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Soil temperature and water content dynamics after disc trenching a sub-xeric Scots pine clearcut in central Sweden

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ABSTRACT

Soil scarification is widely used in boreal forestry to promote the growth and survival of seedlings. The aim of the study was to describe and analyze the impact of disc trenching on soil temperature and water content dynamics during the first six growing seasons after clearcutting. The site is a sub-xeric, coarse textured, coniferous field experiment, near Hagfors, central Sweden. Soil temperature and water content were measured hourly both 20 and 45 cm below the original surface of the mineral soil in three types of microsites created by disc trenching (furrows, ridges, and between-furrow areas) and an undisturbed control microsite outside the disc-trenched area. *Pinus sylvestris* L. seedlings were planted in the furrows and the control area before the measurements. The soil temperature and water content data were analyzed using linear mixed-effect models. Numbers of days exceeding critical thresholds of soil temperature and water content for seedling growth at each microsite were also calculated.

Disc trenching increased soil temperature in the topsoil (< 20 cm) of the furrows throughout the study period, but the effect declined over time. Similar, but weaker, effects were detected in ridges and between-furrows areas. Likewise, the largest daily and seasonal temperature amplitudes at 20 cm depth were recorded beneath the furrows, and the soil temperature sums (baseline 5 °C) over the whole study period were 20% higher in these microsites than in the control area. Soil temperatures never exceeded values considered optimal for root growth at any of the microsites. The soil water content in the furrows and control area only significantly differed during the last three years, when it was somewhat higher beneath the furrows. During the study period, the total number of days with potential water stress for the planted seedlings (volumetric soil water content $< 0.09\ m^3/m^3$) was 423 in the furrows compared to 554 in the control area. None of the microsites was wet enough to hamper aeration of roots in the topsoil.

In conclusion, soil temperature and water regimes were more favorable for the seedlings in the furrows than in the control area for at least six growing seasons. We recommend planting soon after disc trenching to maximize benefits from the improved soil temperature conditions in the furrows.

1. Introduction

Soil scarification is commonly used in boreal forests in ways that promote the growth and survival of planted seedlings on clearcut sites (Hébert et al., 2014; Nilsson et al., 2010; Sutton, 1993). In Sweden, for example, > 80% (ca. 170,000 ha) of the annual regeneration area is mechanically prepared (Swedish Forestry Agency, 2016). Soil scarification aims to change the microclimate encountered by seedlings, creating higher soil temperatures and more favorable soil water conditions. For moist and fine-grained soils in cold regions, a lower water content and increased aeration are often beneficial. On drier and warmer sites, and sites with coarse-textured soils, soil scarifications aims to retain sufficient water in the soil for the seedlings. Further advantages of soil scarification include the removal of competing vegetation and increasing nutrient availability (Johansson, 1994). It also reduces pine weevil (*Hylobius abietis*) damage by providing planting spots with pure mineral soil surfaces, which the weevils avoid (Nordlander et al., 2011). Moreover, the importance of preparing such

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planting spots will increase because use of chemical measures to prevent pine weevil damage is being phased out in forests certified by the Forest Stewardship Council (FSC, 2015).

Disc trenching (harrowing) is a form of soil scarification that creates three main types of microsites: *ridges* with a mixture of organic material and mineral soil; *furrows* where the organic layer is removed and the mineral soil exposed; and areas between two furrows where the original vegetation and organic layer are intact (hereafter *between-furrows*). The soil temperature and water content dynamics in clearcuts are governed by macro- and microclimate (Chen et al., 1993), vegetation (Balisky and Burton, 1995; Bhatti et al., 2000), and soil physical properties (MacKenzie et al., 2005), all of which except the macroclimate are altered by soil scarification (Balisky and Burton, 1995; Boateng et al., 2010). The soil temperature and growing season temperature sum increase in planting locations i.e. ridges/mounds or furrows/patches (Buitrago et al., 2015; Knapp et al., 2008; Kubin and Kemppainen, 1994; Löf and Birkedal, 2009; Simard et al., 2003; Örlander et al., 1998). This is beneficial because low soil temperatures can hinder plant growth by reducing their water uptake (Pallardy, 2008), water conductance (Örlander and Due, 1986), as well as transpiration (Mellander et al., 2004). Moreover, root growth (mass and length) is impaired by low temperatures (Alvarez-Uria and Körner, 2007). For example, the threshold temperature below which root growth is severely affected is around 4–5 °C for Scots pine (*Pinus sylvestris* L.) and 5–8 °C for Norway spruce (*Picea abies* (L.) H. Karst), Alvarez-Uria and Körner, 2007; Vapaavuori et al., 1992). The optimal temperature range for root growth of Scots pine is around 20–25 °C or higher (Söderström, 1974).

In addition, soil scarification typically reduces the soil water content in the upper 10 cm in ridges, tilts, or mounds and does not affect or slightly increases it in furrows, trenches, or patches (Burton et al., 2000; Mäkitalo and Hyvönen, 2004; Sutinen et al., 2006). A reduced soil water content is beneficial on wet sites as excessive soil water may be problematic for plants; an air-filled porosity below 10% reduces seedling growth, as gas diffusion essentially stops below this value, thus restricting soil aeration (Wall and Heiskanen, 2003; Xu et al., 1992). This threshold value can also affect other soil processes, as microbial activity can be severely limited below 10% air-filled porosity (Brady and Weil, 2001). A suggested threshold soil water potential for unfavorably dry conditions for seedling establishment is −0.1 MPa (Örlander et al., 1998). Transpiration rates of conifer seedlings, including Scots pine, start to decline at soil water potential of −0.1 to −0.2 MPa, but the degree of reduction is species-dependent (Jarvis and Jarvis, 1963; Lopushinsky and Klock, 1974). At a soil water potential of −1 MPa, pines transpire at a rate corresponding to 12% of their maximum rate, according to Lopushinsky and Klock (1974). However, newly planted seedlings may still have difficulty taking up water, even if the soil water potential never falls below −0.1 MPa (Örlander and Due, 1986), as their roots are not fully established. Containerized seedlings are more resistant to drought after planting than bare root seedlings as they have a higher root growth potential (Grossnickle, 2012; Grossnickle and El-Kassaby, 2016), but their water uptake may still be reduced for at least two years (Örlander, 1986). The nitrogen and carbon mineralization rates are also affected by soil water content, and the optimum condition for these processes is around 60% water-filled pores of total porosity (Linn and Doran, 1984; Seyferth, 1998).

As shown by the brief summary above, various effects of soil scarification have been examined. However, few studies on forest land have looked at the effect of soil scarification on both soil temperature and water content using detailed temporal resolution (i.a. Bhatti et al., 2000; Burton et al., 2000; Simard et al., 2003). In agriculture the soil temperature and water content dynamics in different tillage systems have been studied (eg. Williams et al., 2016; Yang et al., 2016; Zhang et al., 2015), but not usually long-term dynamics, because agricultural crop rotation is short. In forestry, with rotation periods of several decades, long-term studies are possible, but few have investigated changes in effects of soil scarification on soil temperature and water content dynamics over time (i.a. Devine and Harrington, 2007; Kubin and Kemppainen, 1994). In the study presented here, soil temperature and water content were measured hourly during the first six growing seasons following disc trenching in a clearcut in central Sweden; site of the long-term field experiment *165 Hagfors* (Jacobson and Pettersson, 2010; Johansson et al., 2013; Rappe George et al., 2017; Ring et al., 2013). The data were statistically analyzed to detect trends among the microsites in terms of both absolute values and relative to the microclimatic thresholds for planted seedlings discussed above. The study had three main aims. First, to describe the impact of disc trenching on soil temperature and water content in the created microsites and to assess the duration of any effects. Second, to analyze the data in relation to soil water and temperature threshold values for seedling growth, i.e. numbers of days in each type of microsite that critical thresholds were not met. Third, to evaluate whether the chosen microsites for planting (furrows) were adequate planting spots at the focal site in terms of soil temperature and soil water content.

2. Materials and methods

2.1. Study site

The field site *165 Hagfors* is situated on a sub-xeric podzolized sandy-silty till soil in Sweden, 60°00′N, 13°42′E (Ring et al., 2011), and has a site quality class of 5.9 $m^3\,ha^{-1}\,yr^{-1}$ (Ring et al., 2013), with a field and ground layer dominated by lingonberry (*Vaccinium vitis-idaea*) and lichens (*Cladonia* spp.), respectively (Vaccinium Type, according to Cajander, 1949). It is in the humid continental climate zone, Dfb, according to the Köppen climate classification system (Köppen, 1936), with an annual mean air temperature of 3.5 °C (average for 1961–1990) and a precipitation sum of 671 mm per year on average (Alexandersson and Eggertsson Karlström, 2001).

The previous Scots pine stand was harvested in March 2006, when there was a 0.5 m snow layer, and the studied areas were cleared of logging residues. Soil scarification was performed in May 2006 using a Bracke Forest disc trencher (T26, Bräcke, Sweden, which has two rotating discs at the rear) attached to a Timberjack 1710D forwarder. Three types of microsites were created: furrows, ridges, and between-furrows (Fig. 1a). Micro-topographical effects of disc trenching were measured from the top of the original organic soil surface with a ruler in 2006 (n = 27) and 2012 (n = 54) in the study plots used by Ring et al. (2013), scattered over the same clearcut. Ridges, furrows, and between-furrows were all ca. 70 cm wide. In 2006, the ridges were 21 ± 4 cm tall and the furrows 17 ± 8 cm deep (Ring et al., 2013). Six years later, the ridges were 11 ± 3 cm tall and the furrows 13 ± 5 cm deep (quoted values are means ± standard deviations). In June 2006, 1.5-year-old Scots pine containerized seedlings were planted in the furrows and the control at a spacing of 2 m (Johansson et al., 2013).

Air temperature was measured hourly (2006–2011) at a height of 1.9 m (Rotronic Hygroclip S3, Campbell Scientific Ltd.), and precipitation was collected with a tipping bucket rain gauge (type ARG100) placed at the soil surface. Due to technical problems, there were short periods of missing values for which air temperature and precipitation data were interpolated from the nearby meteorological station in Gustavsfors, operated by the Swedish Meteorological and Hydrological Institute, SMHI (Rappe George et al., 2017). During the studied seasons (May–October) in 2006–2011 the mean air temperature varied between 10.8 °C (in 2009) and 13.5 °C (in 2006 and 2011) and the accumulated precipitation between 377 and 628 mm, with the two lowest precipitation values in 2006 and 2011 and the highest in 2009. Generally, the ground water level, measured four times per season, tended to be deeper than 1 m.

2.2. Soil temperature and water content measurements

Soil temperature and water content were measured hourly in the