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A Closer Look at Phosphorus Uptake by Plants

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ALMOST ALL PLANT PROCESSES require phosphorus (P) to operate. Phosphorus is essential for life sustaining reactions including energy transfer, activation of proteins, and regulation of metabolic processes. While the primary source of P for plants is inorganic phosphate, there are very few soils that naturally contain a sufficient P supply to allow unrestricted plant growth.

Compared with the other major nutrients, P is the least soluble and available to plants in most soil conditions and therefore it is commonly a major limiting factor for plant growth. Even in well-fertilized soils, the P concentration rarely exceeds a few hundred parts per billion (ppb) and is commonly less than 50 ppb in the soil solution.

Up to half of the soil P is commonly found in organic forms, derived from materials such as plant residues and soil organisms. However, organic P must be mineralized to inorganic phosphate (the form found in most fertilizers) before it can be taken up and used by plants for growth.

Because of its strong reactions with soil components, P is principally supplied to plant roots by diffusion rather than mass flow. Phosphorus uptake occurs primarily at the young root tip, into the epidermal cells with root hairs, and into cells in the outer layer of the root cortex.

The young root tips, continually expanding into fresh soil, are exposed to P concentrations found in the bulk soil solution (**Figure 1**). While P is rapidly taken up along the root surface, a P depletion zone of 0.2 to 1.0 mm develops surrounding the root. Root hairs help expand the surface area available for P absorption. Mycorrhizal fungi, growing in association with root cells and extending up to several centimeters into the soil, can also transfer P to the root.

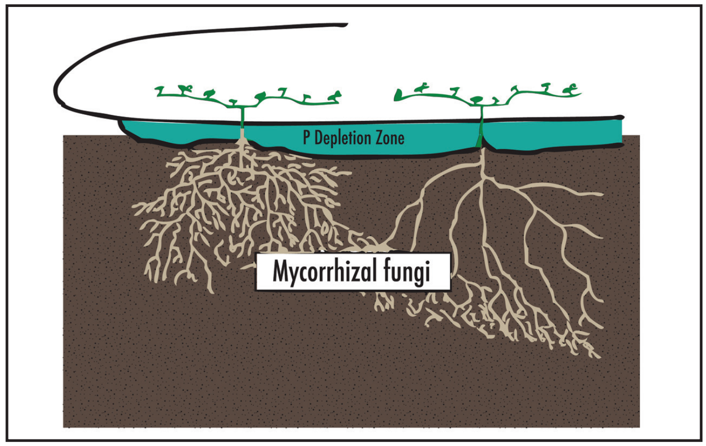


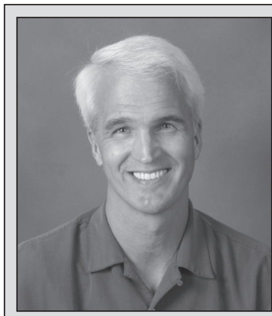
Figure 1. The P depletion zone surrounds a plant root. Mycorrhizal fungi can extend the nutrient extraction zone up to several centimeters out into the soil.

Various crops have been shown to have different abilities to extract P from the soil and to make these beneficial associations with mycorrhizal fungi that extend their effective root system.

Rhizosphere is the soil zone (within 2 mm, or the thickness of a nickel from the root) that is influenced by heightened biological activity, nutrient uptake, and chemical changes that result from root activity.

Getting P into the Plant: Apoplastic and Symplastic Transport

The **apoplasm** comprises the root walls, the cortical cells and the open spaces between these tissues (**Figure 2**). This "dead space" consists of interlaced fibers that form an open latticework in roots that serves to filter the soil solution. The soil solution moves through these spaces and pores until it reaches the tough "Casparian strip" that surrounds the core (stele) of the root. A net negative charge associated with the cell wall fibers repels anions...such as phosphate and nitrate (NO_3^-) in solution and confines their transport to larger pores within the apoplasm. Movement of nutrients through the apoplasm into the root is greatest near the root tip. Mucilage, a complex mixture of organic materials excreted around the root, also carries negatively charged hydroxyl groups which



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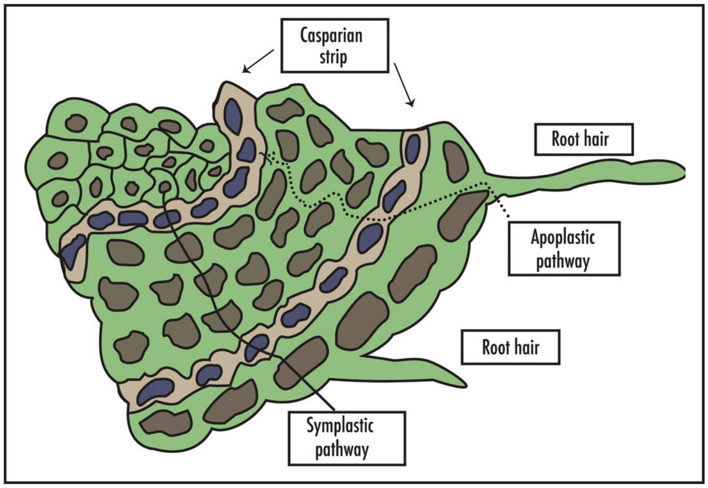

Figure 2. A root cross section, showing the apoplastic and the symplastic pathways of nutrient movement.

can further repel the movement of anions towards the root.

The **symplast**, by contrast, is a living system within the plant that connects each growing organ. It consists of thinwalled cells called parenchyma, which have small openings acting as "tunnels" where the content of one cell connects with the contents (protoplasm) of the adjacent cell. The symplast is very fragile and requires the rigid framework of the apoplast to hold it in place.

Although the soil solution P concentration may be less than 50 ppb, the concentration in plant cells is much higher…50 to 500 parts per million (ppm). For plants to boost their internal P concentration by over a thousand times, active transport (requiring energy) across the root membranes (the plasmalemma) is required.

The movement of P from the apoplast across root cell membranes is the critical step in the transport of nutrients into the plant, requiring an energy-driven transport mechanism to move P through the membranes into the plant root cells (phosphate transporters). Researchers are currently working on ways to increase the uptake of P by stimulating these nutrient transport proteins found in the root.

Other changes take place in the rhizosphere to improve P uptake and recovery. Many roots exude **organic acids** (primarily citrate and oxalate) into the rhizosphere, which enhance P availability. While this response has been frequently measured, the major effect may be due to the organic compounds displacing P held by the soil (ligand exchange), rather than a direct effect of the organic acids on the rhizosphere pH. Some microorganisms living in the rhizosphere have been shown to help solubilize soil P. These mechanisms can help improve P recovery, but they all require that P be present in the soil to begin with. **No amount of excreted organic acid, root-zone microorganisms, or mycorrhizal fungi can allow a plant to recover P from a soil that does not contain P to begin with.**

Plant roots can also have a considerable effect on rhizosphere pH. This pH change comes from the release of H^+ or OH^- (as HCO_3^-) as plants balance their uptake of excess cations or anions. Nitrogen nutrition plays the most important part in this ion balance since it is the mineral taken up in the largest quantity by most plants and it can occur as either an anion (NO_3^-) or a cation (NH_4^+). Research suggests that greater P uptake that occurs as plants are fertilized with a source of NH_4^+ may be the result of rhizosphere acidification that occurs with this N source. However, depending on the buffering capacity of the soil, only little change in pH may be observed in some soils.

There are many complex biological and chemical reactions occurring under our feet as roots invisibly work to meet the nutritional needs of the growing plants. Research is underway in many areas to improve the efficiency of P fertilizer use. Advances in improving root function may someday lead to better ways of meeting the nutrient demands of crops. **For now, the focus remains on maintaining adequate soil fertility by using regular plant and soil testing, proper fertilization techniques, and appropriate management to keep the nutrients where they are needed for the growing plant.** ■

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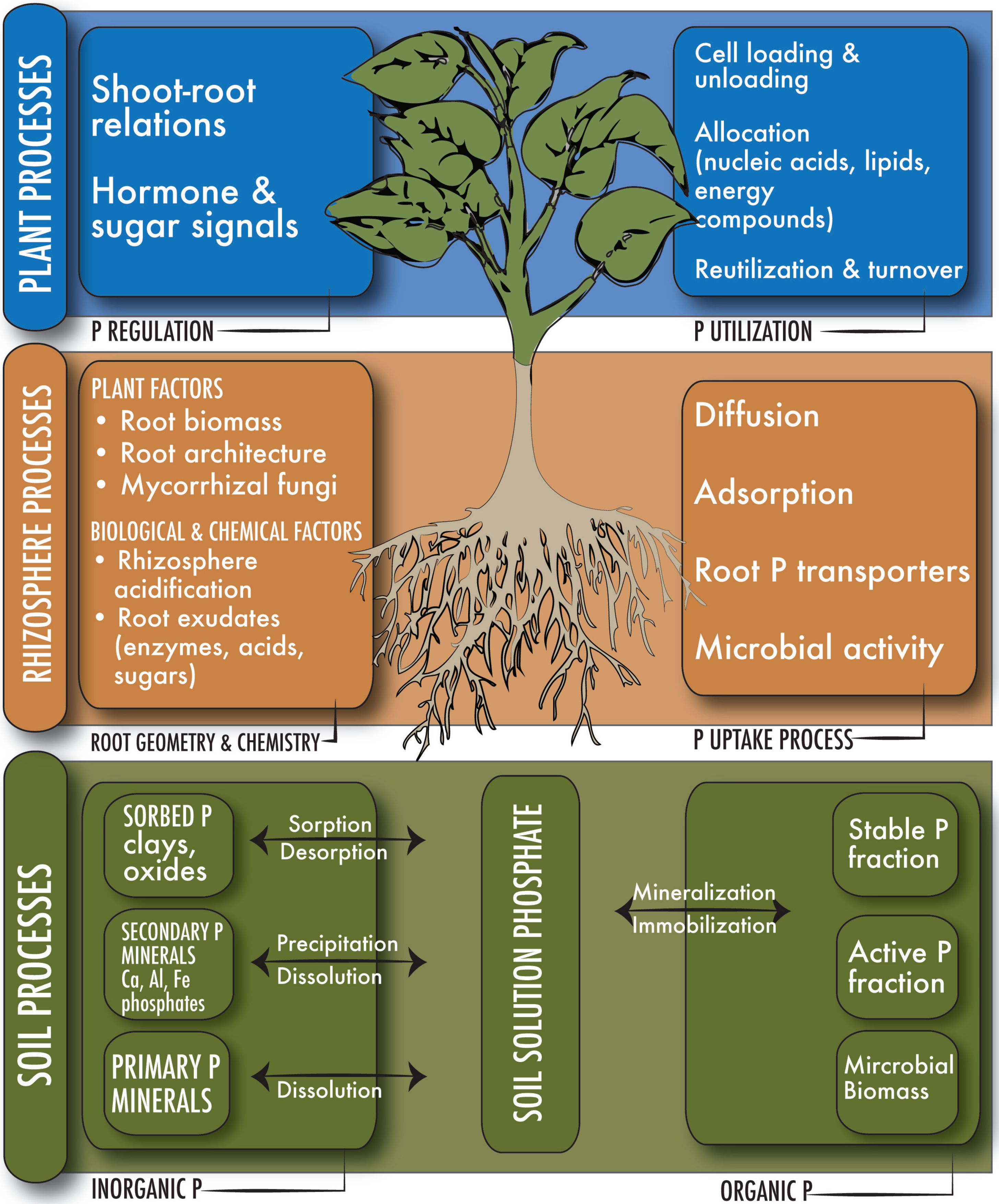

Figure 3. Nitrate (NO_3^-) sources tend to increase the rhizosphere pH (dark color) and ammonium (NH_4^+) sources tend to decrease the pH (light color). Phosphorus availability can be influenced by this change in soil pH.