Mechanisms of Nutrient Uptake: Is Fertilization Enough?

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Nutrient Management Conference
09 Feb. 2016, Morton, MN

University of Minnesota
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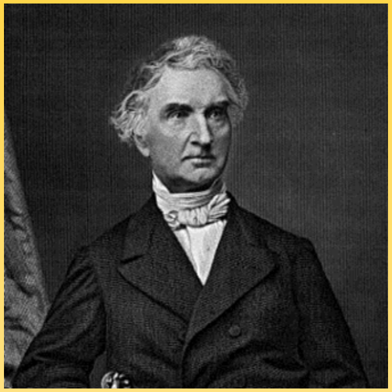
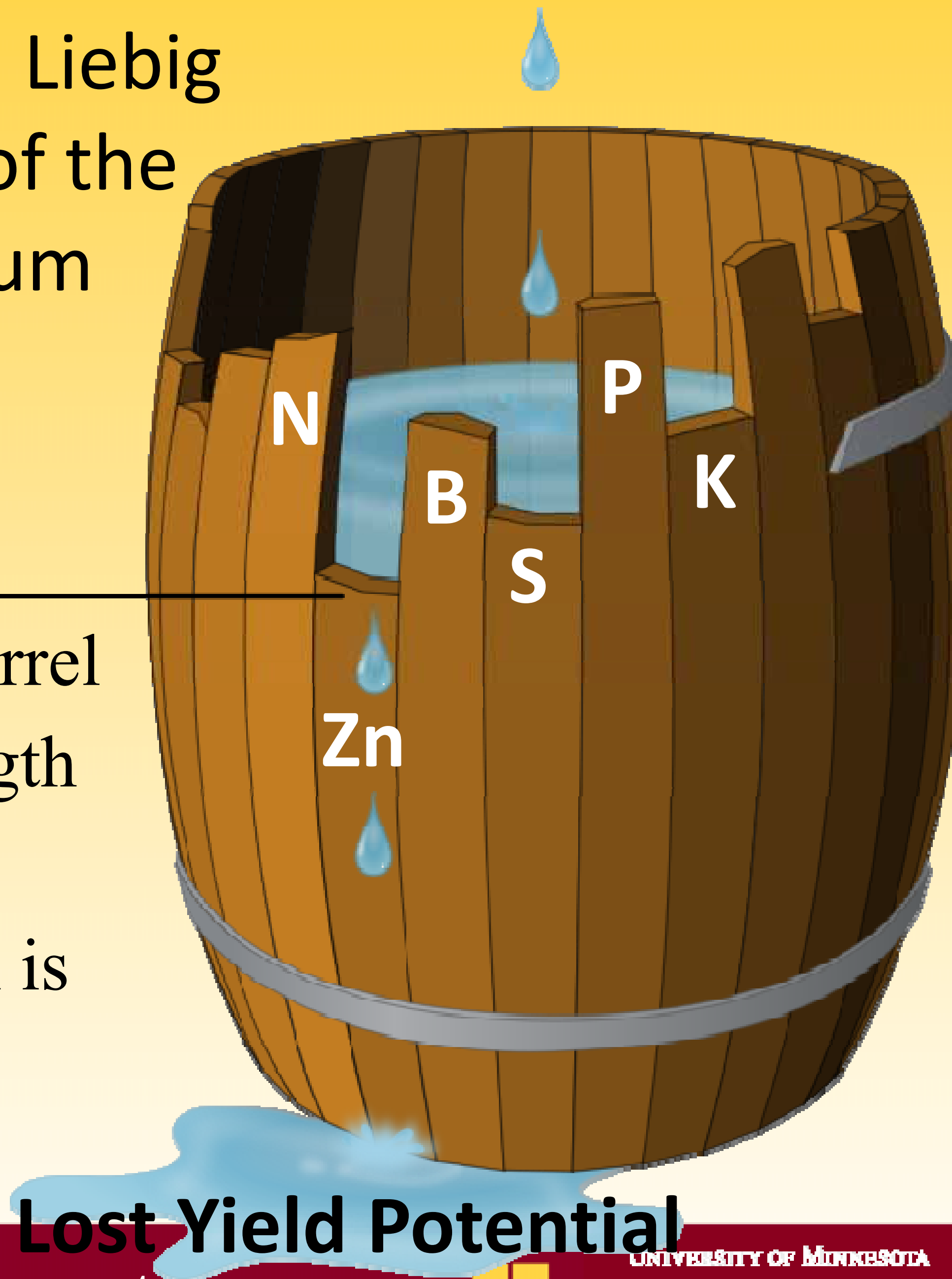


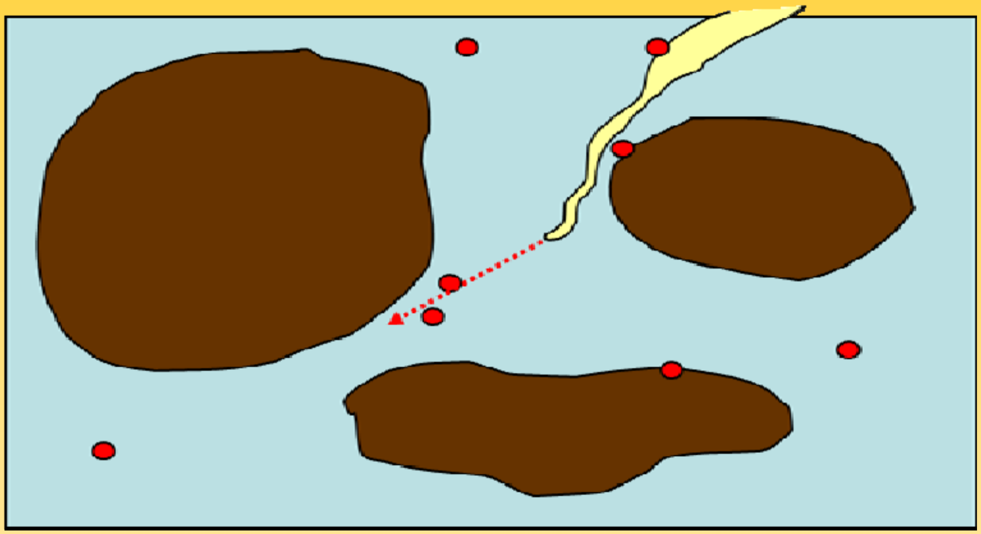
Justice von Liebig The Law of the Minimum



Minimum

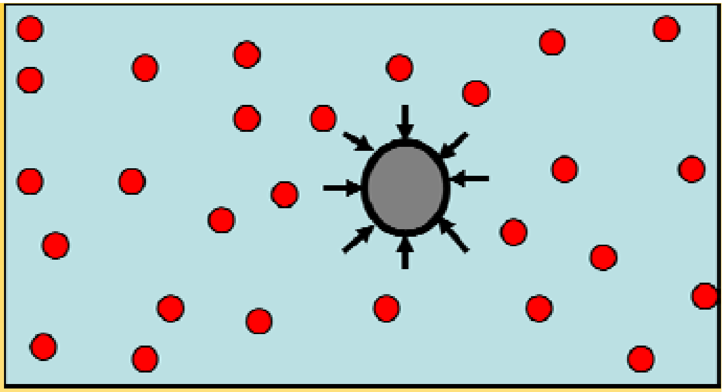
Just as the capacity of a barrel with staves of unequal length is limited by the shortest stave, so a plant's potential is limited by the nutrient in shortest supply

- **Root interception**

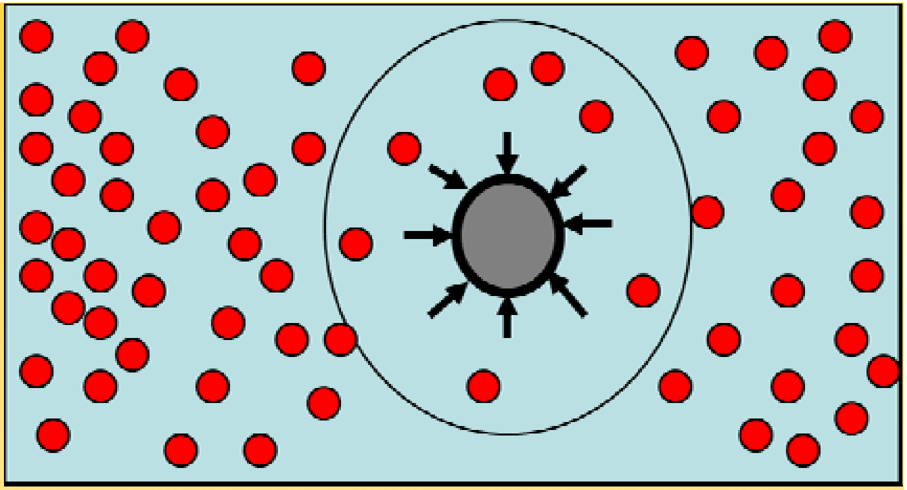


  - **Ions encountered by the root as it grows through the soil**
  - **Roots occupy about 1% of the topsoil volume and less in the subsurface**
  - **Affected by:**
    - Root growth
    - Soil compaction

- **Mass flow**



  - **Ions transported to the root in the convective flow of soil water (transpiration of water that was originally absorbed by the roots through the leaves via the stomata)**
  - **Affected by:**
    - Rate of release to solution: **buffer capacity**, amount and proportion to other ions and solution parameters
    - Plant water use
    - Gravitational water after rain moves nutrients down
    - Capillary action moves water up through soil pores



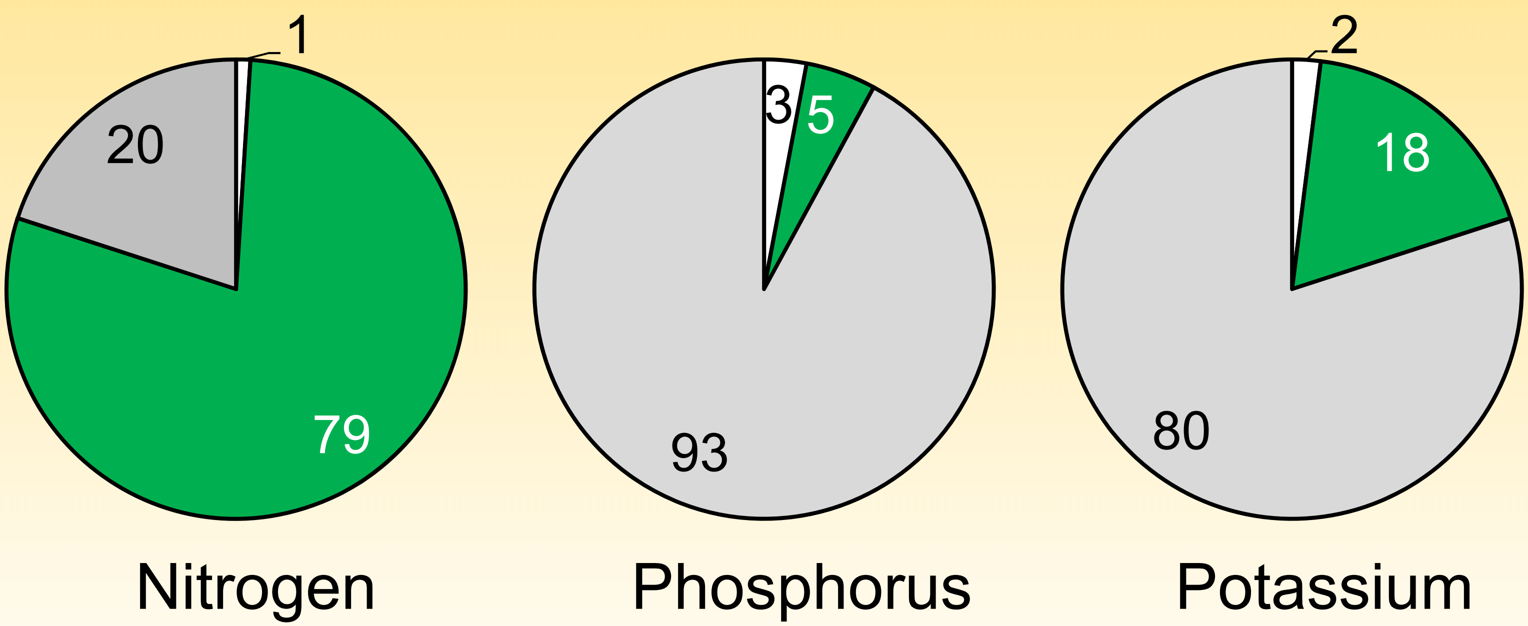
- **Diffusion**
  - **Ion movement along a concentration gradient from points of high concentration to points of low concentration**
  - **Affected by:**
    - Water content
    - Tortuosity (**Effective diffusion coefficient**)
    - Temperature
    - **Nutrient concentration in solution**

Root interception
(root grows into a nutrient location)

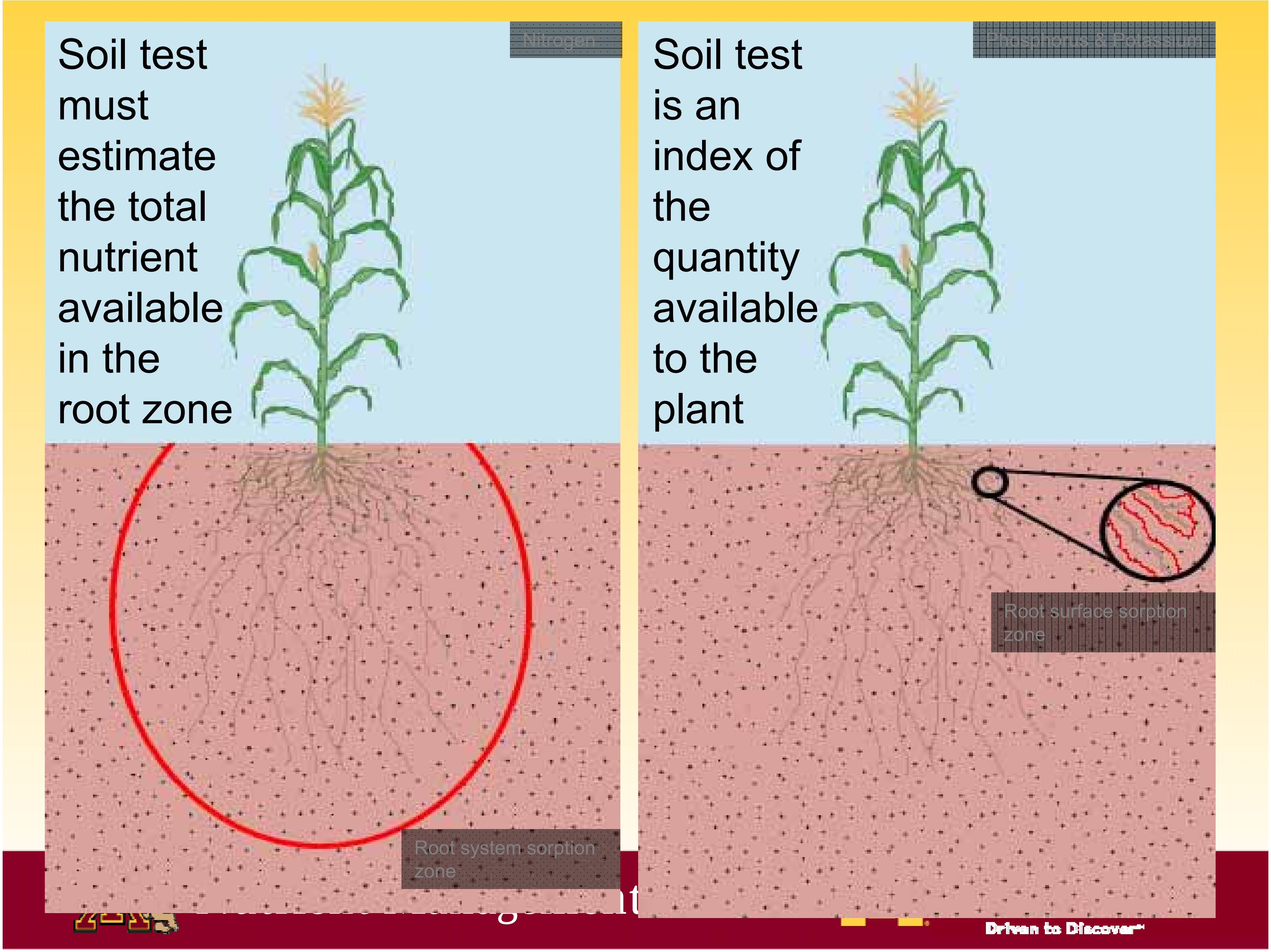
Mass flow
(nutrient moves with the water absorbed by a plant)

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.


Nitrogen
Soil test must estimate the total nutrient available in the root zone
Root system sorption zone
Phosphorus & Potassium
Soil test is an index of the quantity available to the plant
Root surface sorption zone
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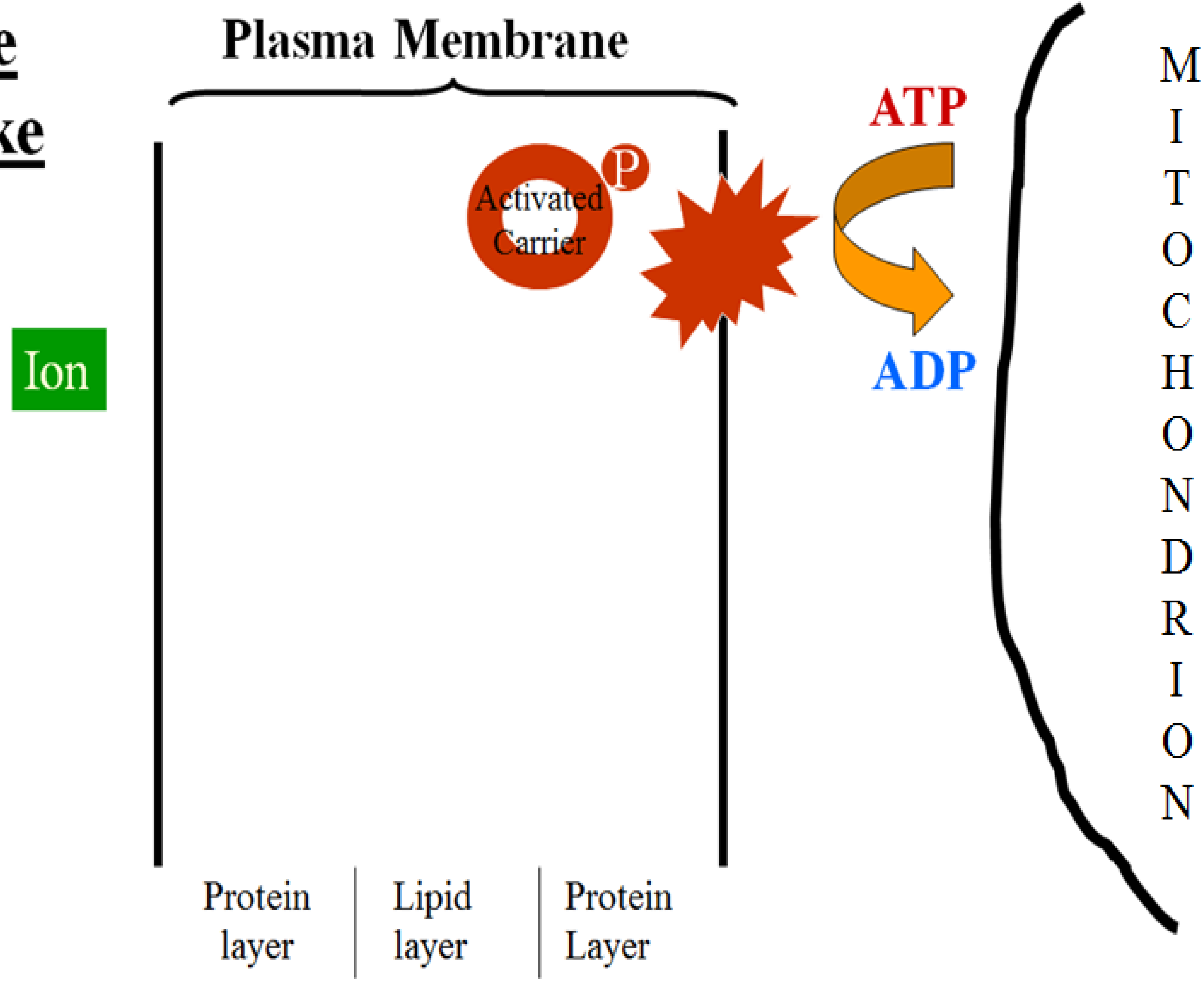
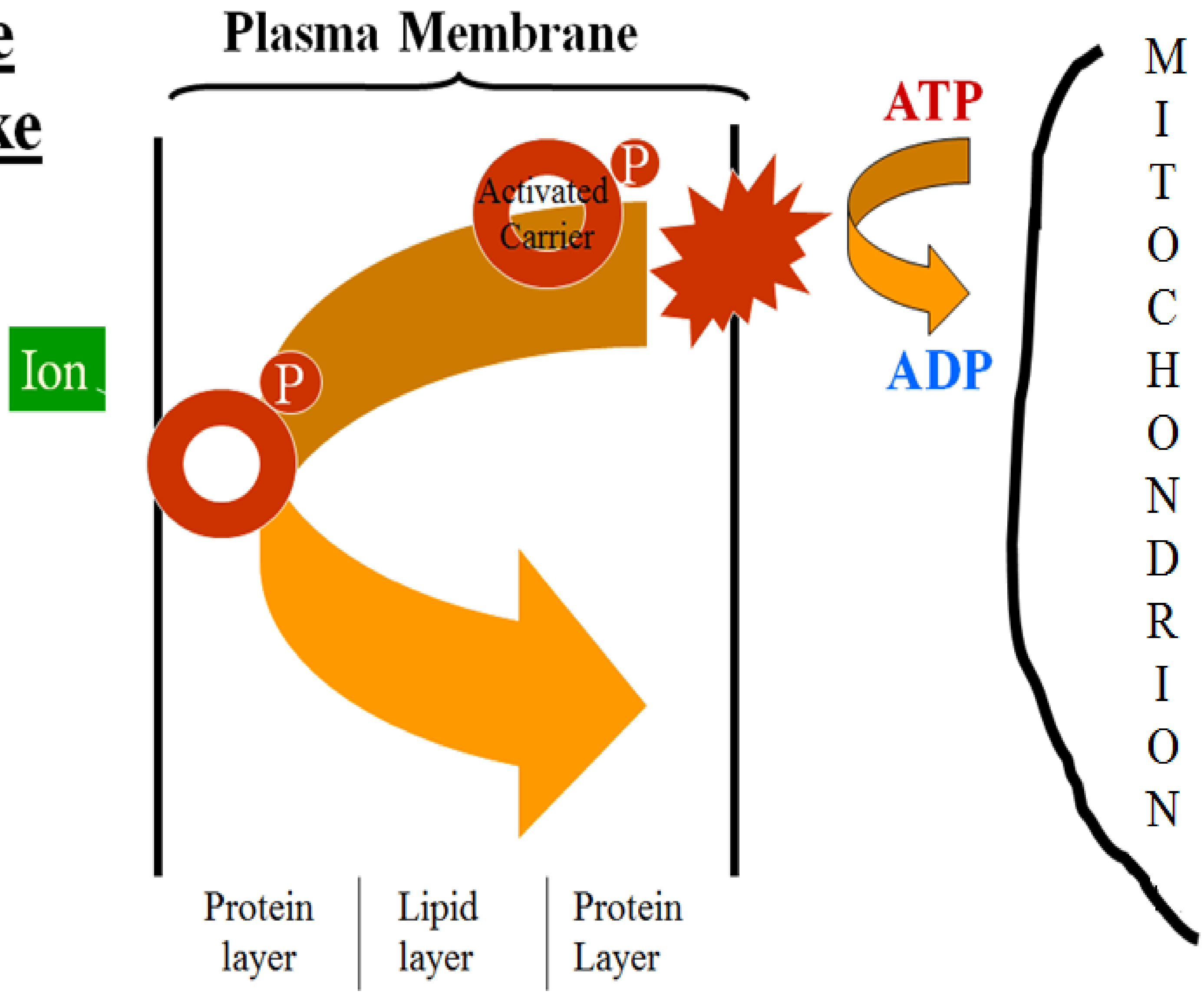
Nutrient uptake by the root

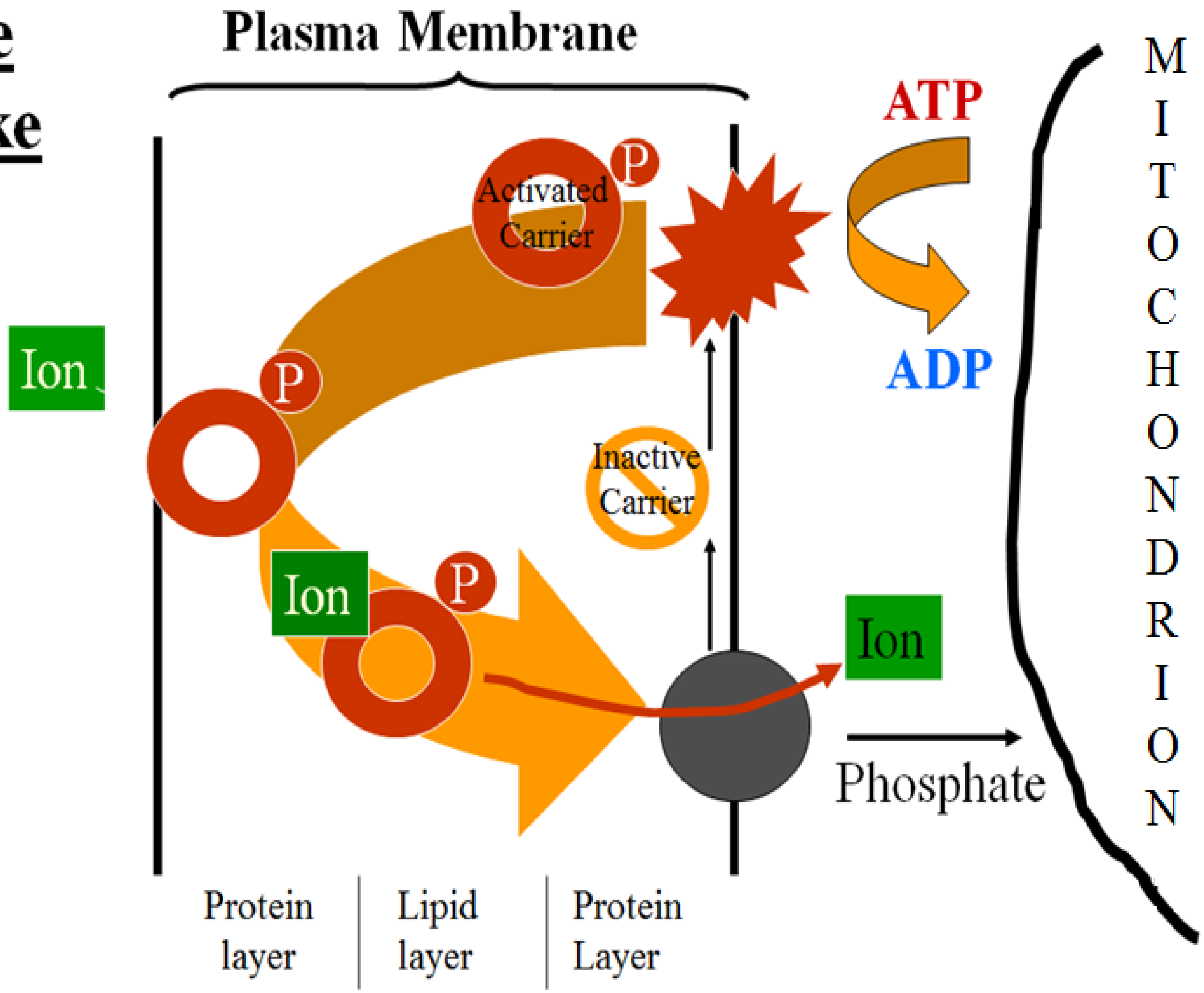
Active Uptake



Active Uptake



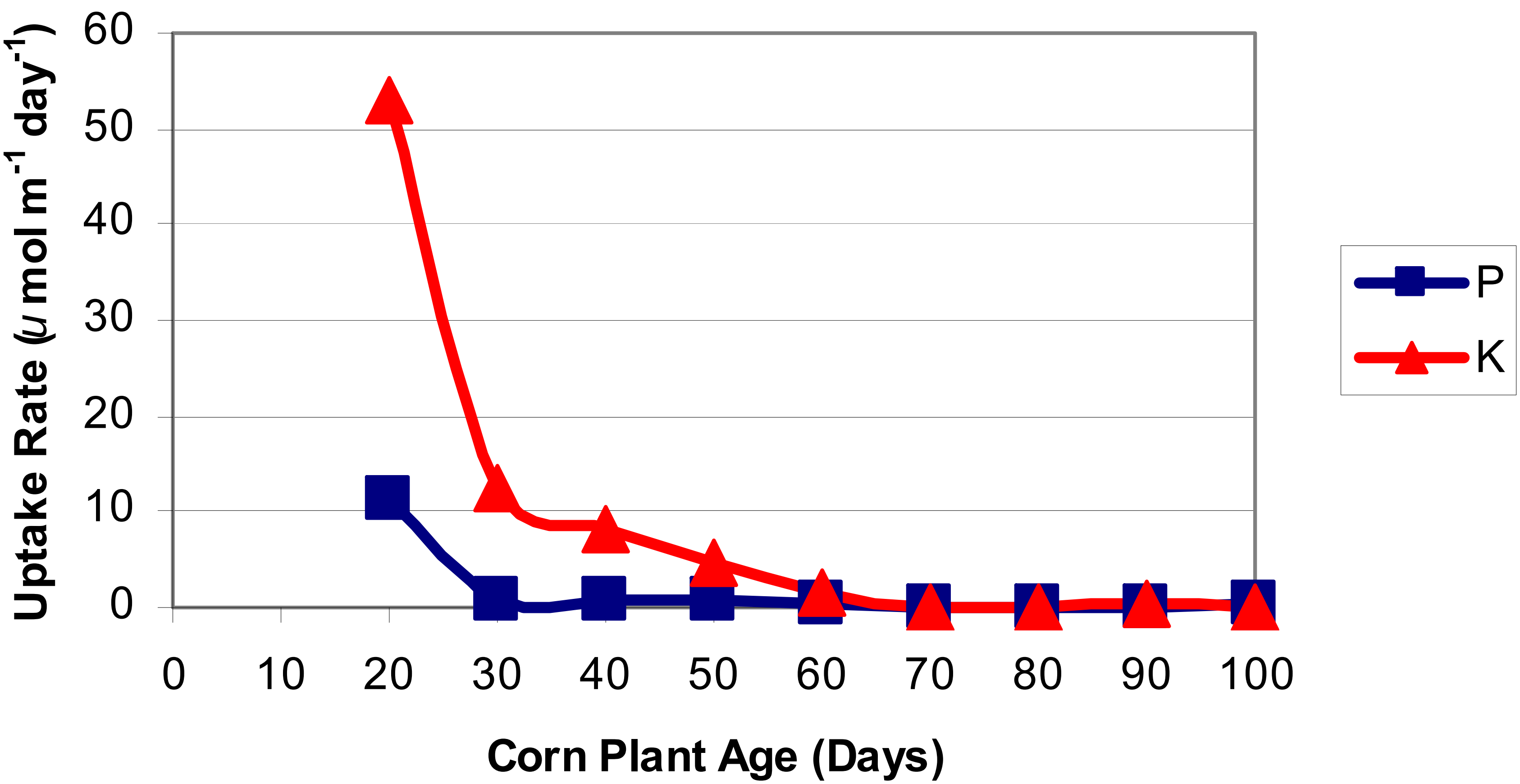
Active Uptake



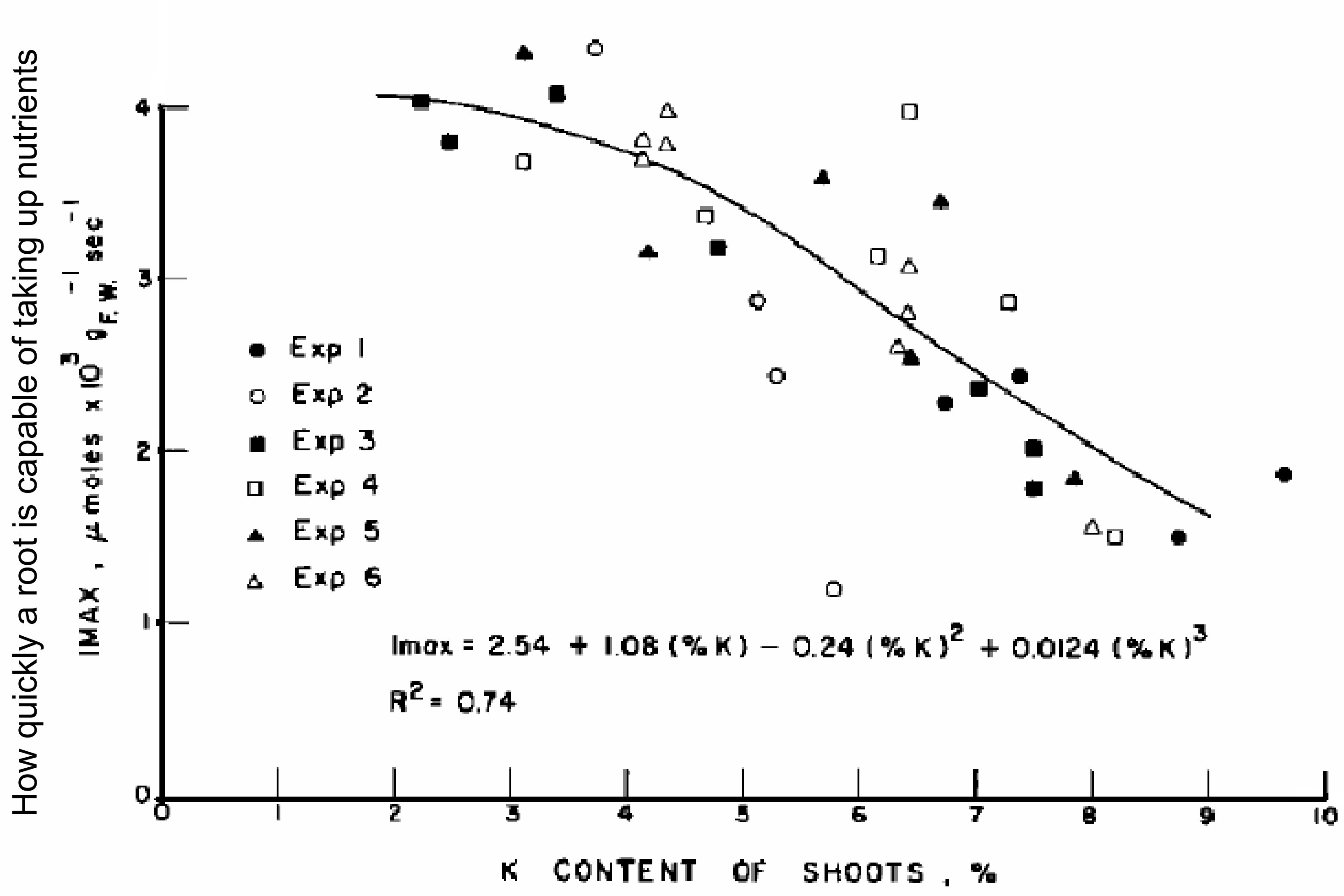
Plant factors

- Plant age
- Nutrient status of the plant
- Temperature
- Transpiration rate
- **Root morphology (length, volume, radius, physical distribution in the soil) and growth rate**

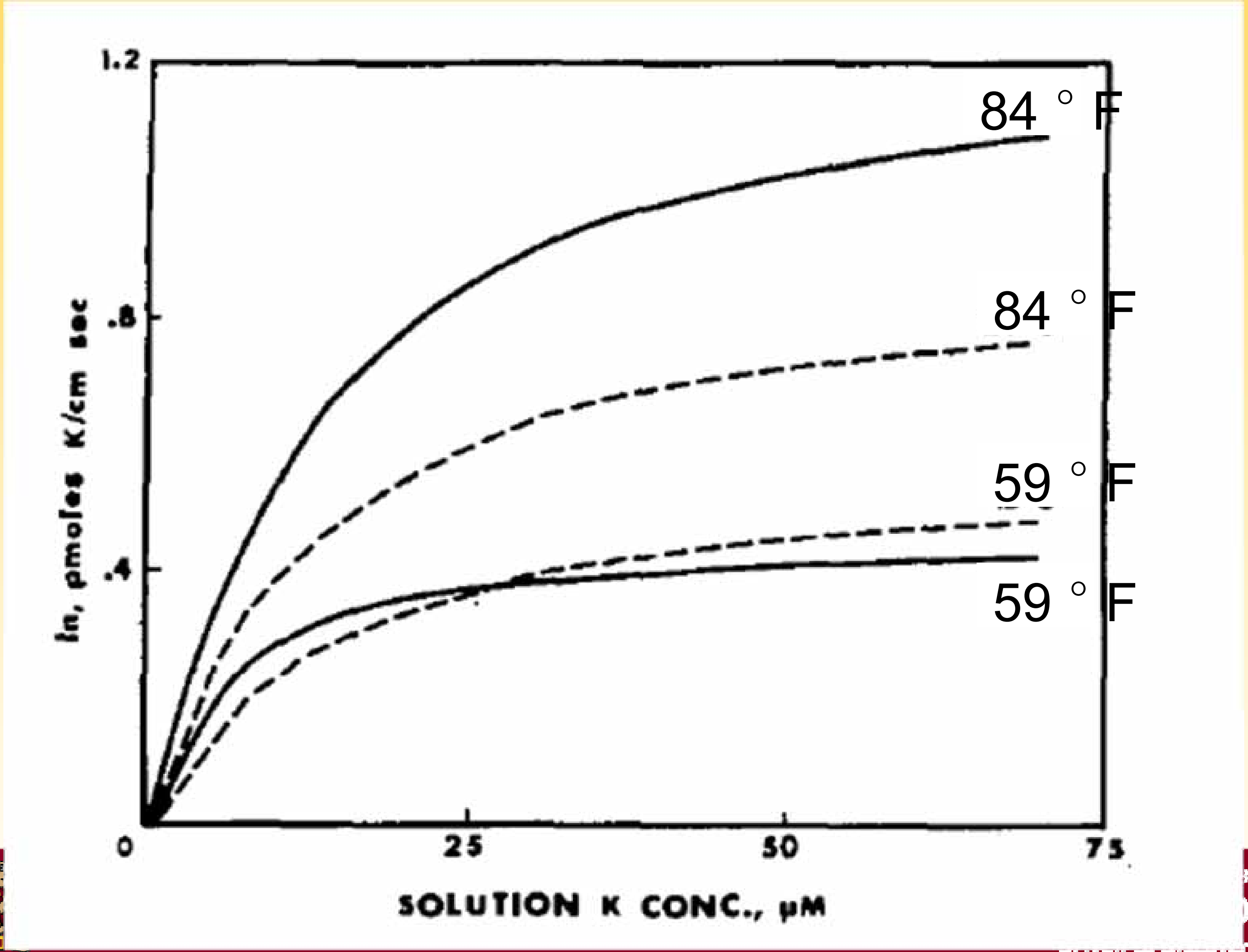
Uptake rate & age



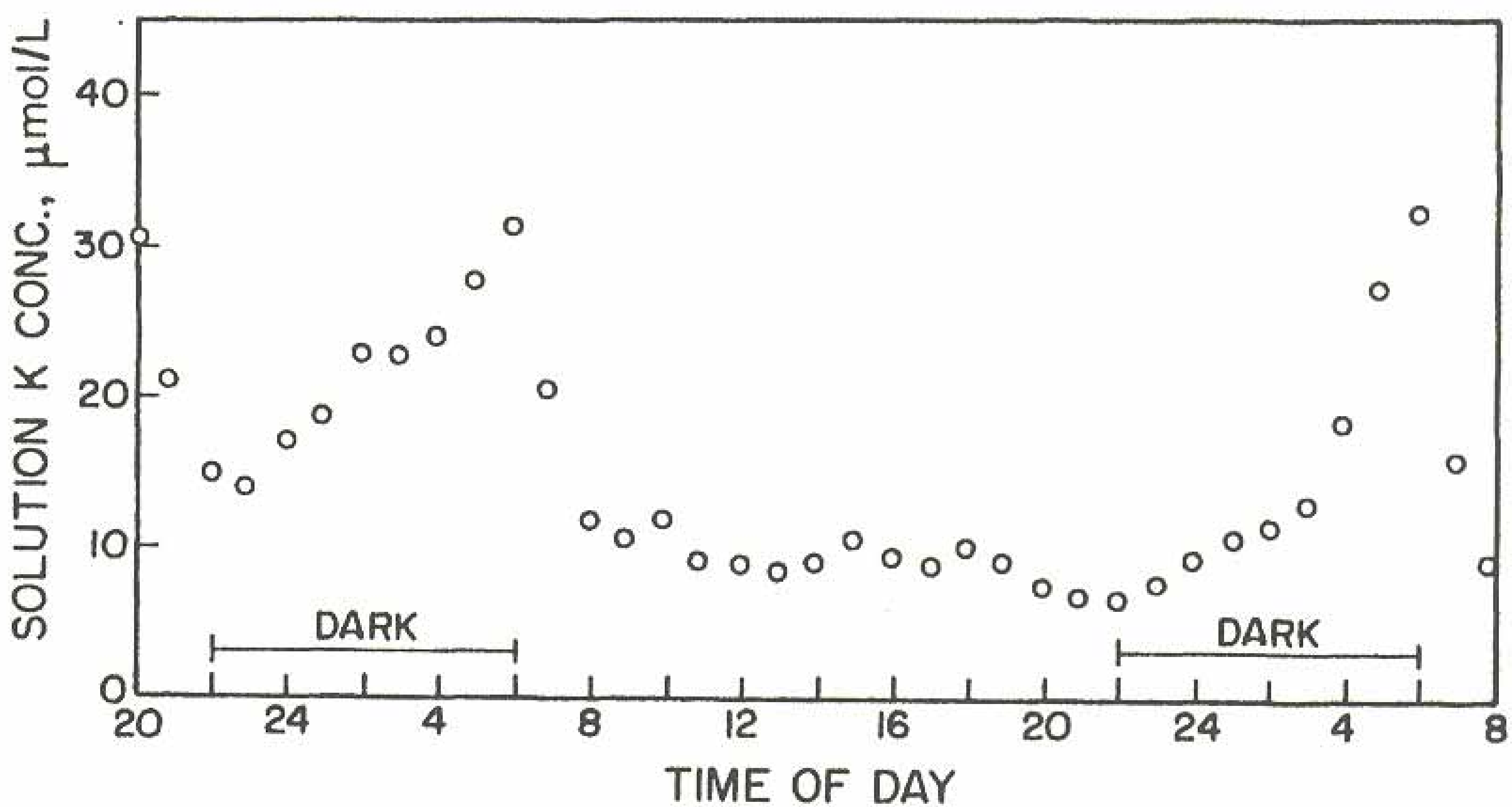
Nutrient status of plant & uptake



Root temperature & uptake



Transpiration & uptake

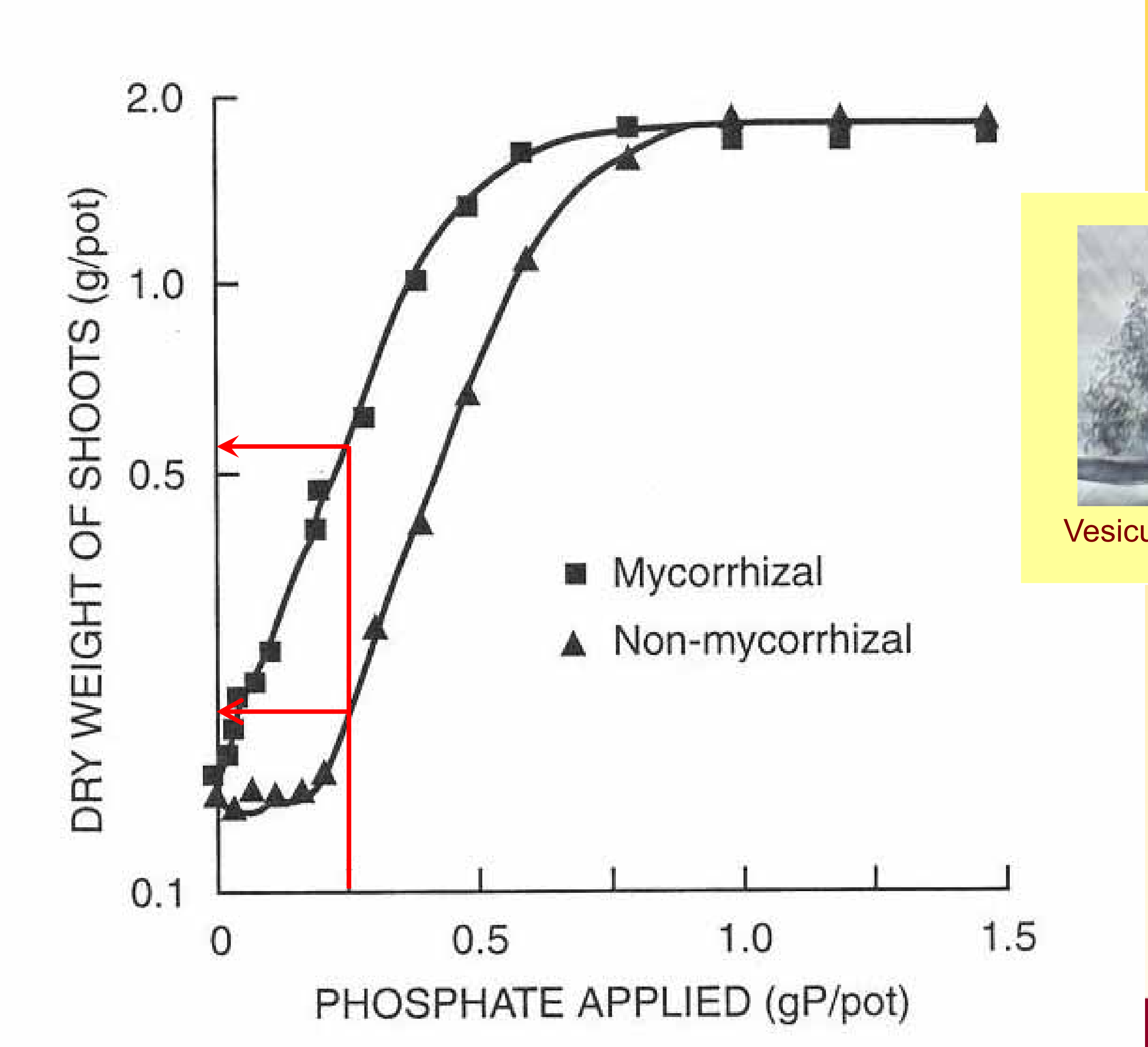


Comparative root exploration of top 6 inches of soil

Soybean
13 in / in^3

Wheat
21 in / in^3

Corn
27 in / in^3

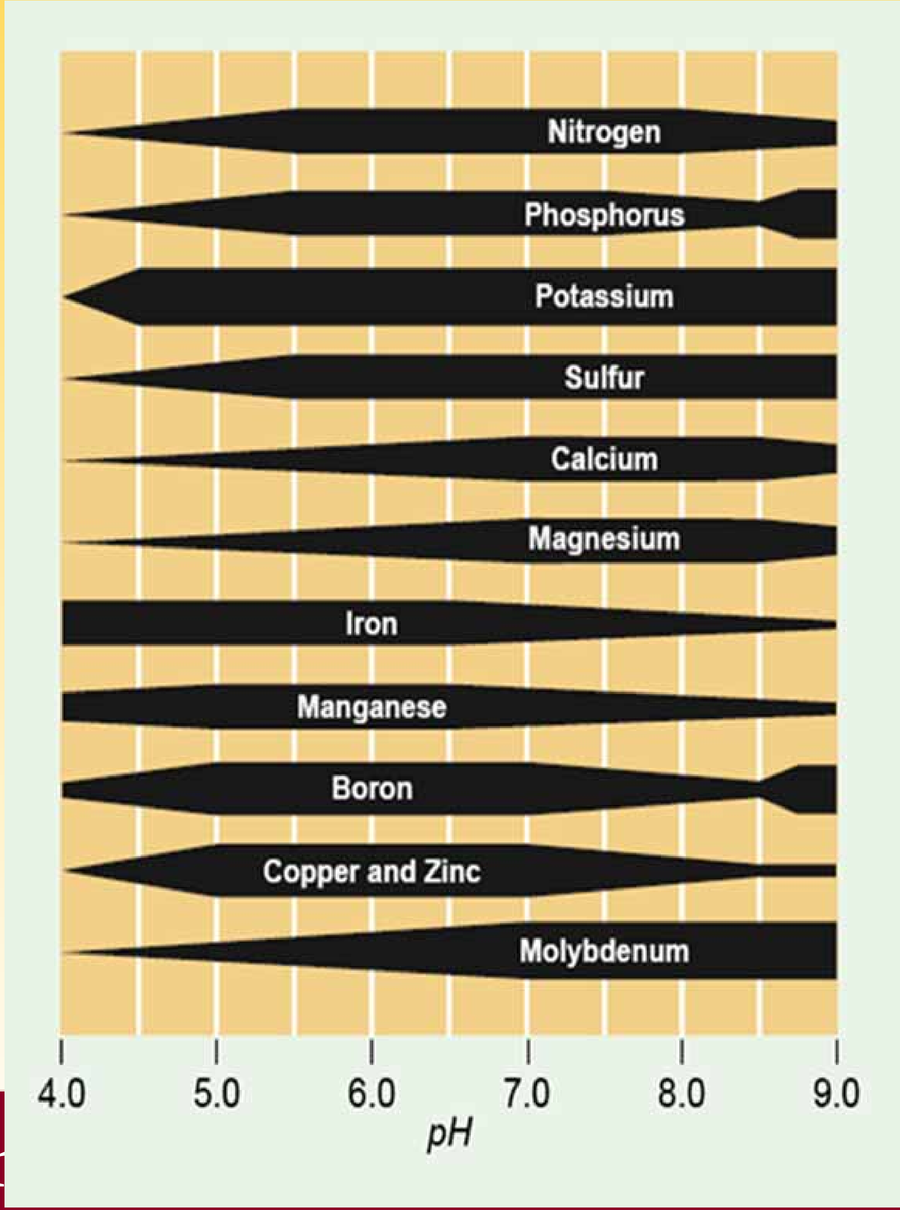


Vesicular Arbuscular Mycorrhiza

External factors affecting root activity

- **Soil fertility**
- **Mechanical impedance**
- **Soil temperature**
- **Soil aeration and moisture**
- **Pests and disease**

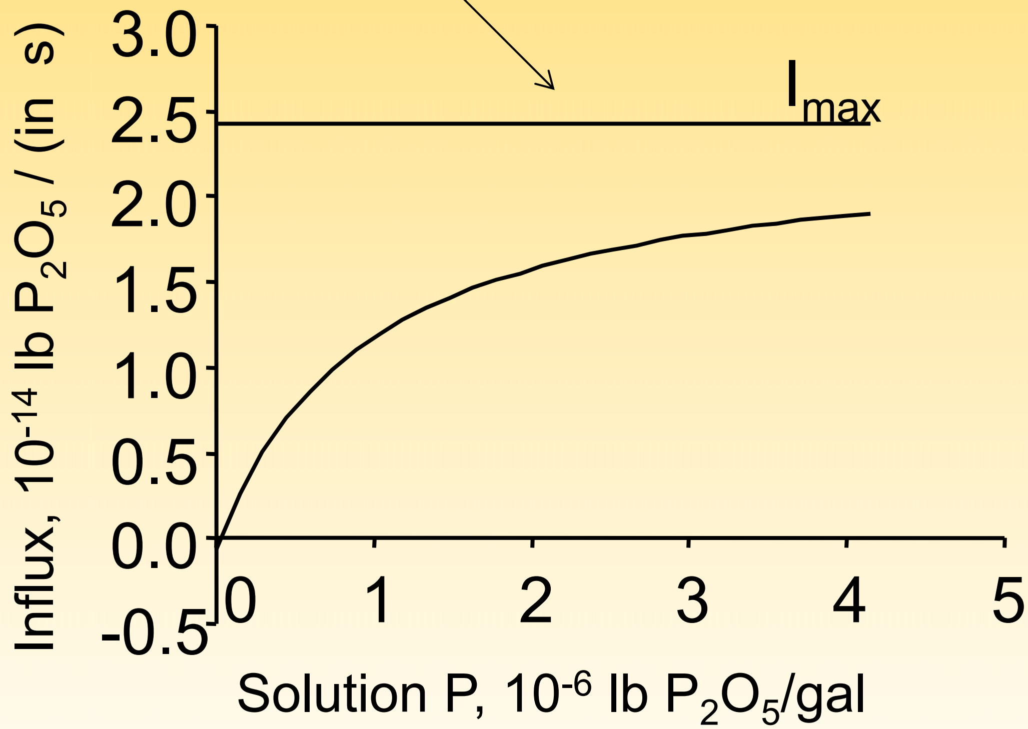
Role of pH in nutrient availability



Nutrient influx by roots

- Ions are not simply absorbed according to their ratios in solution
- Ions with this characteristic influx pattern require energy to be absorbed
  - $H_2PO_4^-$, HPO_4^{2-}
  - K^+
- Simply increasing the concentration of these ions in the soil solution does not result in a directly proportional increase in uptake rate
- Maximum influx is reached at higher solution concentrations (I_{max})

How quickly a root is capable of taking up nutrients



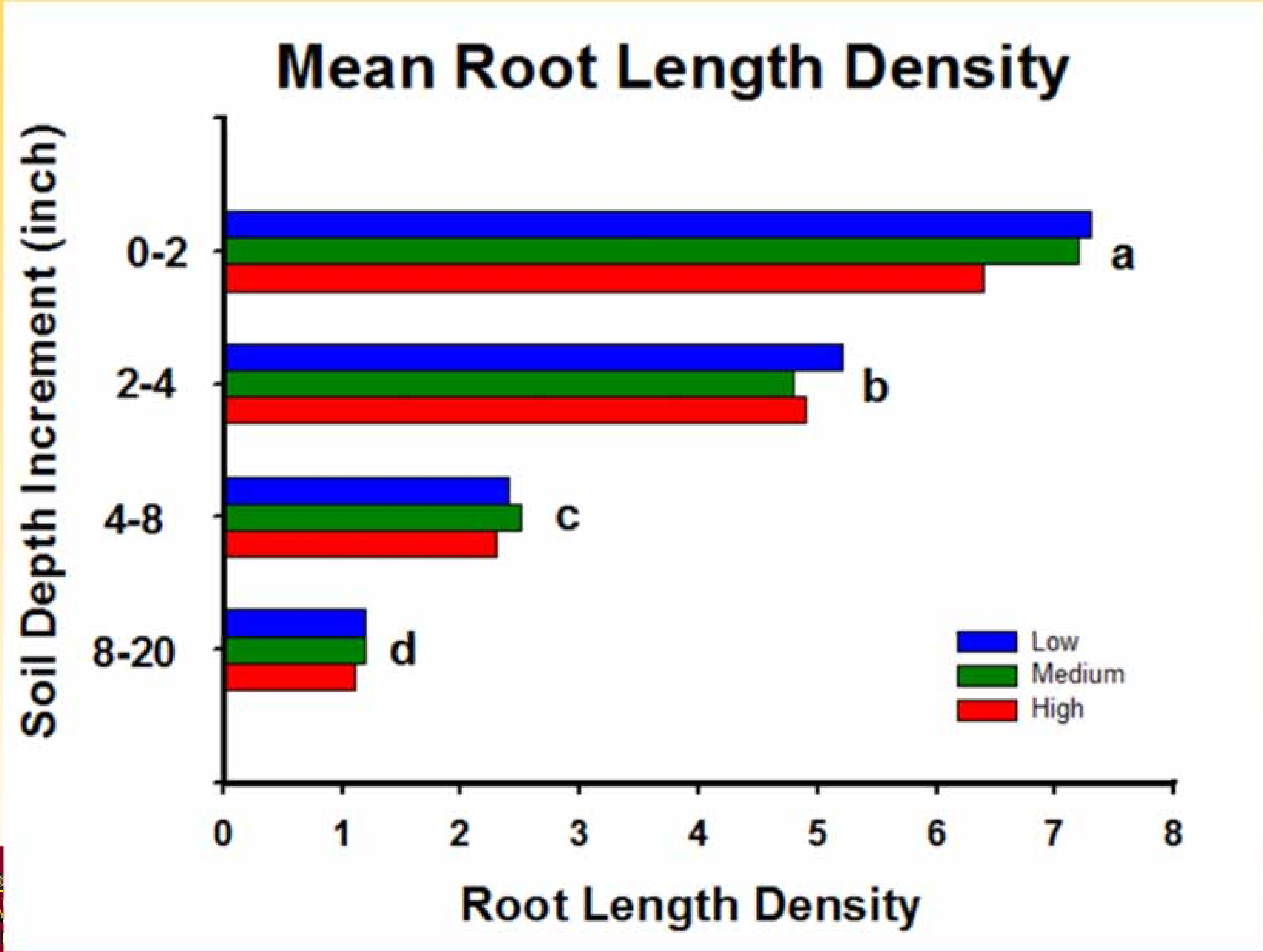
Barber, S.A. 1984. Edwards, J.H. and S.A. Barber. 1976. Agron. J. 68:973-975.

22-23 day old soybean roots

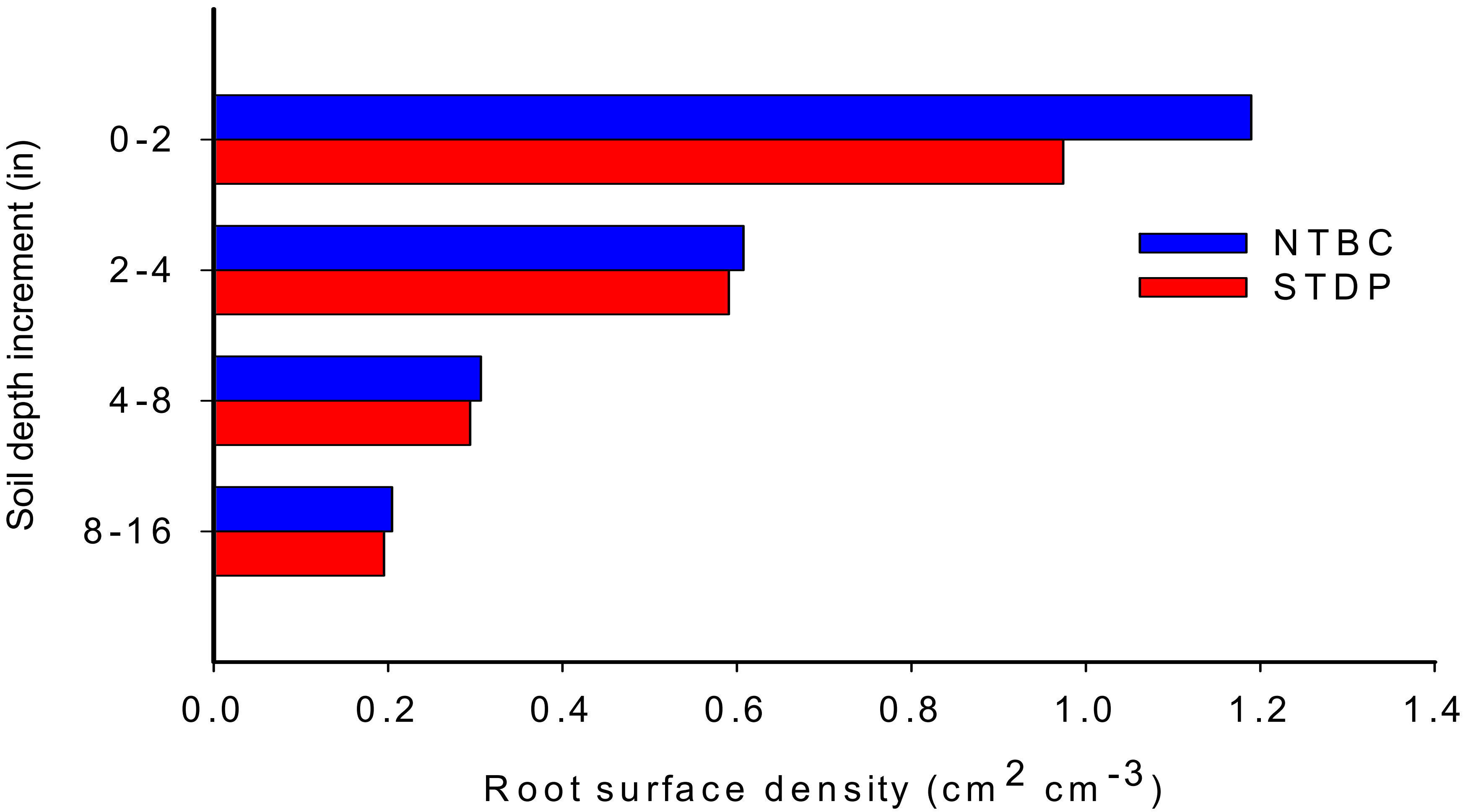
Is stratification a problem?

- Stratification building up indefinitely?
- Vertical stratification forces nutrient uptake to be more dependent on:
  - The way plant roots exploit the soil surface
  - The characteristics of the soil surface
- Soil surface more prone to drying?
- Phosphorous runoff

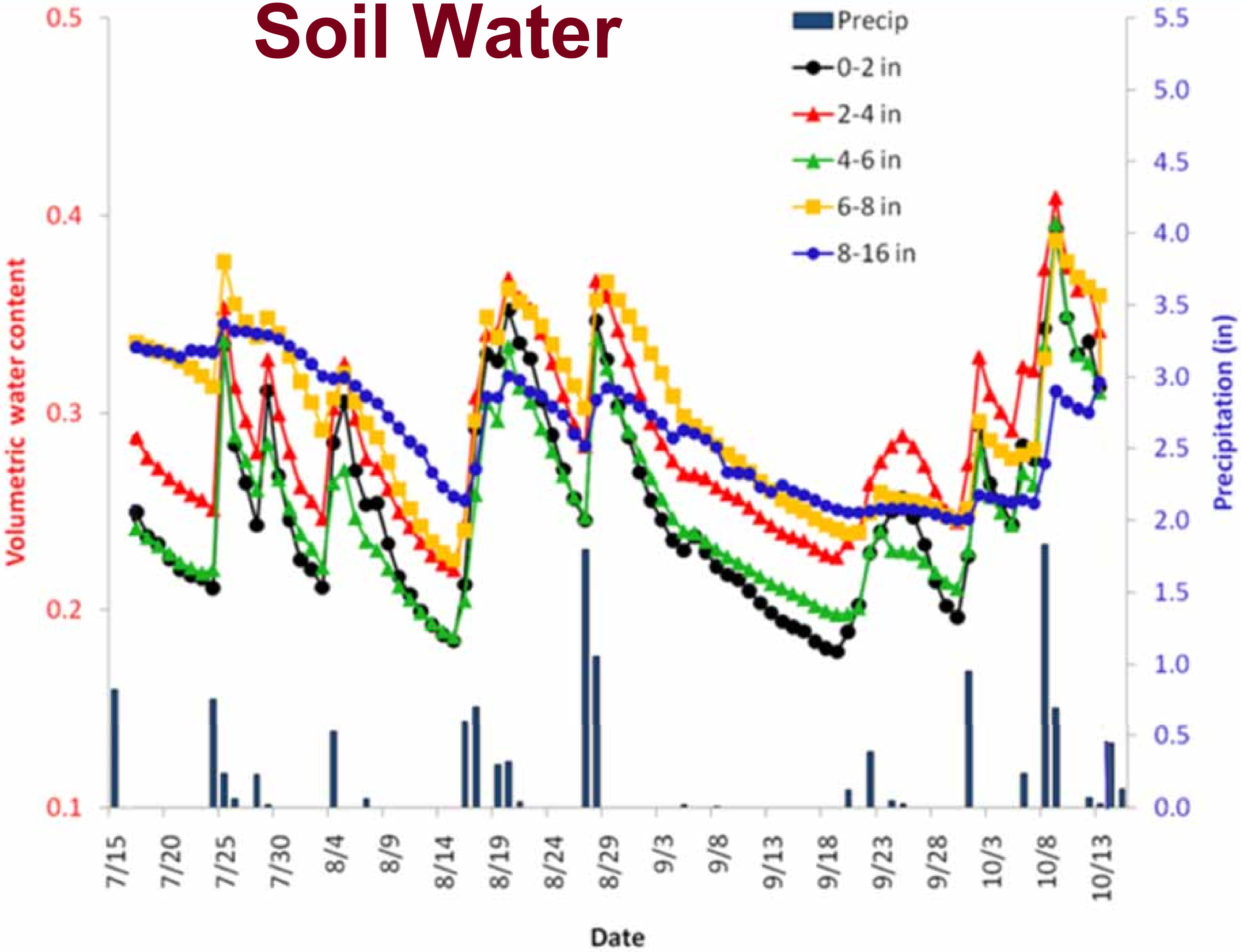
Root development not impacted by fertility



Root development not impacted by nutrient placement

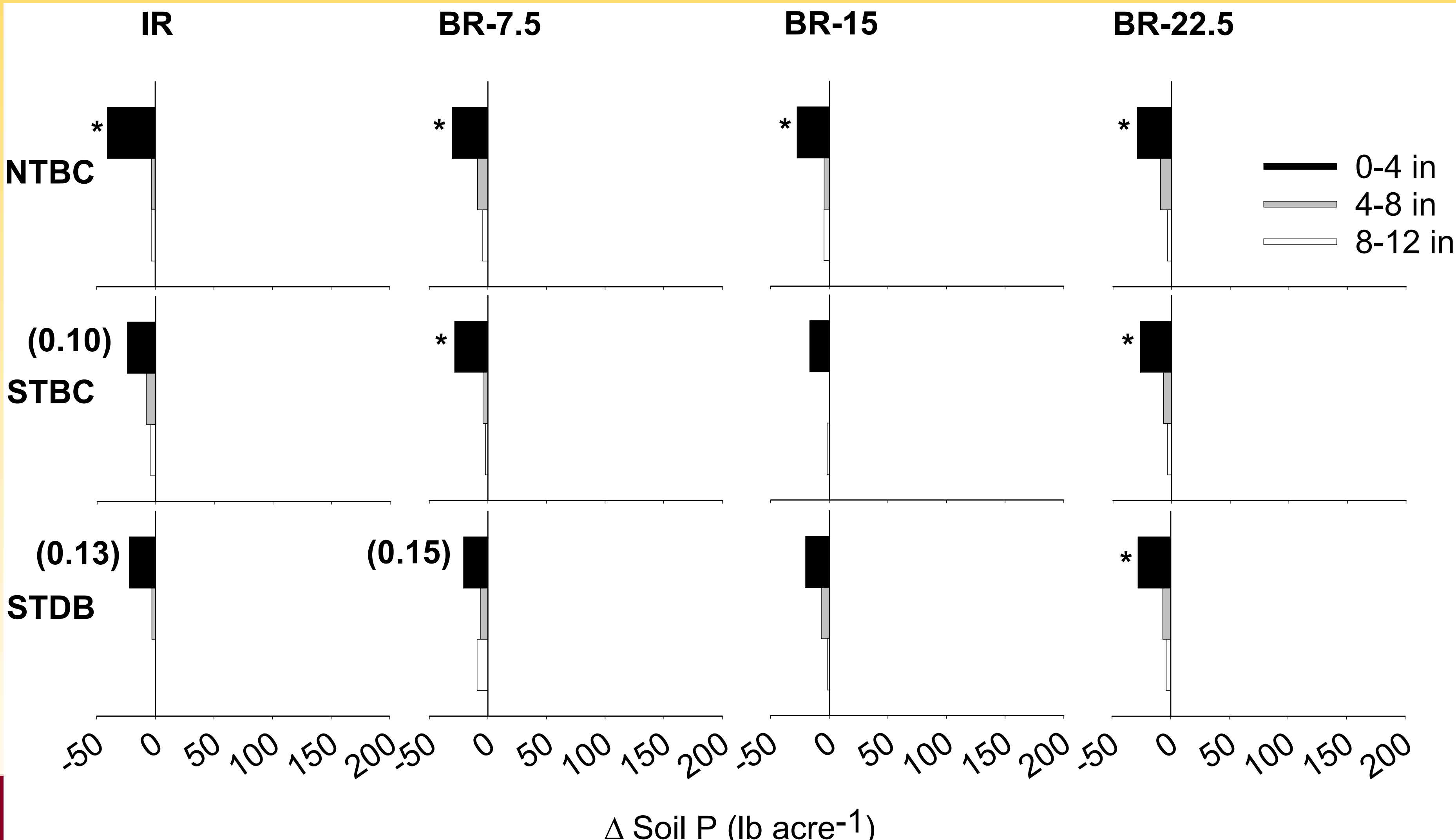


Soil Water

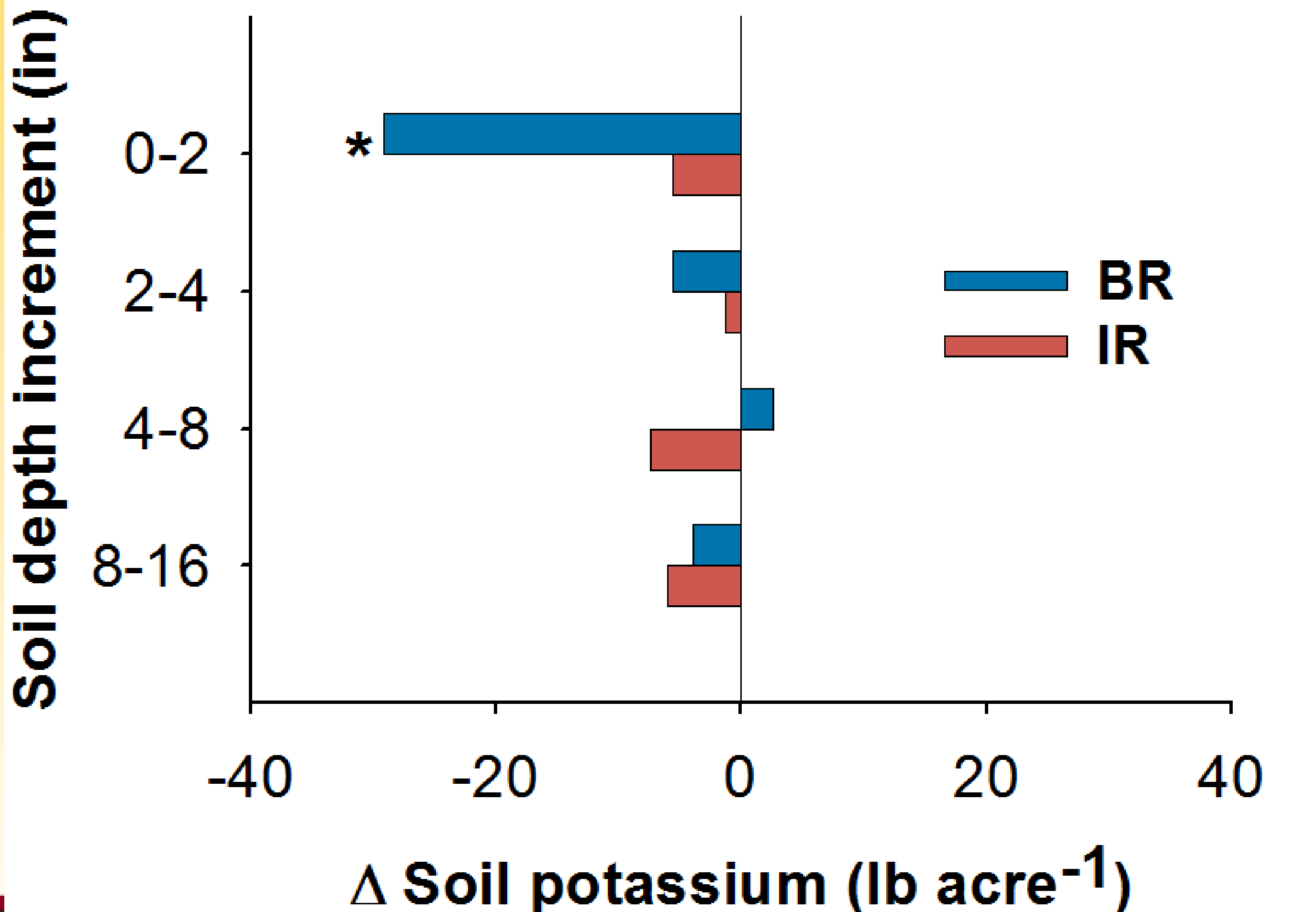


Precip
0-2 in
2-4 in
4-6 in
6-8 in
8-16 in
Volumetric water content
0.5
0.4
0.3
0.2
0.1
Precipitation (in)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
7/15
7/20
7/25
7/30
8/4
8/9
8/14
8/19
8/24
8/29
9/3
9/8
9/13
9/18
9/23
9/28
10/3
10/8
10/13
Date

Check (0 lb P_2O_5)

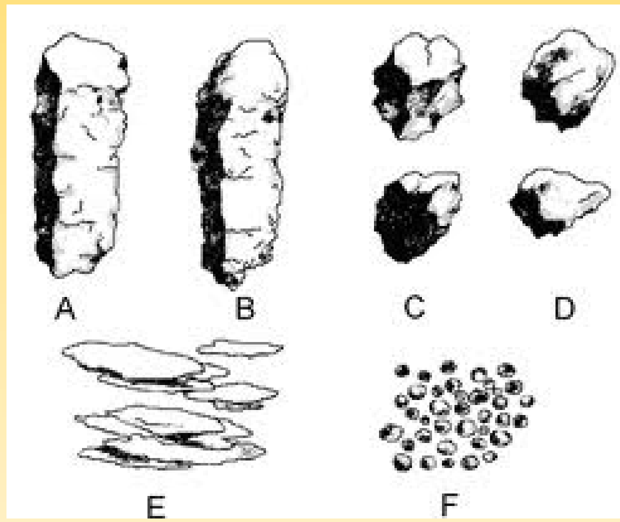


In-Season Soil K Change, V12-R2 (±70% of K uptake)



A

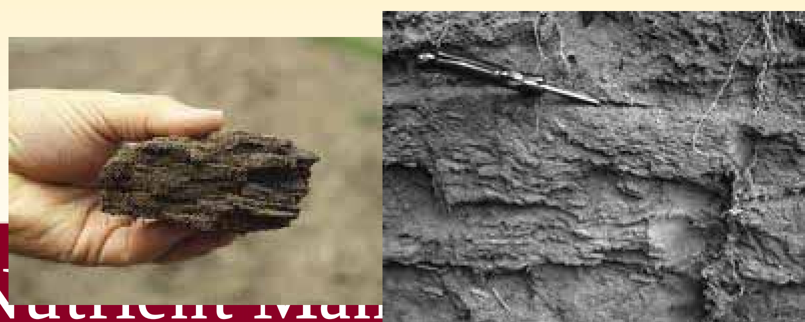
B



C

D

E



F

Aggregate breakdown

- Tillage breaks apart aggregates and forms pans
- Tillage at same depth over time creates a “pan”
- Raindrops break up surface aggregates
- Single particles can form a crust
  - Difficult for water to infiltrate a crust or seeds to push through, and reduce air exchange
- Destroyed aggregates may also lead to increased erosion potential

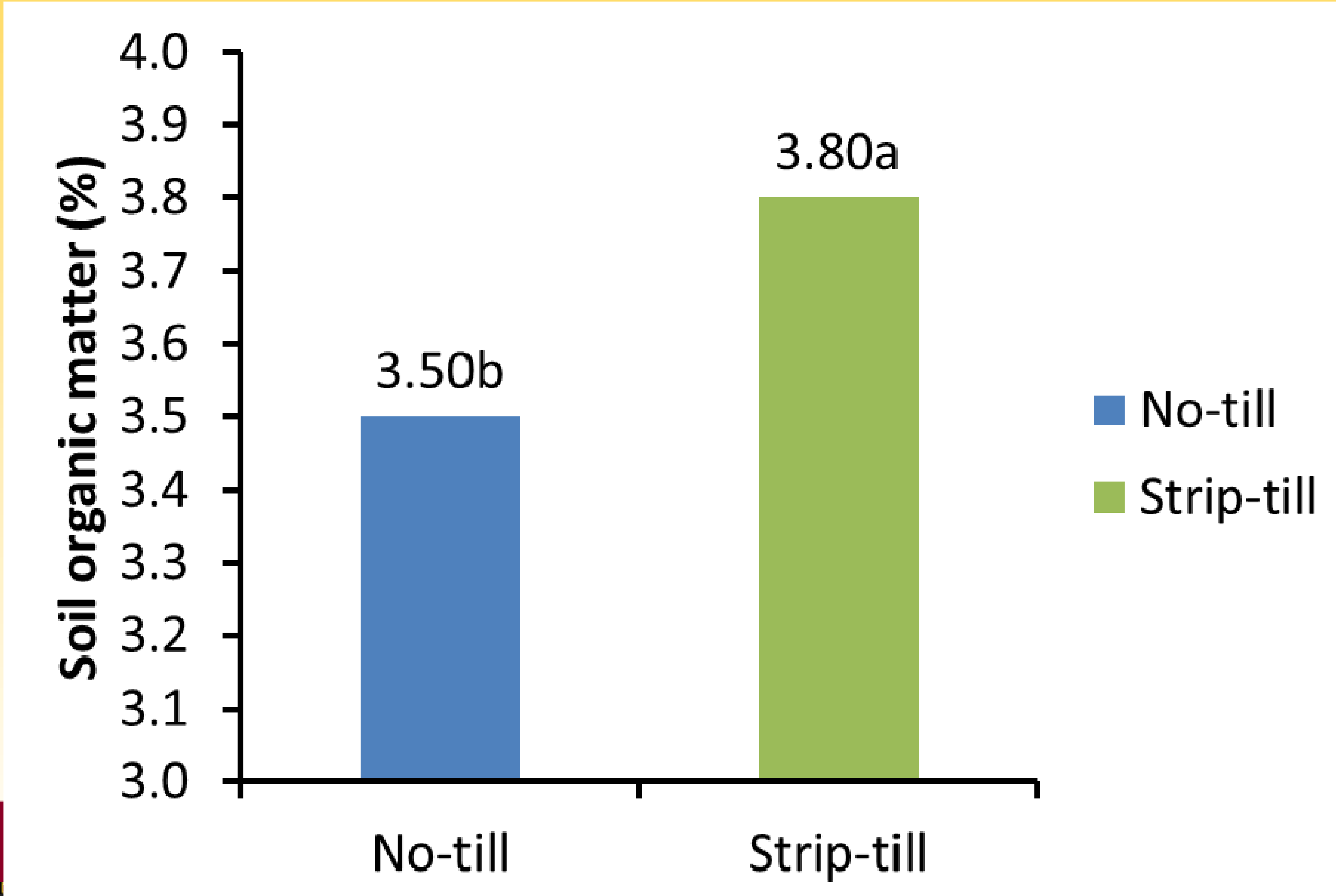
Compaction effects on plant growth

- **Surface compaction**
  - Shallower-than-expected planting depth
  - Poor seedling emergence
  - Increased chemical injury
  - Anaerobic environment not conducive to root growth
  - Reduces water infiltration
- **Subsurface compaction**
  - Reduces infiltration and allows water to saturate soil (enhancing environment for nitrogen loss)
  - Lack of available soil air (O_2) for root uptake
  - Increased disease risk
  - Causes shallow rooted plants and may limit above-ground growth

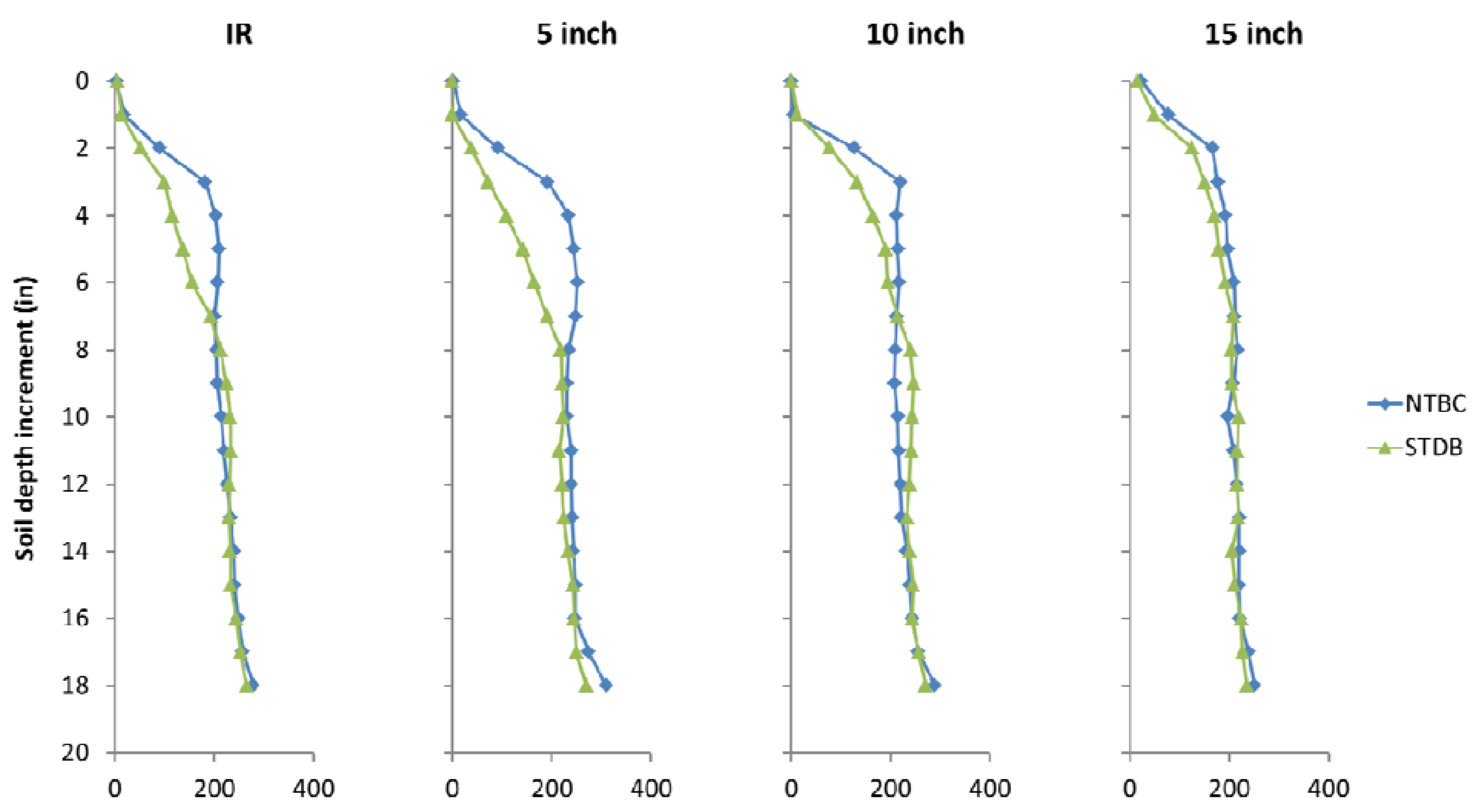
Improving soil structure

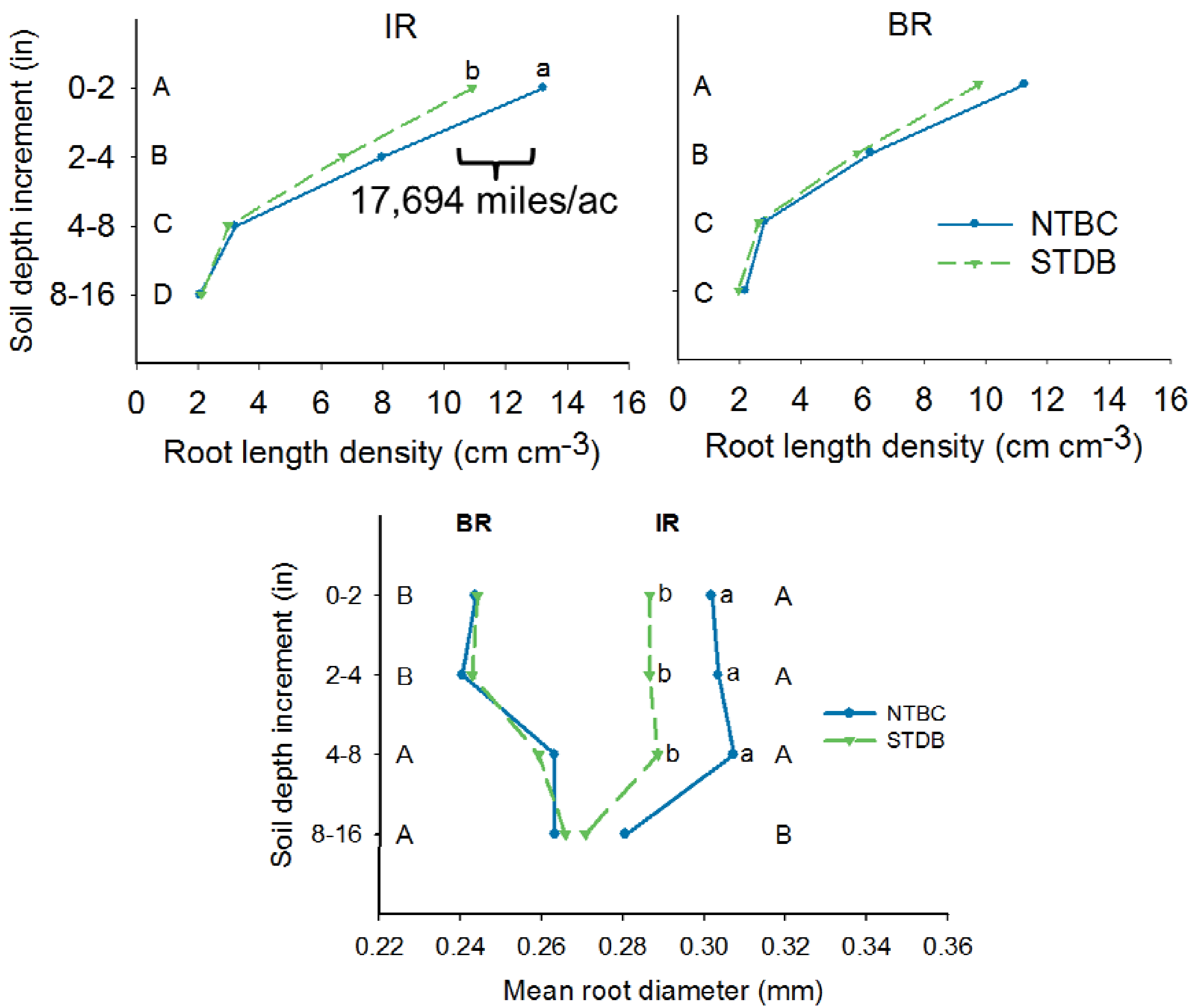
- Involves growing sod crops (grasses/legumes)
- Applying manure
- Returning crop residues
- Controlling erosion
- Minimizing tillage
- Conduct tillage under optimum soil conditions
- Minimizing field traffic
- Soil environment (temperature, moisture, microbial activity, etc.)
- Improve productivity (Increase OM inputs)

Soil Organic Matter



Soil Penetration Resistance (PSI)





IR
BR
Soil depth increment (in)
0-2
2-4
4-8
8-16
A
B
C
D
b
a
17,694 miles/ac
Root length density (cm cm-3)
0
2
4
6
8
10
12
14
16
NTBC
STDB
BR
IR
Mean root diameter (mm)
0.22
0.24
0.26
0.28
0.30
0.32
0.34
0.36

Efficiency

Tillage/fert. placement	RSD	Apparent uptake rate	
		P	K
	$cm^2\ cm^{-3}$	—mg m^{-2} day^{-1}—	
NTBC	0.47a	3.02b	26.58b
STDB	0.40b	3.74a	32.67a

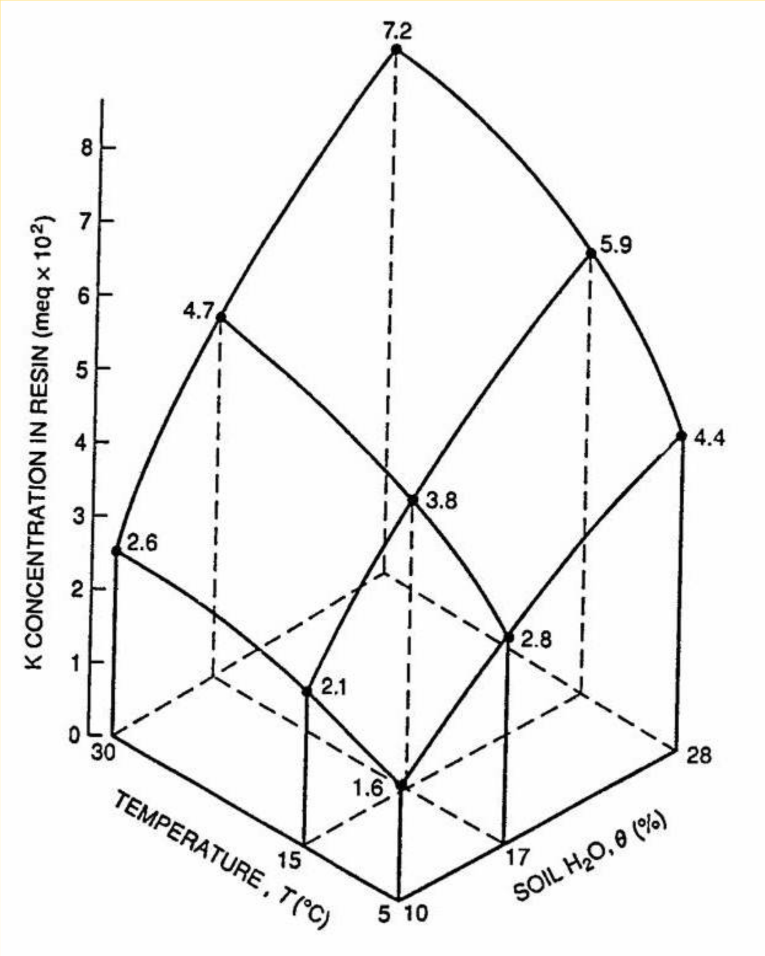
Temperature and soil water

Temperature

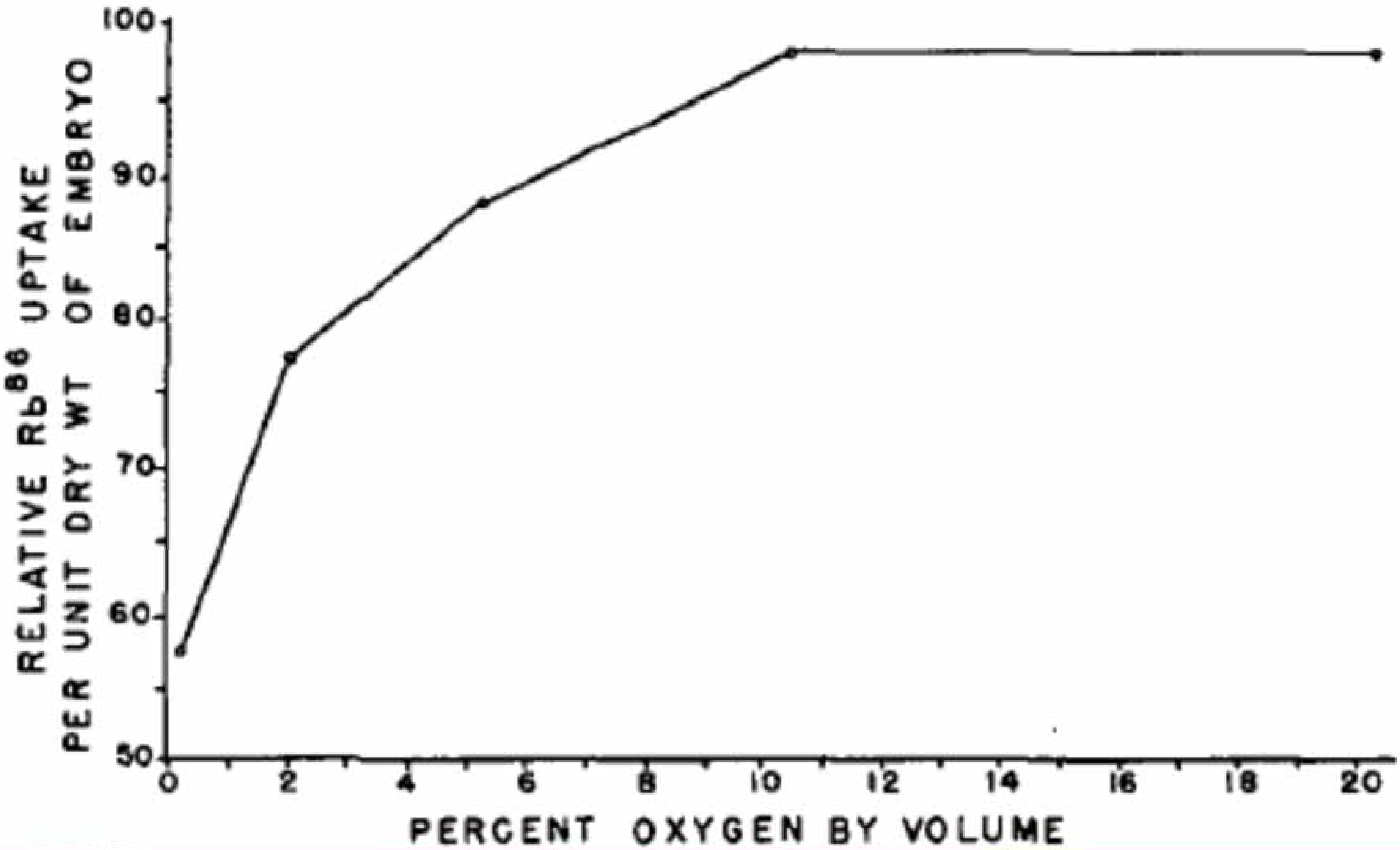
- **Root growth and nutrient diffusion are reduced at low temperatures**

Drainage and aeration

- **Wet soils >> lack of oxygen**
- **Dry soil increase diffusion path and reduce root elongation/activity**



Roots need oxygen!



Water holding capacity

Type	Available Water (in/ft)
Course sand	0.25 to 0.75
Fine sand	0.75 to 1.00
Loamy sand	1.10 to 1.20
Sandy loam	1.25 to 1.40
Fine sandy loam	1.50 to 2.00
Silt loam	2.00 to 2.50
Silty clay loam	1.80 to 2.00
Silty clay	1.50 to 1.70
Clay	1.20 to 1.50

- A 200-bushel corn crop requires about 22 inches of water (about 3,000 gallons of water per bushel)
- About 40% of the water used by corn will come from the first foot of soil, 30% from the second foot and 20% from the third foot. Less than 10 % will come from the soil below 3 feet
- The period of greatest water stress sensitivity coincides with the time of highest water use demands (July and August)
  - Corn water use will average around 7 to 8 inches in July and 6 to 7 inches in August. We get about ½ of that with rain.
  - With temperatures in the 80s, corn will use about 1.75 inches per week. Temperatures in the 90s will increase the water demand to around 2.1 inches per week.

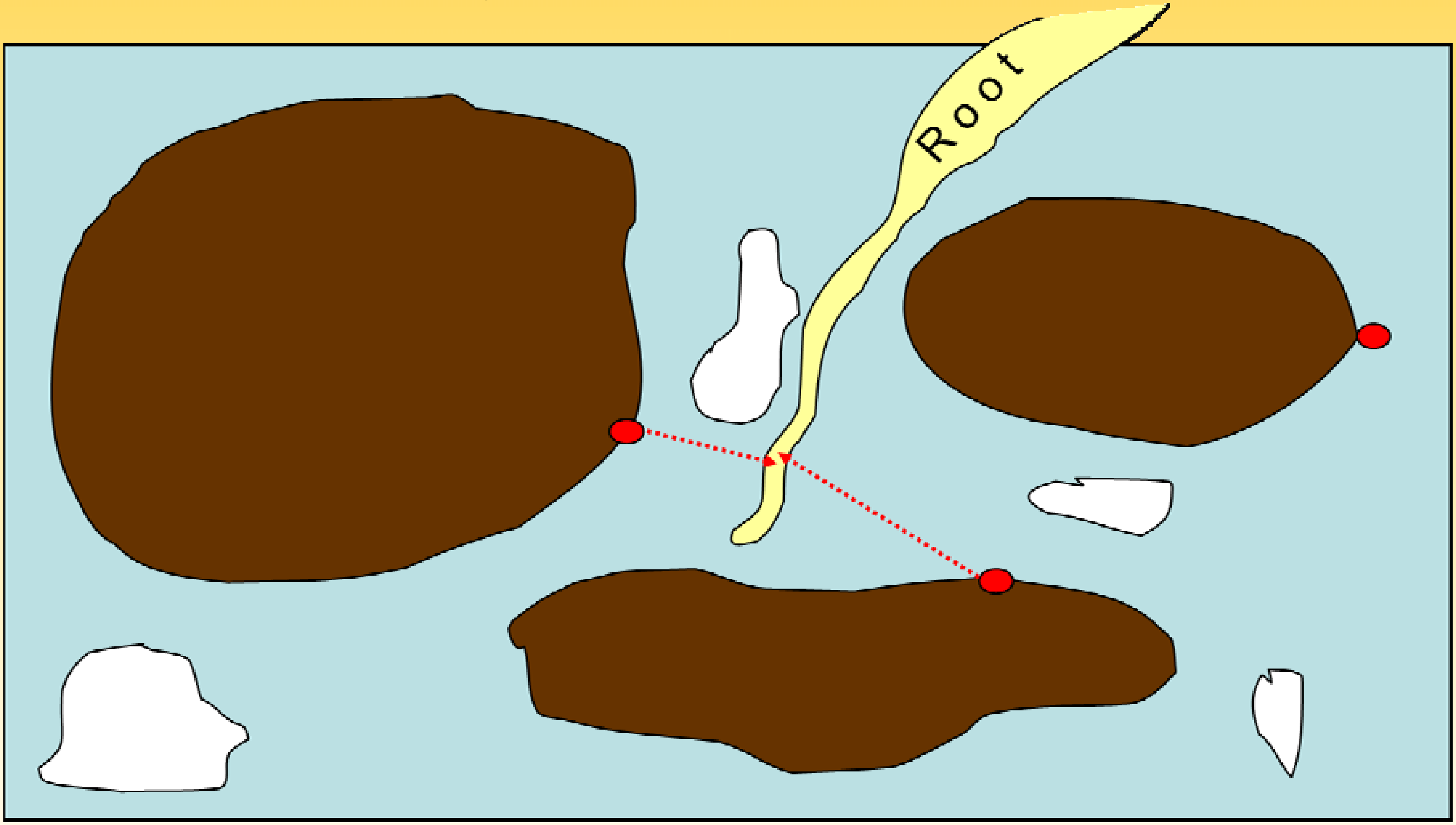
Infiltration: the capacity of the soil to intercept rain-water

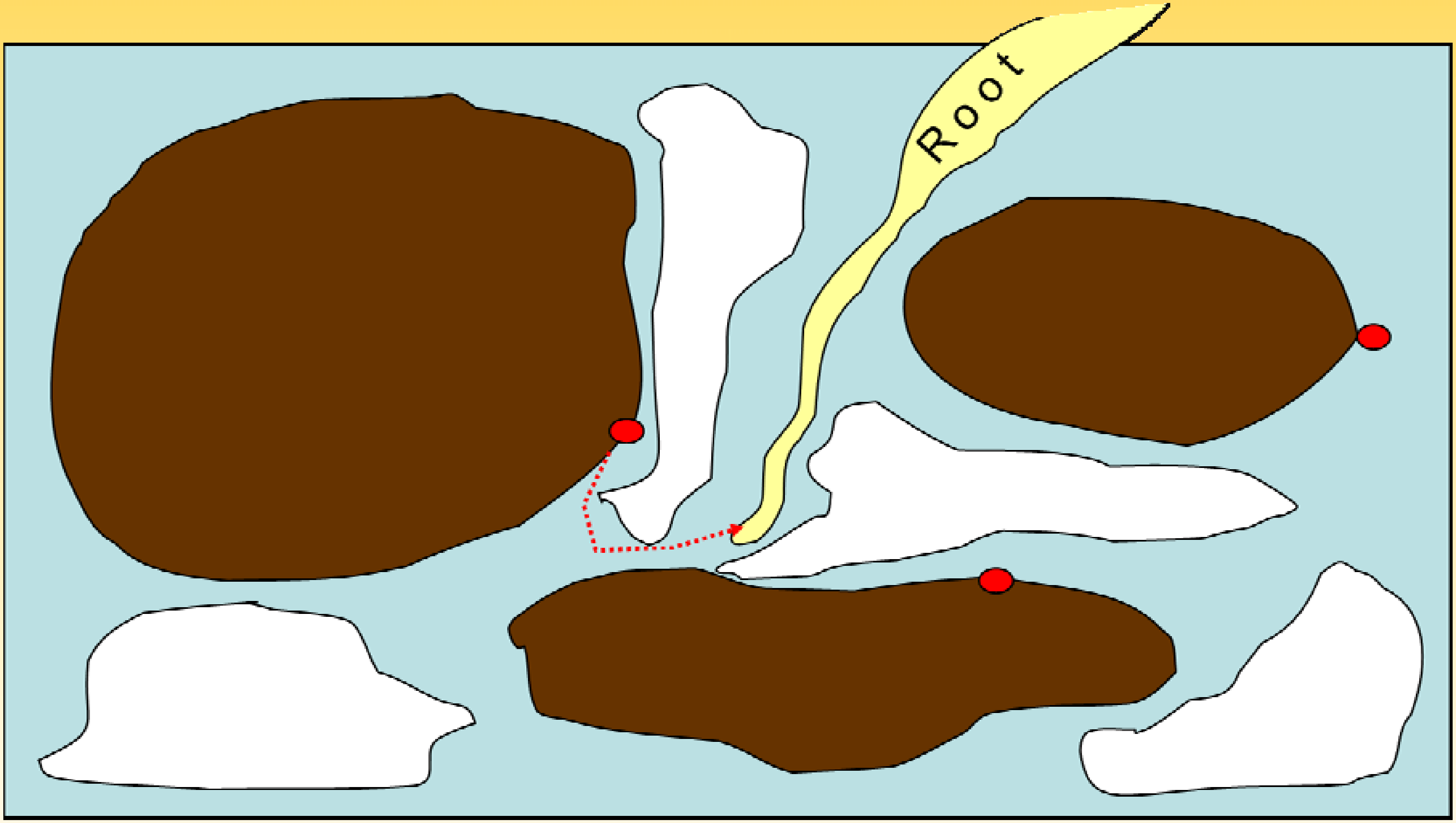
- **Minimize disruption of pore conductivity**
  - **Increase rain water infiltration**
  - **Increase root penetration**
- **Maintain surface residue**
  - **Prevent soil crusting (water infiltration surface runoff)**

Soil water conservation

- **Tillage increases air exposure**
- **Maintenance of crop residue cover**
- **Controlled drainage**
- **Weed control**

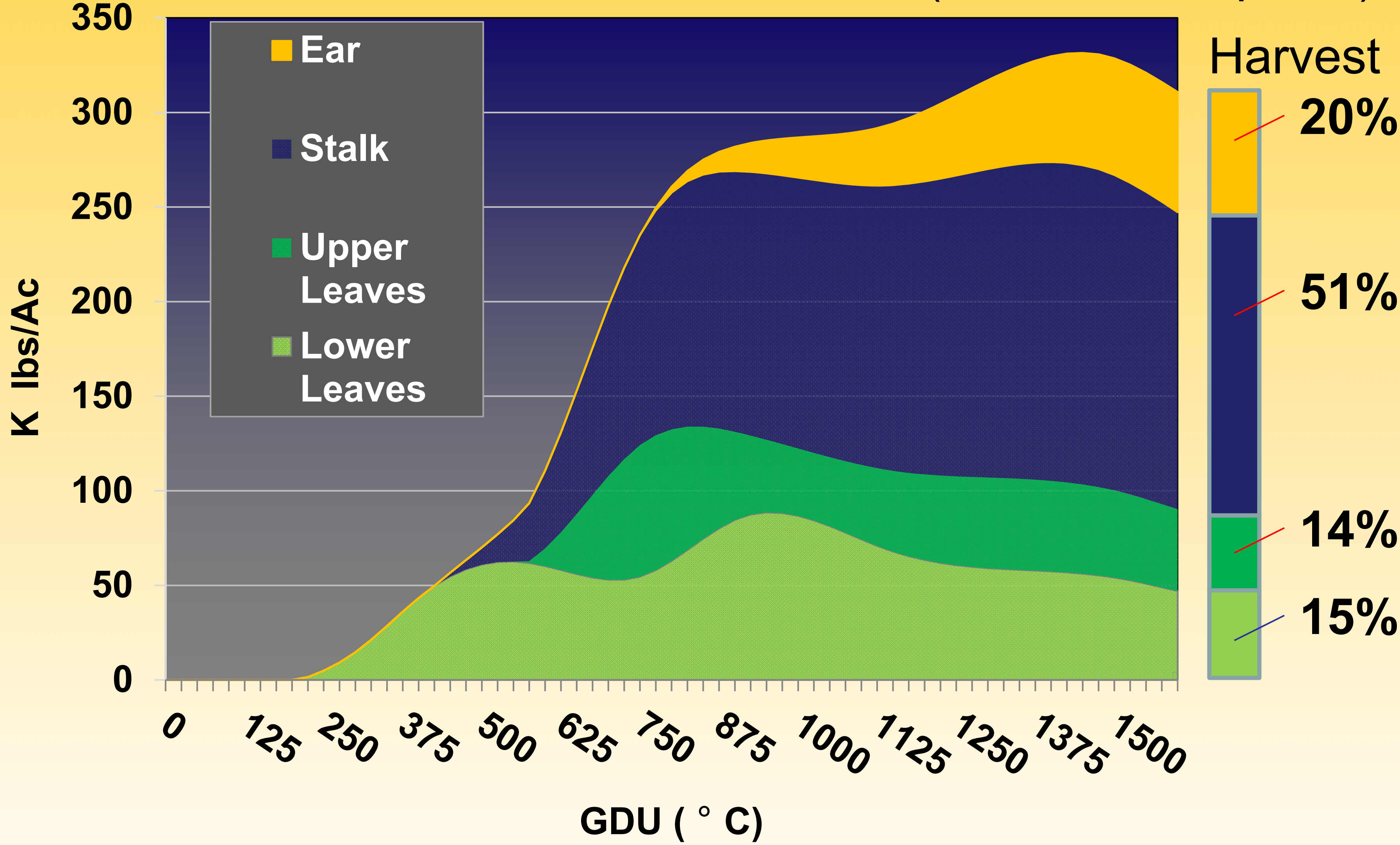
*Diffusion distances during the growing season are short: P = 0.2 mm; K = 2 mm




Root

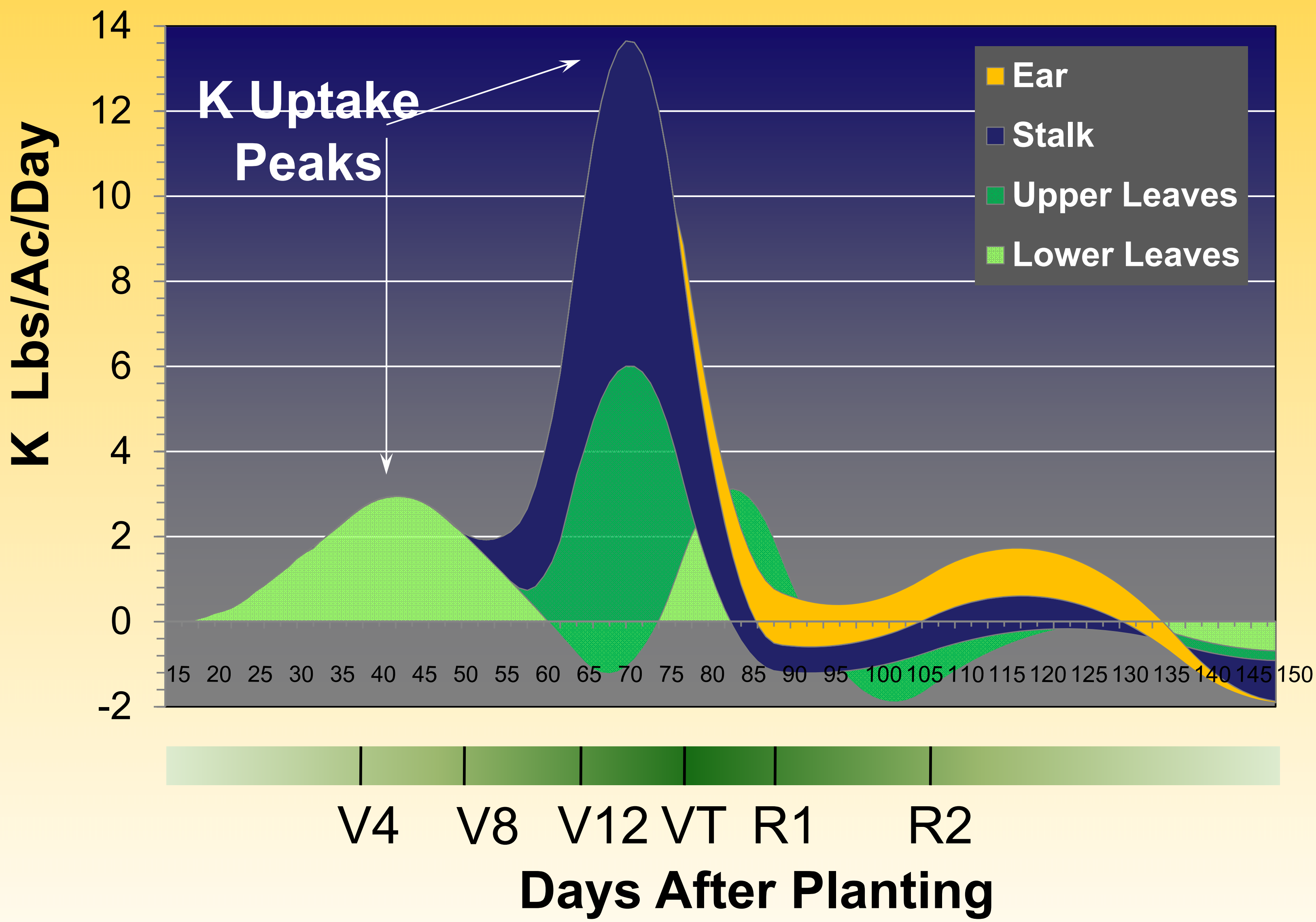
Corn aerial potassium accumulation

V12-R2 (±70% of K uptake)

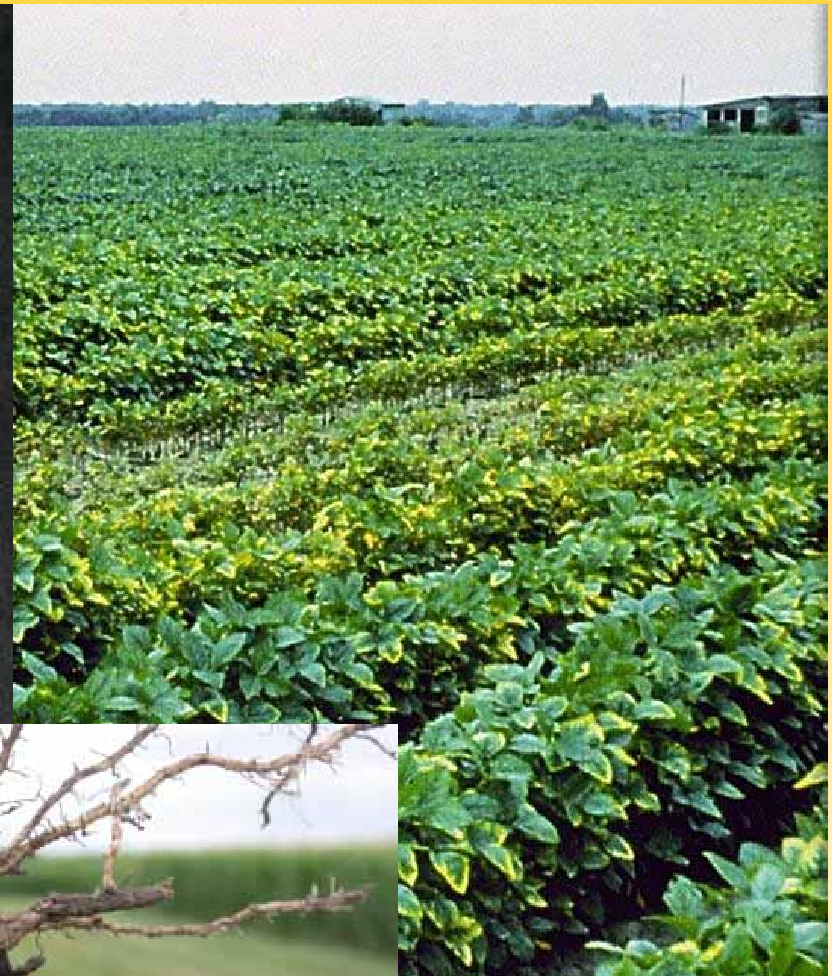


From Karlen et al, 1988

Corn potassium aerial accumulation rate



Karlen et al, 1988



Diseases

Pests

Take home message

- **Supply adequate fertility**
- **Manage for good root development**
- **Maximize nutrient availability by protecting soil water**