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 very 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 that has numerous barriers to the movement of both microbes and chemicals.

In soil fertility we are greatly interested in the soil chemical environment. 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 the soil 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 hydraulic and/or chemical transfer.

The transfer of nutrients in soil is dependent on their concentration 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 and where 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 very low concentrations and is strongly adsorbed by the soil surfaces. In contrast, nitrogen usually is found in much higher concentration in the soil solution (usually as NO_3^-) and is very weakly adsorbed. Consequently, phosphorus fertilizers must be placed very close to the seed to be effective, whereas nitrogen can be broadcast over the surface of the soil where it is washed down to plant roots. That said, it is generally more efficient to place fertilizers close to (but not in contact with) the plant or seed where it can be quickly obtained by growing roots regardless of the fertilizer type.

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. The most current theory is the plant root exchanges H^+ (hydrogen ions) for essential cations such as NH_4^+, K^+, Ca^{+2}, Mg^{+2}. Bear in mind, a plant's root system contacts with about one percent of the total soil mass it is growing in. Hence, root interception does not figure significantly in plant nutrient uptake. The root interception mechanism is very 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 inch 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 is the 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 is the 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 the soil solids would never get to the root. But nitrogen which is held very weakly by soil readily moves along with the water.

6.2 A Final Word about Roots

If plants obtained all of their nutrients from the air and depended on the soil only for anchorage, the purview of soil science, at least in agriculture, would be very limited indeed. But soil is the environment in which plants grow, and from which plants must obtain 14 of the 17 known essential mineral elements including water. Most farmers pay attention to the above-ground portion of plants, seeking therein signs of health, vigor, hunger, or distress. Roots, being buried 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 expose them for inspection outside of digging. But this is exactly what every farmer or farm advisor must do when signs of plant stress become evident 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 reduces the rooting volume of a plant must necessarily reduce yield. The challenge to every farmer is creating a soil environment in which roots can grow unconstrained. Only when this condition is met can we begin talking about plant health and maximizing yield potential. It really doesn't matter how many pounds per acre N, P, K that are present in each furrow slice (*organic* or *inorganic*). If plant roots are not functioning no amount of nutrient content in the soil will improve production.

Prepared by:

Robert Walters
Department of Soil Science
North Carolina State University
101 Derieux St. CB 7619
Raleigh, NC 27695

waltersrobt@gmail.com