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Geoderma 136 (2006) 411–422
GEODERMA
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Effect of mechanical site preparation on soil quality in former Norway spruce sites

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Received 19 August 2005; received in revised form 16 March 2006; accepted 2 April 2006
Available online 6 June 2006

Abstract

Mechanical site preparation (MSP) enhances Scots pine (*Pinus sylvestris* L.) plantation establishment on cutover pine sites in northern Fennoscandia, but long-term impacts of MSP on soil quality on cutover Norway spruce (*Picea abies* (L.) Karst.) sites have remained obscure. We measured soil dielectric permittivity (ε) as dependent on soil water content (θ_v), soil electrical conductivity (σ_a) and soil solution electrical conductivity (σ_w) at 14 former spruce sites, 8–23 years post-MSP in Finnish Lapland. The sites were mechanically prepared with Marttiini-plough that had created cross-contour disturbance tracks with following microsites: trench, tilt and untreated control between the tracks. Soil water content in trenches or untreated control was not lower as compared to that of spruce forest reference. Tilts were lower in soil θ_v, but this feature, however, appeared to vanish within 23 years. Soil electrical conductivity of all microsites was much lower as compared to spruce forest reference, and significant degradation of soil quality was observed such that untreated control-σ_a>tilt-σ_a>trench-σ_a. The soil σ_w was consistently lowest in trenches, evidently due to snowmelt induced leaching cycles. MSP treatments were unable to contribute to permanent changes in soil water regimes and site-specific soil water regimes appeared to be attributable to spatial variability of soil physical properties rather than MSP.

Keywords: Norway spruce; Mechanical site preparation; Dielectric; Soil water content; Conductivity; Leaching; Lapland

1. Introduction

Mechanical site preparation (MSP) is a common practice for establishing conifer plantations in northern boreal forests of Fennoscandia. Because of its high timber value, Scots pine (*Pinus sylvestris* L.) has been greatly favoured in artificial forest regeneration for a half century in northern Finland and Sweden. The objective of MSP is to alleviate soil drainage and nutrient availability as well as increase soil temperature to outplanted pine seedlings (Pohtila and Pohjola, 1985; Örlander et al., 1996). In addition to short-term effects, MSP has been shown to increase long-term site productivity on cutover pine sites with light textured and nutrient-poor soils (Örlander et al., 1996). Even though Scots pine is suited on sites with well-drained sandy glacial materials (Richardson, 1998) also poorly drained sites formerly covered by stands dominated by Norway spruce (*Picea abies* (L.) Karst.) have been tried

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doi:10.1016/j.geoderma.2006.04.018

out to artificially regenerate to Scots pine. One of the most severe MSP methods, ploughing (Marttiini), has been shown to improve performance of young pine plantations on mesic and fertile sites occupied formerly by Norway spruce (Pohtila and Pohjola, 1985). Despite success in the early stages, diebacks of pine saplings have, however, occurred as late as 6–20 years since regeneration (Pohtila and Pohjola, 1985; Hansson and Karlman, 1997; Witzell and Karlman, 2000; Sutinen et al., 2002a). Mortality of saplings has coincided with excess soil water content and concomitant disease incidences, *Gremmeniella abietina* in particular (Witzell and Karlman, 2000; Sutinen et al., 2002a). No reports are available to show MSP to permanently reduce soil θ_v on former Norway spruce sites to meet edaphic site requirements applying to Scots pine.

The soil θ_v is influenced by soil texture and structure (Vachaud et al., 1985; Bouten et al., 1992; Hänninen, 1997; da Silva et al., 2001) hence MSP treatments result in site-specifically diverse soil θ_v conditions. A number of short-term (2–10 years) experiments have demonstrated that seasonal soil θ_v of mechanically created microsites, such as mounds and ridges, tends to be lower than that of untreated control sites (Elliott et al., 1998; Burton et al., 2000; Staples et al., 2001). Mechanically created furrows, trenches and patches tend to be higher in the soil θ_v as compared to that in undisturbed control in glacial tills, but lower in stratified silt deposits as compared to mounds or undisturbed control sites (Mallik and Hu, 1997; Simard et al., 2003). Even though soil-specific and somewhat ambiguous, these observations demonstrate that MSP treatments change microsite soil moisture conditions at least for seedling/sapling stage. A key issue of MSP effects on soil properties is the length of time such treatments impact drainage and nutrient availability, and thereby site productivity (see Jurgensen et al., 1997). This is particularly a concern in northern boreal climate of Fennoscandia, where at least 20 years are required for the stabilization of Scots pine plantations (Hansson and Karlman, 1997).

MSP has an impact on nutrient cycling and tends to enhance height and volume growth of planted saplings (Jurgensen et al., 1997; Haeussler et al., 1999; Simard et al., 2003). Due to heterogeneity of glacial materials concentrations of chemical elements, however, vary by site and landscape (Lestinen, 1980; McBride et al., 1990; Sutinen et al., 2002b). Hence, the MSP responses to survival and height of some species may on some sites be negligible, but particularly on nutrient-poor sites severe MSPs may even lead to a decline of the species diversity of plant communities (Haeussler et al., 1999). Even though a number of short-term (2–9 years) experiments have indicated that organic matter decomposition and leaching of nutrients in soil surface and upper mineral soil sequences had enhanced following MSP (Van Cleve and Dyrness, 1983; Schmidt et al., 1996; Merino and Edeso, 1999; Hansen et al., 2000; Bock and Van Rees, 2002; Simard et al., 2003), little is known about long-term effect of MSP on soil quality on cutover Norway spruce sites in northern Fennoscandia.

Soil quality can be estimated by the soil solute content obtained with terrestrial electromagnetic induction or galvanic measurements of soil electrical conductivity (σ_a) (Rhoades and Oster, 1986; McBride et al., 1990; Hänninen, 1997; Puranen et al., 1999; Sutinen et al., 2002b). A strong correlation has been shown between the soil σ_a and soil attributes associated with forest productivity, such as exchangeable Ca, Mg and CEC (McBride et al., 1990). Site-specific calibrations are needed to estimate concentrations of chemical elements based on the measured σ_a (Das et al., 1999), but on glaciated terrain with known lithology and distribution of geochemical elements in tills (Lestinen, 1980; Pihlaja and Manninen, 1993) the measured σ_a, however, provides a justified basis to estimate relative differences in nutrient regimes between disturbed (cut-off and MSP) sites and adjacent uncut spruce forest reference sites (Sutinen et al., 2002b; see Schmidt et al., 1996; Pennock and Van Kessel, 1997; Bock and Van Rees, 2002). Simultaneous measurements of the soil θ_v and σ_a enable determination of the soil solution electrical conductivity (σ_w) to be of help to estimate site-specific soil quality along the soil θ_v gradient.

The objective of this study was to see (i) if MSP with Marttiini-plough is able to contribute to persistent reduction in the soil θ_v to meet site requirements by Scots pine and (ii) if MSP has long-term effects on soil quality at clear-cut harvested Norway spruce sites in Finnish Lapland. We minimized the effect of climatic events by applying one-time electrical measurements in the late growing season to characterize microsite soil conditions (ε, σ_a and σ_w) 8–23-years post-MSP treatments. For conversion of the soil ε we applied ε/θ_v calibration presented by Topp et al. (1980) as follows: $\theta_v = -0.053 + 0.029\varepsilon - 0.00055\varepsilon^2 + 0.0000043\varepsilon^3$. We compared soil quality between the disturbed (clear-cut and MSP) sites and undisturbed (uncut) references, which existed in analogous naturally established mature Norway spruce stands near the MSP sites. Also, a baseline reference for the soil θ_v was obtained on mature Scots pine sites. Simultaneously with the MSP-treated sites, Norway spruce and Scots pine references were