Soil Organic Phosphorus and the Nutrition of Plants in Natural and Agricultural Ecosystems

Benjamin L. Turner
Smithsonian Tropical Research Institute, Republic of Panama
Email: TurnerBL@si.edu

1. Introduction

Most studies on the phosphorus nutrition of plants have focused on inorganic phosphate as the only plant-available form. This is probably due to a variety of factors, including the observation that plants only seem to take up phosphate into their roots, analytical problems in the measurement of organic phosphorus in soils, and the agricultural basis of most research on plant nutrition. However, organic phosphorus is abundant in soils (typically 30–65% of the total phosphorus[1]) and its turnover can supply the majority of the phosphorus taken up by plants[2]. Importantly, plants can manipulate their access to organic phosphorus through mechanisms such as the synthesis of hydrolytic enzymes, secretion of organic anions, and association with symbiotic fungi (see below). In this presentation I will discuss recent developments in research on soil organic phosphorus and its significance for our understanding of plant nutrition in both natural and agricultural ecosystems.

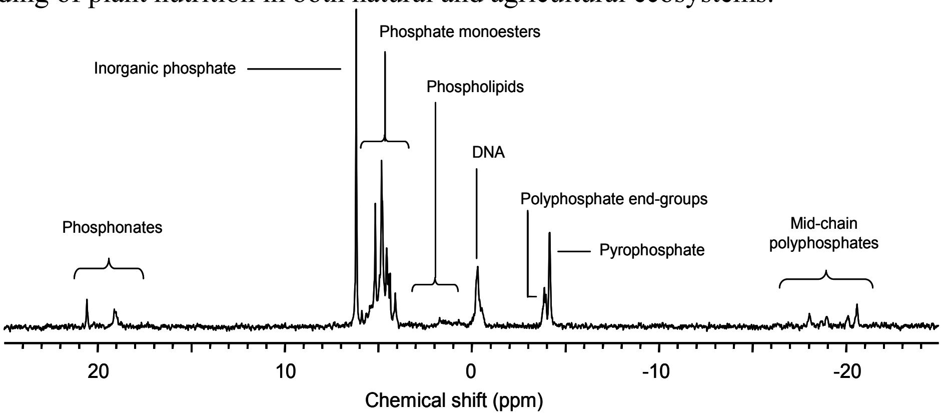

Fig. 1. An example of the identification and quantification of soil organic phosphorus by alkaline extraction and solution ^{31}P NMR spectroscopy. The sample is a Swedish tundra soil[3].

2. Forms of soil organic phosphorus

Soil organic phosphorus occurs in a variety of forms, including phosphate monoesters, phosphate diesters, phosphonates, and phosphoanhydrides. These compounds exhibit marked differences in their behaviour in soils, which influences their biological availability[4]. For example, the phosphate diesters, including the nucleic acids, constitute most of the organic phosphorus in biological tissue, but degrade rapidly in soil and are therefore relatively bioavailable. In contrast, the inositol phosphates (a type of phosphate monoester) constitute only a small fraction of the organic phosphorus in biological tissue, but react strongly in soils and accumulate to form a large component of the soil organic phosphorus. Despite the conventional problems with the analysis of soil organic phosphorus, its composition can now be conveniently determined by alkaline extraction and solution phosphorus-31 nuclear magnetic resonance spectroscopy (Figure 1), which has facilitated novel insight into its behaviour in the environment[5].

3. Plant acquisition of soil organic phosphorus

Although soil microbes play a major role in organic phosphorus turnover, plants also possess a variety of mechanisms that allow them to maximize their access to soil organic phosphorus. Of particular significance is the synthesis of phosphatase enzymes – a ubiquitous response of plants to phosphorus stress, which provides a clear indication of the importance of organic phosphorus in plant nutrition. Plants also secrete organic anions, which although often thought to solubilize only inorganic phosphorus, can also solubilize considerable amounts of organic phosphorus. Of considerable significance is the association of plants with mycorrhizal fungi – ectomycorrhizae and ericoid mycorrhizae are known to use soil organic phosphorus, and even arbuscular mycorrhizae, often thought to use only inorganic phosphate, are now known to be able to use organic phosphorus as a sole phosphorus source[6].

4. The significance of inositol phosphates

Of the various organic phosphorus compounds found in soils, the inositol phosphates are of particular interest[7]. They accumulate in soils and are therefore often thought to contribute little to the nutrition of plants. However, recent evidence has challenged this assumption, because it is now clear that many rhizosphere organisms[8], as well as arbuscular mycorrhizae[7], express phytase activity and therefore have the capacity to utilize inositol phosphates. This is supported by experimental studies that have detected the depletion of rhizosphere organic phosphorus, including the inositol phosphates, following the growth of *Pinus radiata* on temperate soils[9], as well as agroforestry species on tropical Oxisols[10]. A key factor determining the fate of inositol phosphates in soils appears to be the phosphorus status of the ecosystem, because although inositol phosphates accumulate in fertilized soils, they are virtually absent in soils of lowland tropical rain forests, freshwater wetlands, and strongly-weathered soils supporting 'retrogressive' forests. Striking evidence of this was recently reported from the Franz Josef soil chronosequence, New Zealand, which demonstrated that inositol phosphates accumulate rapidly in young soils supporting nitrogen limited forest, but decline to low levels as phosphorus limitation increases during pedogenesis, presumably due in part to biological degradation[11]. The implications of these findings for agriculture and ecology will be discussed, especially in relation to the potential agricultural exploitation of inositol phosphates through the genetic manipulation of plants.

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