Chemistry in Soil-Plant Relationships

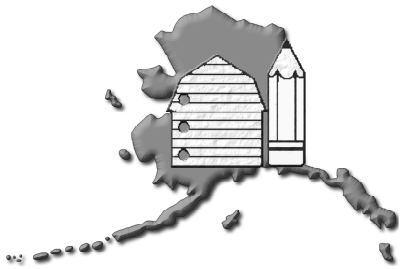
By Andrew and Erin Oxford, Bethel

Objective
Apply the science of chemistry to soil and plant relationships.

Suggested grade levels
11-12

Alaska Content Standards
Science, D1,D3

Terms to Define
ion
nutrients
diffusion
migration
mass flow
transpiration
concentration gradient
solubility
tortuosity



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A. Movement of nutrients from the soil to the plant root
For nutrients to be absorbed by plants, they must come in contact with the roots. There are three ways this can occur.

1. Mass Flow
Definition: nutrient ions are transported to the root surface via the flow of water. Plants transpire water which causes a gradient that allows water to flow towards the root. If nutrients are in the water, they will be absorbed by the root.

Nutrients supplied to plant roots by mass flow: Ca^{+2}, Mg^{+2}, NO_3^-, Cl^-, H_3BO_3
These nutrients are not held tightly by the soil which is why these nutrients can be supplied by mass flow.
Mass flow is most important for nutrients or ions in relative abundance in the soil solution.

Factors influencing mass flow:
Soil moisture-drier the soil, less mass flow
Size of root system
Soil temperature-cooler temperatures means less transpiration

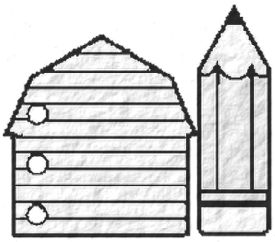
2. Diffusion
Definition: in chemistry, diffusion is the spontaneous migration of substances from regions where their concentration is high to regions where their concentration is low. Ion diffusion occurs in the soil solution. Ions dissolved in the soil solution will move from areas of high concentration to areas of low concentration.

Area around the root of an actively growing plant is depleted of nutrients (low concentration), so nutrients in the soil will migrate towards the root

Nutrients supplied to plant root by diffusion: P and K
These nutrients have a low solubility
Factors influencing diffusion:
Concentration gradient- Diffusion rate = Dc x Area x gradient
Dc = Diffusion coefficient (tortuosity)
Area = root area
Gradient = concentration gradient

Tortuosity — the path the diffusion ion must take
Large soil pore and adequate soil moisture decreases tortuosity, so diffusion is easier and occurs more.
Small pores (clay soil) and low soil moisture increases tortuosity which makes diffusion more difficult

Temperature — motion of atoms or ions increases with temperature; hence diffusion rates are greater at higher temperatures; cool soil temperatures often limit diffusion rates in Alaska soils



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Peter Bierman, UAF Cooperative Extension Service Land Agent in Palmer, contributed to this lesson.

Chemical and physical properties of the soil
Lower the pH, the more quickly ions will diffuse

How far can nutrients diffuse at field capacity?
1 cm/day for N
0.2 cm/day for K^+
0.02 cm/day for $H_2PO_4^-$

Field capacity is the percentage of water remaining in a soil two days after being saturated and allowed to freely drain.

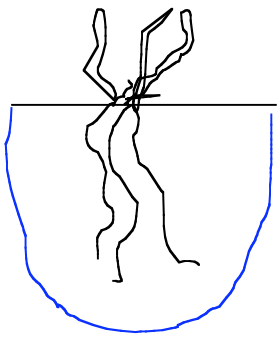
3. Root Interception
Definition— as roots extend through the soil, they continually come in contact with previously unexplored soil. Therefore root surfaces come in direct contact with nutrients during this displacement process.

Factors influencing root interception
The quantity of nutrients absorbed by root interception is a function of the root volume. Typically, no more than 1% of the soil by volume is ever directly contacted by roots. Ca and Mg are most often intercepted by root contact

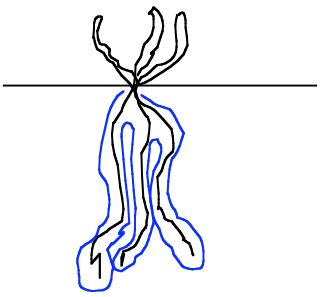
Mycorrhizae can increase nutrient uptake by root interception. Mycorrhiza are a symbiotic association between fungi and the roots of seed plants. This association increases the surface area that roots can extract nutrients from.

B. Root system sorption zone for mobile and immobile nutrients
Mobile nutrients form soluble compounds and do not interact with the soil (i.e. they do not attach to soil particles) and are found in comparatively high concentration in the soil solution. The nutrient sorption zone will be comparatively large.

Immobile nutrients are insoluble and attach to the soil particles. The nutrient sorption zone is more localized around the plant roots.



Mobile Nutrient Root Sorption Zone
NO_3^- is mobile



Immobile Nutrient Root Sorption Zone
K and P are immobile

Soil-Plant Relationships Problems Solutions (see problems on separate student sheet)

1. a. Diffusion is the movement of ions or nutrients from areas of high concentration to areas of low concentration in the soil solution. Generally, the area around plant roots is void of nutrients, so they will diffuse from the bulk soil to the roots. Diffusion is most important for P and K.

b. Diffusion is the least important for N. N moves to the plant roots by mass flow.

c. Three factors that influence diffusion rates are tortuosity, temperature, and soil pH. Tortuosity is the path an ion takes to the root, so if the path is easy and open (soil with large pores) then diffusion will be quicker and easier. Diffusion rates are greater at higher temperatures and less at lower temperatures. The lower the soil pH is, the faster diffusion occurs and vice versa.

2. Soil weight = 2×10^6 lbs/acre = 2,000,000 lbs/acre
Soil moisture (water) content = 2,000,000 lbs/acre (0.20) = 400,000 lbs/acre

2000 lbs/acre biomass (0.025) = 50 lbs/acre of N in the plants (0.025 = 2.5% N)
2000 lbs/acre biomass (0.002) = 4 lbs/acre of P in the plants (0.002 = 0.2% P)

400,000 lbs/acre H20 x ($100/10^6$ or 1,000,000) = 40 lbs/acre of N
400,000 lbs/acre H20 x ($0.2/10^6$ or 1,000,000) = 0.08 lbs/acre of P

40 lbs/acre of N in the soil solution / 50 lbs/acre of N in the plants = 0.80 = 80%
0.08 lbs/acre of P in the soil solution / 4 lbs/acre of P in the plants = 0.02 = 2%

Amount of N supplied by mass flow = 80%
Amount of P supplied by mass flow = 2%

3. Fertilizer placement is more important with immobile nutrients because in order for them to be utilized by the plant, they need to be placed near the roots. They need to be placed near the roots because they are insoluble and attach to the soil which means they only move by diffusion and not mass flow. In order for the root to be able to readily absorb the immobile nutrients, they must be placed in the root sorption zone which is in direct contact with or in the immediate vicinity of the plant roots.

Name _____

Soil-Plant Relationship Problems

1. Nutrients with low soil solution concentrations move to the plant roots primarily by diffusion. Consider the three nutrients N, P, and K.

a. Briefly define diffusion and indicate for which of these nutrient(s) would you expect diffusion to be the most important for movement to the plant root?

b. For which of these nutrient(s) is diffusion the least important and how does this nutrient move to the plant root?

c. Indicate three factors that influence the rate at which ions diffuse and briefly explain why.

2. A soil contains the following nutrients in solution: Nitrogen (N) at a concentration of 100 ppm and Phosphorous (P) at a concentration of 0.2 ppm. The soil has a moisture content of 20% by weight. Range and pasture grasses growing at this site have the potential to produce 2000 lbs/acre of biomass. Assume the N and P concentration in the plant tissue produced is 2.5% and 0.2%, respectively. What fraction of the N and P could potentially be supplied by mass flow from the soil (top 6'' only)?
Assumptions: Consider only the nutrients present in the solution and assume no additional recharge of nutrients from the soil; Top 6" of soil weighs 2 x 10^6 lbs/acre

3. Is fertilizer placement a more important issue with mobile or immobile nutrients? Why?