limiting factors (moisture, pH, other nutrients)
   - *BUT* the probability of a response to nutrient additions on low testing soils is greater than high testing soils
   - Correlation

Objectives of Soil Tests

3. Provide a basis for recommendations on the amount of lime and fertilizer to apply
   - Relationships obtained through laboratory, greenhouse, and field studies

Overriding Goal of Soil Testing

- To obtain a value that will help to predict the amount of nutrients (fertilizer) needed to supplement the nutrient supplying capacity of the soil such that maximum <u>economic</u> yield is achieved
  - Now, and more so in the future, we will need to balance environmental degradation with economics

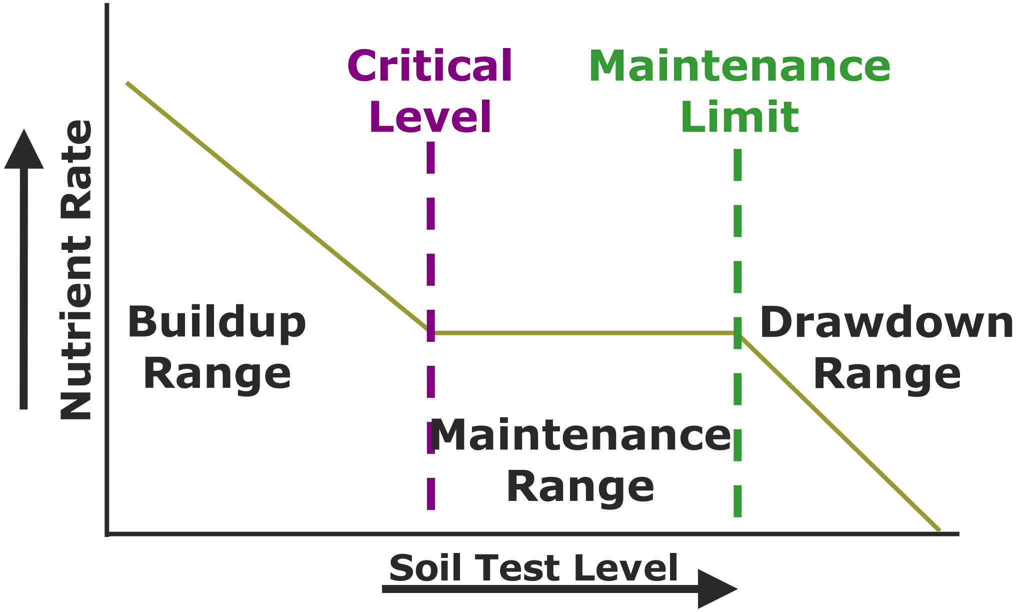
Nutrient Recommendation Philosophies

- Build and Maintain
- Sufficiency Level
- Cation Ratio/Balance

- For immobile nutrients
  - Primarily P & K, not N

Build and Maintain

- Goal: Apply nutrients such that soil tests are built up to a certain level and then maintained within a range



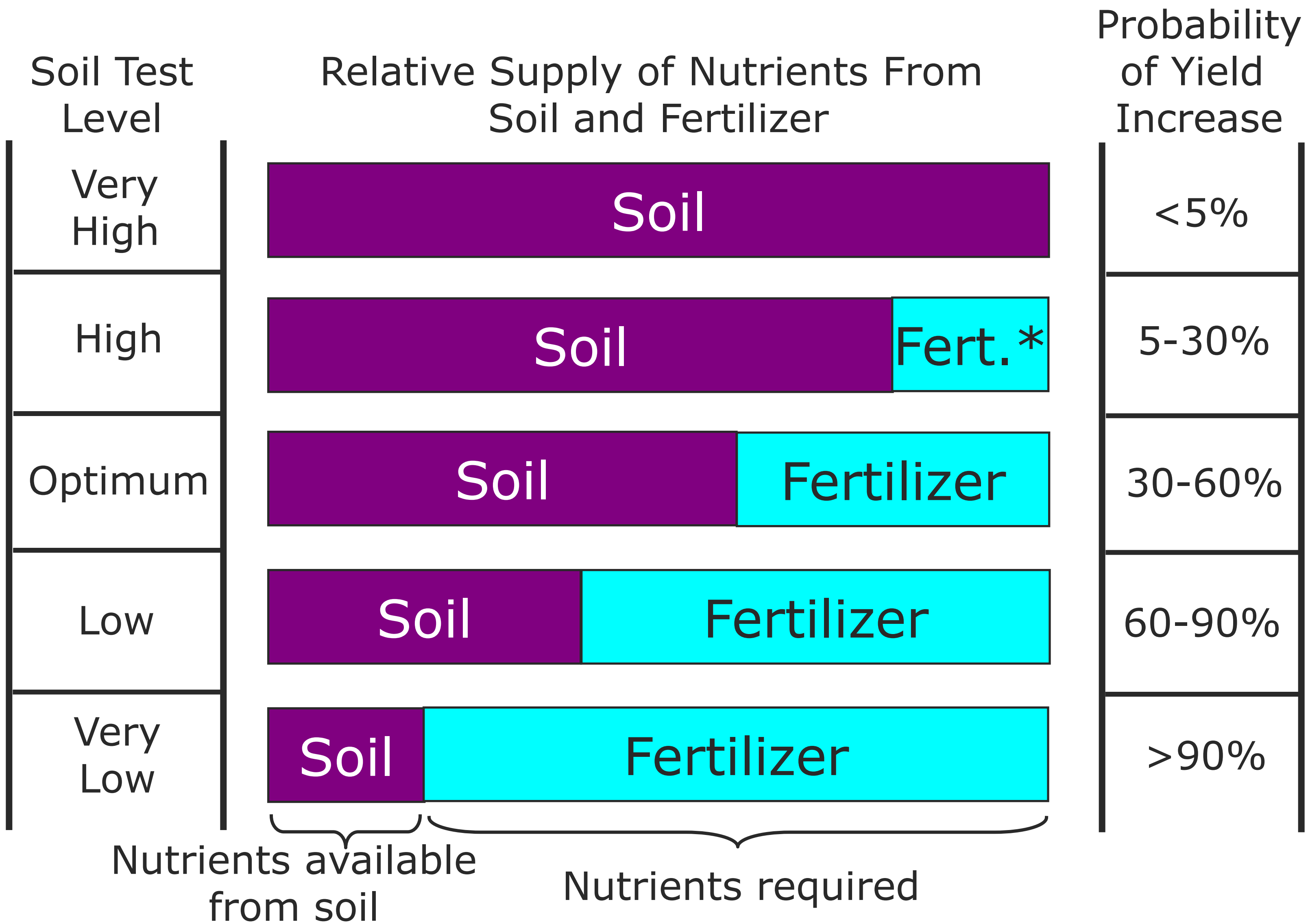
- Feed the soil theory
- Provides a margin of safety to compensate for differential crop response

Sufficiency Level

- Soil test levels established & identified by likelihood of a crop response
  - Low soil test = crop response assured
  - Medium soil test = crop response possible
  - High soil test = crop response marginal
  - Very high soil test = crop response unlikely

- Nutrient recommended only for low through high soil tests
- Fertilize the crop theory

Soil Test Interpretation Categories



Adapted from Havlin et al.,1999 using WI interpretations

* Fertilizers used at high soil test levels are for starter or maintenance purposes

Relationship Between Soil Test and Fertilizer Recommendations in WI

Soil Test Category	Recommendations
Very Low, Low	Crop removal +
Optimum	Crop removal
High, Very High	½ or ¼ Crop removal
Excessively High	None

Basic Cation Saturation Ratios (BCSR)

- Concept that there is an ideal ratio or range of ratios that maximizes crop production
  - Eg. 65-85% Ca, 6-12% Mg, 2-5% K
- Research in WI does not support this theory
- Relying on cation ratios has several drawbacks:
  - OK ratio, but nutrient supply not sufficient
  - Not OK ratio, but nutrient supply sufficient
  - No economic analysis goes into recommendations that use the cation ratio approach

Quotes from BCSR Researchers

- "Basic cation ratios <u>per se</u> seem unimportant to the well-being of the crop. Indeed, it appears that instead we should concentrate on sufficiency levels of each basic cation."

  E.O. McLean, 1982

- "Emphasis should be placed on providing sufficient, but non-excessive levels of each basic cation rather than attempting to adjust to a favorable BCSR which evidently does not exist."

  McLean et al., 1983

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