GREENHOUSE NUTRITION AND PHOSPHORUS

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Phosphorous is classified as a macronutrient. A macronutrient is required by the plant in large quantities for adequate plant growth to occur. An adequate internal concentration of phosphorous for higher plants is in the range of .1 to .4 % depending on the species of plant (Tisdale et al 1985). Phosphorous is absorbed by the roots of the plant. Plants primarily absorb phosphorous as the monovalent phosphate anion, $H_2PO_4^-$ or in lesser quantities as the divalent anion, HPO_4^{2-} (Salisbury and Ross, 1992). The pH of the media determines which phosphate anion will be most readily available in the media for absorption by the plant roots. At pH above 7.0, HPO_4^{2-} will predominate whereas below pH 7.0, the phosphorous exists as $H_2PO_4^-$. Plant roots are able to absorb phosphate from very low environmental phosphate concentrations (Mengel and Kirkby 1982). Phosphate uptake by plants is an active process against a concentration gradient between the root cell and the environment (Mengel and Kirkby 1982). The concentration of phosphorous in the plant root cells and xylem sap may be 100 to 1000 times greater than the media environment (Mengel and Kirkby 1982). Upon entry into the plant through the root cells, phosphorous is rapidly converted in organic forms involved in metabolic processes (Salisbury and Ross 1992). Phosphorous is a mobile macronutrient in plants and can be translocated either upward or downward in a plant (Mengel and Kirkby 1982). This macronutrient can be translocated through the xylem as either inorganic phosphate (monovalent or divalent anion depending on the pH) or through organic forms like sugar phosphates (Marschner 1986).

Phosphorous is involved in many essential functions of plant growth such as energy storage and transfer as well as a part of the structure of important molecules. Energy obtained by plants from photosynthesis is stored in the high energy phosphate bonds of adenosine di and triphosphates (ADP and ATP). When a phosphate group from an ADP or ATP molecule is hydrolyzed (split off), a large amount of energy is released. Plants can use this energy to fix CO_2 into carbohydrates. The carbohydrates may be metabolized where they are synthesized or transported to another location. The breakdown of these carbohydrates will result in energy in the form of ATP for use in plant growth. Many processes in a plant use the energy available in the phosphate bonds of ATP. Some of these processes are listed below (from Tisdale et al 1985):

1. Membrane transport. Transporting compounds in and out of a cell requires energy in the form of ATP.

2. Biosynthesis of cellulose, pectins, hemicellulose and lignin. These molecules are building blocks to form cell walls in plants.

3. Photosynthesis. Energy is required in the form of ATP in this process.

4. Protein synthesis. ATP is the energy source utilized in protein synthesis.

5. Phospholipid biosynthesis. Phospholipids are components of cell membranes.

6. Nucleic acid synthesis. DNA and RNA are the molecules which determine the genetic properties of a plant.

7. Respiration. Degradation of carbohydrates to produce energy requires energy in the form of ATP.

Besides playing a vital role in energy transport through ATP, phosphorous is an important component in the structure of many molecules in plants such as nucleotides, nucleic acids, phospholipids, coenzymes and sugar phosphates. Phosphorous is a vital element necessary for plant growth as is evident by the numerous functions and plant structures which require this macronutrient.

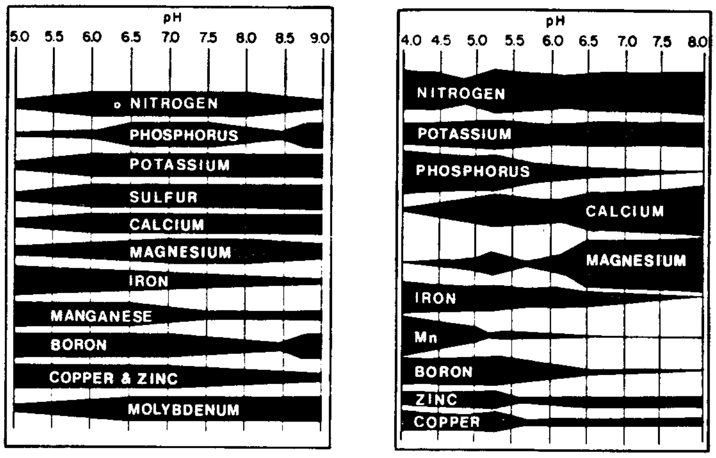
Listed below are some observations of plant growth which are characteristic of either (A) an adequate phosphorous level or in (B) a deficiency in phosphorous. Since phosphorous is a mobile plant nutrient and can be moved between different areas of the plant readily, when a phosphorous deficiency occurs, the effects may be noticed in the older plant tissues first. Deficiency symptoms are observed in the older regions first because phosphorous is removed from the older tissues and transported to the younger, growing areas of the plant where energy requirements will be greater than in the older plant tissues.

A. Adequate supply of phosphorous:

1. Increased root growth, thus a lower shoot/root ratio (Mengel and Kirkby 1982).
2. Early maturation of crops, especially grain crops (Tisdale et al 1985).
3. Increased disease resistance of some fruit, vegetable and grain crops (Tisdale et al 1985).
4. Chlorophyll content per unit leaf area is lower than in phosphorous deficient plants.

B. Inadequate supply of phosphorous:

1. Plant growth is generally slowed.
2. Plant leaves may be darker green in color than normal plants. The darker green color results because the plant cells and leaves expand more slowly while the chlorophyll formation precedes at a normal rate (Marschner1986). Therefore, the chlorophyll content per leaf area is higher thus producing the dark green color from the higher concentration of chlorophyll in the decreased tissue area.
3. Decrease in flower number (Marschner 1986).
4. Delay in flower initiation (Marschner 1986).



(a) (b)

Figure 1. The graphs in this figure compare the influence of pH on the availability of various plant nutrients from (a) a mineral soil (Troug 1948) and (b) a soil-less plant growth media consisting of sphagnum peat moss, composted pine bark, vermiculite, perlite and sand (Peterson 1982). The more wide the shaded area, the greater the availability of the compound to the plant.

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The amount of phosphorous available to plants is dependent upon the type of growth media of the plants.

Phosphate in the soil solution is the phosphate that is dissolved in the water around the soil particles.

The majority of phosphorous found in soils originated from the decomposition of rocks containing the mineral apatite.

Phosphorous contained in fertilizer solutions reacts with the plant growth media to create less soluble forms.

5. Formation of fruits and seed is depressed (Mengel and Kirkby 1982).

6. The fruits and seeds which do develop may be of lower quality (Mengel and Kirkby 1982).

7. Some annual plant species are characterized by a red or purple coloration which develops in the plant stems. The red or purple coloration of the stems results from accumulation of anthocyanin, a plant pigment associated with these coloration in plants (Mengel and Kirkby 1982).

The availability of phosphorous to plants is dependent upon a variety of factors. Phosphorous is the most immobile of the plant major nutrients and is leached at the lowest rate (Cooke and Williams). The amount of phosphorous available to plants is dependent upon the type of growth media of the plants (Figure 1). In a soil, phosphate can exist in three different pools (Mengel and Kirkby 1982):

1. Soil solutions contain phosphate.

2. A labile pool of phosphate exists in the soil.

3. A nonlabile pool of phosphate is found in soils.

Phosphate in the soil solution is the phosphate that is dissolved in the water around the soil particles. The labile phosphorous pool consists of phosphate in association with the surfaces of the soil particles. The negatively charged phosphate ions will adhere to the surface of particles in the soil which are positively charged. The phosphate adhered to surface of the soil particles is readily available to replenish the phosphate soil solution pool. The phosphate in the nonlabile pool can become available when the labile pool is depleted but only at a slow rate (Mengel and Kirkby 1982). The majority of phosphorous found in soils originated from the decomposition of rocks containing the mineral apatite, $Ca_{10}(PO_4)_6(F,Cl,OH)_2$ (Tisdale et al 1985).

Phosphorous contained in fertilizer solutions reacts with the plant growth media to create less soluble forms. The phosphate removed from a solution (liquid) phase and retained in the media is described as being fixed. The phosphorous retained by soils depends on several factors (Tisdale et al 1985):

1. Soil components. In general, soils which contain clay in larger quantities will retain or fix more phosphorous. Also, the calcium carbonate content of the soil will influence the amount of phosphorous retained. In soils that have a high calcium carbonate content, phosphorous may react to form calcium phosphate precipitates thus removing some of the phosphorous available to the soil solution. (Tisdale et al 1985).

2. pH. The pH of the media influences the type and amount of phosphorous available to the plant. The type of phosphate ion available at pH either below or above pH 7.0 was discussed in the first section of this article. Phosphorous is most available in the pH range of 6.0 to 6.5 (Tisdale et al 1985). At lower pH values, phosphorous can be retained by reaction with iron and aluminum. At pH values above 7.0, calcium, magnesium and carbonates may form insoluble phosphorous precipitates thus decreasing availability of phosphorous to the soil solution.

3. Cation Effects. The type of cation which prevails in the system will influence the retention of phosphorous in a growth media. Cations with a +2 charge like calcium when present in clays will retain greater amounts phosphorous than cations with a +1 charge like sodium. The action of cations is also depend upon pH. At pH values less than 6.5, calcium assists in adhering the phosphorus to the surface of clay minerals. However, at higher pH

values, phosphate may be precipitated with these cations from solution.

4. Temperature. In general, an increased temperature will increase the speed of chemical reactions. Also, as the temperature increases, the phosphorous retention of the media also increases (Tisdale et al 1985).

In general, the finer the media texture, the more enhanced is the retention of added fertilized phosphate. More surface area is available in a finer textured media for the phosphate ion to adhere. Also, the pH is important. The form and amount of phosphorous available to the plant will depend on the pH of the growth media. There are many types of phosphate fertilizers available on the market. The phosphorous content of fertilizers is expressed in the percentage of P_2O_5. Phosphate contained in fertilizers is described as following:

1. Phosphate soluble in water is termed water soluble.

2. Phosphate soluble in 1N ammonium citrate is called citrate soluble.

3. Phosphate which is not soluble in either water or ammonium citrate is described as citrate insoluble.

4. Available phosphorous is the sum of the phosphorous which is either water or citrate soluble.

5. Total phosphorous is the sum of citrate insoluble and available phosphorus amounts (Tisdale et al 1985).

Phosphorous is available to plants in either the water or citrate soluble form. For short season, fast growing crops, fertilizer with a high percentage of water-soluble is favored over high percentage of citrate-soluble phosphate fertilizers. Media which may contain calcareous compounds, granular forms of fertilizers high in percentage of water-soluble phosphate are preferred (Tisdale et al 1985). In general, fertilizers that contain a high percentage of water-soluble phosphate will provide satisfactory results under most circumstances (Tisdale et al 1985).

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