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Review

Impacts of grassland afforestation with coniferous trees on soil phosphorus dynamics and associated microbial processes: A review

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Abstract

Grassland afforestation with coniferous trees, occurring in many parts of the world, can greatly affect the nature and transformation of soil organic matter and associated nutrients, including phosphorus (P). This review critically examines the shifts in soil P availability and chemical nature, microbial properties and soil quality, and possible mechanisms involved in the changes in P nature and transformation as a result of grassland afforestation, based on the published and unpublished data from investigations carried out in recent years. Grassland afforestation with coniferous trees is found to enhance mineralization of organic matter and associated P and consequently improve P availability in topsoil. This is attributed to a combination of factors including the greater P demand and uptake by trees, the improved solubility of organic P by root and microbial exudates (e.g. low molecular weight organic acids), greater tree root phosphatase activity associated with ectomycorrhizae, and favourable soil moisture and temperature conditions. In addition, grassland afforestation also modifies the chemical nature of soil organic P, with a decrease of inositol phosphates (including *myo*- and *scyllo*-inositol hexa*kis*phosphate) in soil under forest compared with grassland. On the other hand, grassland afforestation leads to lower soil microbial biomass carbon (C) and P, soil respiration and phosphatase activity, indicating a decrease in soil biological fertility. This may be associated with lower and less labile organic inputs into the mineral soil under coniferous forest compared with grassland and other chemical changes (e.g. lower soil pH) due to grassland afforestation. Future studies should focus on quantifying root and leaf litter inputs and turnover, characterization of the source, chemical composition and role of organic acids in the solubilization and hydrolysis of organic P using isotopic tracing and nuclear magnetic resonance (NMR) techniques, assessment of shifts in the composition, activity and function of the soil microbial biomass in relation to grassland afforestation using appropriate molecular techniques, and comparative study on particular roles of different mycorrhizae-root associations on the utilization of organic P in the soil environment.

Keywords: Grassland afforestation; Soil phosphorus availability; Organic phosphorus mineralization; ^{31}P NMR spectroscopy; Soil biological fertility

Contents

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1. Introduction

Land-use change has been of a topic attracting great interest and subject to intensive study in the past decades in relation to its potential impacts on carbon sequestration, soil quality, long-term sustainability and the environmental change (e.g. Davis and Condron, 2002; Rudel et al., 2005; Richards et al., 2007; Tate et al., 2007). As one of major forms of land-use change, grassland afforestation with coniferous trees has occurred in many parts of the world, including New Zealand, Australia, USA, Canada, China and some Africa and European countries (e.g. Maclaren, 1996; Otto and Simpson, 2005; Rudel et al., 2005; Oxbrough et al., 2006). This land-use change can occur in response to changes in political, social, economic or environmental conditions (Rudel et al., 2005). The major factors involved include increasing demand for timber and wood products and expected high economic returns from forestry, the desire to reduce soil erosion and conserve soil, and the potential for forests to sequester carbon (C) to counter climate change (Maclaren, 1996; Romanya et al., 2000; Zinn et al., 2002; Farley and Kelly, 2004; Rudel et al., 2005). For example, in New Zealand alone, approximately 440,000 ha of grassland and scrub were planted to exotic pine species (predominantly radiata pine (*Pinus radiata*)) over the decade between 1990 and 2000 (Davis and Condron, 2002). Grassland afforestation is likely to alter soil chemical, physical and biological properties significantly, which will, in turn, influence aspects of soil, water and environmental quality (Davis and Lang, 1991; Fahey and Jackson, 1997; Ross et al., 1999; Chen et al., 2000). Thus, this land-use change may have important implications for the long-term sustainable management of land resources and associated watershed processes (Fahey and Jackson, 1997).

Soils generally contain between 100 and 3000 mg P kg^{-1} soil, ca. 15–80% of which is present in organic forms (Condron et al., 2005). Much of soil P is not immediately available for plant uptake due to its physiochemical properties and soil chemistry (Holford, 1997; Ticconi and Abel, 2004). Low availability of soil P is a major nutritional constraint for primary production in many agricultural and forest ecosystems in the world. It is estimated that ca. 5.7 billion hectares of land worldwide is P-deficient for crops to achieve optimum yield (Batjes, 1997). Plants have developed various strategies for P acquisition from the P-limiting soil environment, including modifying root morphology and the rate of root growth to increase active root surface areas, activating expression of P transporter genes localized in the plasma membranes of roots and root hairs, enhancing interactions with soil bio-components by establishing close associations with mycorrhizae and other non-symbiotic micro-organisms and altering root biochemical processes by increasing root exudation of organic acids, phosphatase and other biologically active substances (Vance et al., 2003; Ticconi and Abel, 2004; Raghothama and Karthikeyan, 2005). These diverse capabilities by plant species may, in turn, differently modify the chemistry and biochemistry of soil P (Chen et al., 2000; Spears et al., 2001; Vance et al., 2003; Raghothama and Karthikeyan, 2005). In addition, changes in quantity and quality of organic inputs through the leave litter and root turnover (including exudates), as a result of shifts in plant species, can lead to the change in quantity and composition of soil microbial communities, which in turn affect soil P dynamics (Sparling et al., 1994; Kourtev et al., 2003; Niu et al., 2007).

Most of the recent detailed studies on the impacts of grassland afforestation with conifers on soil properties and processes were carried out in New Zealand, and this paper synthesizes data from these and other studies to critically examine the impacts of land-use change from grassland to coniferous plantation forest on soil P availability and dynamics and associated microbial processes. In addition to the shift in plant species through grassland afforestation, different management practices (e.g. animal grazing, P fertilization) may be introduced through land-use change. In order to differentiate the effects caused by the shift in plant species from those by management practices, this paper will focus mainly on the data from the experiments (both the field and the glasshouse) that excluded the impacts of management practices (e.g. fertilization, grazing).

2. Soil phosphorus availability and dynamics

Fisher and Stone (1969) observed an increased concentration of available P in the root zone of conifers compared with the open soil. In recent years, results from a series of paired site studies in New Zealand and other countries have shown that concentrations of total P and organic P in surface mineral soils under coniferous plantation forests were generally lower than those in adjacent grassland soils (Table 1), and this difference was more pronounced when comparing the forest soil with the improved grassland soil due to P fertilization of the improved grassland. On the other hand, concentrations of available inorganic P were greater in soils under the coniferous forest compared with the adjacent unimproved grassland (Table 1). Approximately, 14–74% of organic P in original grassland soils was mineralized after conversion from grassland to coniferous forest (Table 1). The impact of grassland afforestation on soil P availability may vary with experimental site and age of plantation forest. Using soil P fractionation, Chen et al. (2000) further found that in the surface soil of a Dystrochrept, all forms of organic P ($NaHCO_3$ and NaOH extractable) were lower under a 19-year-old forest stand (mixture of *Pinus ponderosa* and *Pinus nigra*) than under the adjacent unimproved grassland,