Technical Note 6. Nutrient Transport to Roots

6.0 Background

The soil contains millions of pores of all sizes and shapes, many of which are blocked by bits of organic matter and mineral particles. Now, imagine you are a microbe trying to move around in the soil. The pore surfaces are highly active and capable of adsorbing ions and organic molecules. As you make your way around, the system changes as moisture is depleted or added with each wet–dry cycle, or freeze-thaw cycle. Maybe a burrowing earthworm deposits a casting that blocks your path. In short, the soil is a dynamic, "constantly changing" system with innumerable barriers to the movement of both microbes and chemicals including that all-important one, water (H_2O).

In soil mineral fertility, we are concerned with the quantity of nutrients in the soil and their chemical form. For a nutrient to be available for plant uptake it must first be in the proper chemical form to pass through the root membrane and most importantly it must be *available at the root surface*. Roots have no genetic ability to find water or nutrients dissolved in water. The only way a nutrient can be made available to plants is if the root grows toward the nutrient, or if the nutrient is conducted to the root surface in the soil solution via some transport mechanism. There are two mechanisms that largely govern the movement of nutrients in the soil: hydraulic and chemical.

The transport of nutrients in soil is dependent on their concentrations in the soil solution, how strongly they are adsorbed by clays and organic matter, and how fast they can move. If we know how a given nutrient moves in the soil, then we can use this information to decide how, where, and when to apply different kinds of fertilizers.

For example, phosphorus exists in the soil solution as the orthophosphate ion ($H_2PO_4^-$ or $H_2PO_4^{-2}$) in low concentrations and is strongly adsorbed by surface-active particles. In contrast, nitrogen is found in much higher concentrations (usually as NO_3^-) and is weakly bound by particle surfaces. Consequently, phosphorus fertilizers must be placed in a narrow band in close proximity to the seed to be effective whereas, nitrogen can be broadcast over the surface because it mobilizes more readily in the soil. That said, it is generally more efficient to place fertilizer nutrients near (but not in contact with) the seed or plant row where they will be rapidly intercepted.

Primary Uptake Mechanisms in Nutrient Transport to Roots

Nutrient	*Root Interception*	*Mass Flow*	*Diffusion*
Nitrogen		●	
Phosphorus	●		●
Potassium			●
Calcium		●	
Magnesium		●	
Sulfur		●	
Manganese			●
Zinc			●
Iron	●		●
Copper	●		
Boron		●	

6.1 Transport Mechanisms

There are three ways plant roots obtain nutrients from the soil:

- Root interception
- Diffusion
- Mass flow

Root interception (contact exchange) is where root hairs and small roots grow throughout the soil and come into contact with the soil and organic matter particles containing the essential plant nutrients. As such, it's not a transport mechanism per se. The most current theory is the plant root exchanges hydrogen ions (H^+) for essential cations like ammonium (NH_4^+), potassium (K^+), calcium (Ca^{+2}), and magnesium (Mg^{+2}). Keep in mind that a plant's root system contacts with about 1% of the total soil mass it's growing in. Hence, root interception does not figure significantly in plant nutrient uptake. The root interception mechanism is valuable, however, because root growth can extend to areas where mass flow and diffusion take over. For example, a root may grow within a quarter centimeter of a phosphorus fertilizer pellet. Although the root does not technically bump into the nutrient and intercept it, the root is close enough for diffusion to occur.

Diffusion describes the chemical migration of nutrients (ions) from an area of higher concentration to an area of lower concentration. An example of diffusion is a fertilizer prill in the soil. Once the prill is wet, the nutrients will diffuse (move) away from the prill. The prill is the area of higher concentration and the surrounding soil is the area of lower concentration. Diffusion is a slow, but important method for plants to obtain certain nutrients from the soil.

Mass flow describes the hydraulic process of movement of dissolved nutrients in the soil solution towards the plant root as the plant root takes in water. The nutrients are swept toward the plant root along with the water. Nutrients like phosphorus that are strongly adsorbed to surface active particles will never contact the root by this method. But nitrogen, particularly dissolved nitrate (NO_3^-), sulfate (SO_4^-) and some cations like K^+, Ca^{+2}, and Mg^{+2} readily move along in the water. Hydraulic gradients can equally sweep nutrients away from the plant root, something we would like to avoid happening.

6.2 A Final Word about Roots

If plants obtained all of their nutrients from the air and depended solely on the soil for anchorage, the purview of soil science, at least in agronomics, would be quite limited. But soil is the natural environment in which plants have evolved to grow, and from which plants must obtain 14 of the 17 known essential mineral elements including water needed to complete their life cycle. Most farmers pay attention to the above-ground part of plants, seeking therein signs of health, vigor, hunger, or distress. Roots, growing in the soil, are ‘out of sight-out of mind’. This is an easy trap to fall into given that roots are concealed from our view with no simple way to examine them apart from digging them up with a shovel. But this is exactly what every farmer must do whenever signs of stress or loss of plant vigor are detected above-ground.

From the plant’s point of view, the concentration of nutrients in the soil solution and reserve factors buffering what’s removed by uptake from the soil solution are only as important as the mass of root system growing and taking up nutrients. It stands to reason that soil factors controlling roots have a much greater impact on plant productivity than the supply of nutrients in the soil. The *rooting volume* of the plant is the principal factor governing nutrient and water uptake. Any condition that constrains the maximum rooting volume of a plant must necessarily constrain plant growth and in turn, yield. The challenge to every farmer is creating a soil environment wherein roots can proliferate without barriers. Only when this condition is met can we begin talking about plant and soil health and maximizing yield potential. It really doesn’t matter how many units per hectare there are of N, P, K in each furrow slice (*organic* or *inorganic*). If plants can’t access those reserves, then no amount of nutrient supply in the soil will build or sustain productivity.

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