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Soil–water content and air-filled porosity affect height growth of Scots pine in afforested arable land in Finland

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ABSTRACT

We examined the soil–water content (SWC) and air-filled porosity (AFP) of afforested arable land *in situ* and related them with tree growth, which was expressed as the total length of 5-year-height growth above 2.5 m stem height. A total of 34 randomly selected sites in western Finland afforested with Scots pine (*Pinus sylvestris* L.) were sampled and SWC was measured using time domain reflectometry (TDR). Increasing AFP up to 30% and correspondingly decreasing SWC significantly increased tree growth while concentrations of foliar nutrients and contents of soil nutrients had no effect. Increasing organic matter content (OMC) and decreasing bulk density (BD) were accompanied by increasing SWC and decreasing AFP in the 0–10 cm soil layer. SWC values above 70% indicated critical AFP below 10%. It was found that 44% of the studied sites had mean AFP lower than 10%. The results obtained indicate that the afforested Finnish arable land with high soil OMC is commonly characterized by high SWC and low soil aeration, which can limit tree growth.

1. Introduction

Tree growth requires adequate availability of water and oxygen from the soil as well as a sufficient supply of nutrients, light, and heat. The availability of oxygen to the roots depends on the rate of influx of oxygen into and the efflux of carbon dioxide out of the soil to the atmosphere (i.e. soil aeration). Soil aeration is positively related to air-filled porosity (AFP) and negatively to soil–water content (SWC) (Glinski and Stepniewski, 1985). AFP is defined as a measure of the relative air content of the soil (Hillel, 1982). The results of poor soil aeration include reduction of growth or ultimately the death of trees (Kozlowski, 1986). Poor aeration may also result in a shallow rooting pattern and consequently in instability and propensity of trees to windthrow (Armstrong et al., 1976).

AFP is usually measured at a fixed matric potential value representing the upper limit of plant available water content (field capacity), which has been reported to vary from −5 kPa to −33 kPa (McKeague et al., 1984). The field capacity is defined as the presumed SWC at which internal drainage allegedly ceases (Hillel, 1982). In general, AFP is higher in coarse-textured than in fine-textured soils, and decreases with increasing bulk density (BD) of the soil (Heinonen, 1954; Archer and Smith, 1972; Reeve et al., 1973). Decreased AFP and impeded aeration can result from the mechanical compaction of the soil, the dumping of fill material, poor drainage and water logging, and heavy soil texture (Ruark et al., 1982).

Although there may not be a single critical value for soil aeration (Cook and Knight, 2003), usually the AFP value of 10% is presented as the minimum limit for gaseous diffusion and for plant root respiration and growth (Päivänen, 1973; Theodorou et al., 1991; Xu et al., 1992). Wall and Heiskanen (2003a) showed a curvilinear relationship between AFP and growth of Norway spruce seedlings in soils with high organic matter content (OMC) and the most suitable range of AFP for seedling growth to be 20–40%.

In recent decades, afforestation of arable land has been an important land use change in all over the world. In the case of Finland, over 240 000 ha of arable land, corresponding to 1% of the area of forest land, has been afforested (Anon., 2006). Afforested arable land range from mineral soils to peat soils, in the latter the surface soil being composed of peat and mineral soil mixed together in various proportions as a result of agricultural practices (Wall, 2005). Thus, afforested soils may vary considerably in OMC, SWC, and AFP, which can also affect the plantation performance and tree growth.

In the case of afforested arable land in Finland, the high water table levels associated with the predomination of small pores in the soil pore space means that there is a potential risk of impeded aeration and reduced tree growth (Wall and Heiskanen, 1998; Wall

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