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Why Plants Need Phosphorus

By D.G. Blevins

Healthy soybean leaves track the sun during the day in order to absorb a maximum amount of light, whereas leaves suffering P deficiency may turn their edges toward the sun in order to absorb minimum amounts of sunlight.

Phosphorus is an important essential macronutrient required by all plants for growth, development and reproduction.

> Phosphorus (P) is involved in photosynthesis, seed formation, and numerous other plant functions.

There are many important biochemicals in plants that contain P. Phospholipids are the primary structural component of membranes that surround each plant cell and organelle. Inside the cell, genetic information in the form of DNA and RNA molecules contains P as an integral structural component. These important molecules form the genetic information in the plant and guide the synthesis of proteins that work inside cells.

Proteins

Once proteins are made, when and where they work may be regulated by events that again involve P. Much of the metabolism inside cells is controlled by phosphorylation or dephosphorylation of certain proteins in an important class of proteins called enzymes. The addition or removal of phosphate then becomes a key signaling mechanism for what is happening inside a plant cell. The source of phosphate for signaling events is ATP (adenosine triphosphate). Besides this role, ATP is also the major energy currency in the cell. This molecule contains high energy phosphate bonds, which store and supply energy for cellular functions.

Photosynthesis

One of the keys to "life on earth" is the ability of plants to harvest energy from sunlight and trap it in the form of high energy phosphate bonds, to ultimately build carbohydrate molecules in the process of photosynthesis. Photosynthesis in plants involves P in many ways. Sugars made early in this process are mainly triose phosphates and hexose phosphates. Phosphate must also enter the chloroplast in order for triose phosphates to get out of the chloropast for use in other parts of the cell and in other plant parts. This phosphate/triose phosphate exchange reaction is critical for proper movement of sugar made in photosynthesis. In fact, in soybeans that are deficient in P, small sugars cannot exit chloroplasts properly. These sugars then accumulate and form large starch crystals which eventually cause structural damage to chloroplasts and shut down photosynthesis.

Water Movement

One of the most striking features of plants is their ability to move water in the xylem tissue. Xylem tissue is like an open piping system where water and nutrient elements move from roots to leaves. Water flow up the xylem tissue is very responsive to P and increases with high levels of P nutrition.

The control of the activity of proteins in plants by phosphorylation or dephosphorylation is of critical importance in many plant processes. Several proteins have unique structures that form gated channels through plant membranes, and these channels open and close depending on whether or not they are phosphorylated. These gated channels control, among other things, mineral and water transport in plants.

An adequate level of P nutrition has been found critical for proper magnesium (Mg) and calcium (Ca) uptake by roots and translocation up the xylem to leaves. The flow of Mg, Ca, and water up the xylem may be dependent upon availability of the high energy currency, ATP. With high levels of ATP, more P would be available for phosphorylation reactions opening Mg, Ca, and water channels in plant cells. More work needs to be done on specific channels in plant roots to determine their responses to the level of phosphate nutrition and ATP concentration in cells.

Photo source: Lauer and Blevins

Soybeans grown with adequate P nutrition (left) can rotate their leaves during the day to maximize interception of sunlight. With inadequate P nutrition, soybean plant leaves may have edges turned toward the sun and absorb minimal amounts of sunlight.

Seeds

During the late stages of plant reproductive growth when young seeds are being formed, P is remobilized from older leaves and moves into developing seeds. This makes a lot of sense, because seeds will contain important genetic information in the form of DNA. Phosphorus in seeds is also stored in phytic acid molecules. Each molecule of phytic acid contains six carbon atoms and six P atoms, and each of the P atoms has a negative charge. Therefore, the entire molecule contains six negative charges which can attract positively charged cations like potassium (K), Mg, Ca, copper (Cu), zinc (Zn), and iron (Fe). This is an effective way for seeds to store P and important cations for the next generation of plants.

Availability

Low soil level of plant-available P is a common condition around the world. Even though the total soil P may be high, the P is tightly bound to organic and inorganic soil components and is unavailable for uptake by roots. However, plants have developed many strategies for gaining access to bound P. These strategies include association with mycorrhizal fungi which attach to plant roots and develop hyphae that penetrate the soil, extract P, and then deliver it to the plant root in exchange for sugar. Some plants secrete organic acids, such as citric acid and malic acid, which form complexes with aluminum (Al) and Fe, releasing P for uptake by roots. Roots also secrete special enzymes like phosphatases, which break down organic forms of P in soil and make the P available for uptake by plant roots. Some plants have developed unique root architecture that helps them 'mine' P from the soil. These strategies are a few of the plant survival techniques that occur under stressful conditions.

Deficiency Symptoms

When plants are suffering from P deficiency, they have "hidden hunger" or they may show obvious visible symptoms. Visible effects of P deficiency are small, dark leaves and in some cases, purple coloration of stems and leaves. Roots of some plants suffering severe P deficiency may grow longer and skinnier than normal. This is fascinating since P deficient plants would not be equipped to handle a rapid rate of photosynthesis. BC

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