Extended abstract. No. 69

DOES SOIL PREPARATION STIMULATE OR SEDATE HETEROTROPHIC SOIL RESPIRATION AND PINE SEEDLING GROWTH IN NUTRIENT-POOR CLEARCUT PEATLAND FOREST?

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SUMMARY

Preparing soil after clearcutting may influence the rate at which peat soil decomposes and hence increase the loss of CO_2 into the atmosphere. At the same time, soil preparation is considered a necessary means to expedite stand establishment due to its presumably beneficial effects on soil properties and decomposition. Mounding, scalping, and control treatments were applied to a drained, formerly Scots pine-dominated clearcut peatland. Astonishingly, neither mounding nor scalping increased soil CO_2 emission (g m^{-2} h^{-1}) relative to leaving soil undisturbed. In addition, Scots pine seedlings planted in unprepared spots grew equally well as those in mounds, while both the survival rate and growth in scalps proved inferior to the aforementioned microsites. Thus, we found soil preparation on nutrient-poor, forestry-drained peatland sites to pose only negligible climatic risk whilst providing rather meager silvicultural benefits.

KEY WORDS: soil preparation, peatland forest regeneration, CO_2 emission

INTRODUCTION

Soil preparation applied after clearcutting may alter the speed with which peat soil decomposes and hence aggravate the loss of CO_2 into the atmosphere, but these effects are largely unknown (Minkkinen *et al*., 2008). From the forestry perspective, it has long been assumed that soil preparation is a necessary means to expedite stand establishment due to, e.g., its ameliorative effects on decomposition and thus nutrient mineralization (Sutton *et al*., 1993), although concrete evidence supporting this theory, particularly on peat soils, is lacking (Prescott *et al*., 2000). Mounding is the primary method of soil preparation applied on deep peat sites (Saarinen, 1997), most importantly because it improves soil aeration and local drainage for seedlings (Sutton, 1993; Londo and Mroz, 2001) in the otherwise soggy soil conditions typically ensuing afer clearfelling (Paavilainen and Päivänen, 1995). However, very few relevant comparisons between different methods of soil preparation, including the option of leaving soil undisturbed, have actually been implemented on drained peat soils. Saarinen (2005) has presented promising regeneration results with scalping on suitably drained peatland sites. Roy *et al.* (1999), on the other hand, emphasized the careful selection of planting spots in unprepared peat soil (hummock as opposed to hollow) as a means of encouraging seedling survival and growth. Clearly, a need exists for testing alternative measures of stand establishment and soil preparation on peatlands in commercial forestry use.

In the following, we weighed the outcome of soil preparation on peat decomposition and Scots pine regeneration success. The hypotheses were:
1) Organic matter decomposition rate is most rapid in mounds compared to scalps and unprepared microsites (mounds > scalps > unprepared).
2) Survival and growth of pine seedlings (regeneration success) in mounds surpass those of seedlings planted in scalps and unprepared microsites (mounds > scalps > unprepared).

MATERIAL AND METHODS

Study sites and experimental treatments

Our experimental area was located on a 6-ha riverside peatland in Hyytiälä (61°50'41"N 24°17'19"E), Central Finland. First drained in 1933 followed by ditch maintenance in 1986, it was divided into Northend (N) and Southend (S) sites which represent a transitional site type between dwarf shrub (Vatkg) and *Vaccinium vitis-idaea* (Ptkg II) drained peatland types according to the Finnish classification system (Vasander and Laine, 2008). Prior to clearcutting in March 2006, Scots pine forest (155 m^3 ha^{-1}) covered the sites. The close proximity of the river combined with minimal site inclination creates soggier soil conditions overall in the Northend site than the Southend one as witnessed by the prevalence of cottongrass (*Eriophorum vaginatum* L.). The thickness of the moderately decomposed (H4-5 on the von Post scale of humification) *Carex-Sphagnum* peat deposit exceeds 1.5 m in the Northend and Southend alike.

On both sites, mechanical soil preparation (mounding and scalping) and control (unprepared) treatments were randomly allocated to 30 × 30 m subsites; thus, the Northend and Southend sites constituted replicates of the 3 treatments. Mounding resulted in approximately 20-30 cm high compacted peat heaps atop unprepared ground next to excavated pits. This technique left the deeper peat exposed on top of mounds with the original vegetated surface buried underneath. Scalping created discontinuous 1-1.5 m long, 35 cm wide, 10 cm deep bare peat patches from which the humus layer and vegetation had been removed. The soil in control subsites was left undisturbed. In May 2007, both sites were planted with year-old containerized Scots pine (*Pinus sylvestris* L.) seedlings of equal size at a density of 2000 seedlings ha^{-1}.

Plot preparation and CO_2 efflux measurements to determine rate of peat decomposition

For the purpose of quantifying the heterotrophic peat soil respiration rate, 18 plots total were established as follows: 3 mounds, 3 scalps and 3 unprepared microsites in the Northend and likewise in the Southend. Sample plots were cut around with a handsaw and thereafter an aluminum collar (d=31.5 cm) with a 25 cm long sleeve (area=0.078 m^2) was inserted so as to eliminate root respiration and the production of new roots. Furthermore, aboveground parts of ground vegetation were removed. Throughout the measurement campaign, any sprouting vegetation was regularly clipped and newly deposited litter disposed of.

Soil CO_2 effluxes were measured 3-4 times per month during the growing season by employing the closed chamber method (Alm *et al*., 2007). For this, a portable infrared gas analyzer attached via rubber hoses to a soil respiration chamber (h=12.2 cm, d=31.5 cm) was used (EGM-4 Environmental Gas Monitor for CO2 + modified SRC-1 soil respiration chamber, PP Systems, UK). The soil CO_2 efflux (g CO_2 m^{-2} h^{-1}) is based on the linear increase over time of the CO_2 concentration in the chamber. The CO_2 efflux measurement campaign commenced in July 2007 and concluded in August 2009.

Survey of regeneration success

At the end of their third growing season, the survival rate and height of the 4-year-old planted pine seedlings on all six subsites were assessed by means of circular fixed-area sampling. On each subsite, 3 circular sample plots with a radius of 3.99 m (area=50 m^2) were situated within a minimum of 2 m from each other and subsite boundaries. Seedling stand density (seedlings ha^{-1}), and consequently survival rate based on the initial planting density, was calculated as the mean density of the 3 circular sample plots by subsite. Mean seedling height was based on the combined total number of living seedlings found in the circular sample plots of a given subsite.

Statistical methods

Based on the characteristics of the experimental design, a general linear mixed model (Mixed procedure in the SPSS 17 statistical software package) with restricted maximum likelihood (REML) estimation method was chosen to test the effects of treatment on the dependent variables (instantaneous CO_2 flux, seedling survival rate and height). We lacked independent replicates of the two types of site, therefore this research is a case study in nature.

RESULTS

Neither mounding nor scalping intensified heterotrophic peat soil respiration relative to the control treatment **(Fig. 1)**. In the wet Northend **(Table 1)**, mounds and scalps emitted CO_2 at a similar rate, but at only approximately half the rate of unprepared microsites. In the dry Southend **(Table 1)**, equal rates of peat decomposition in mounds and the control were observed, while scalps clearly emitted the least CO_2. Overall, no significant differences in decomposition rate were found between treatments. The maximum emission rates according to microsite type and site were as follows (in decreasing order): mounds S, 1.19 g CO_2 m^{-2} h^{-1} ; control N, 0.92; control S, 0.77; mounds N, 0.52; scalps N, 0.40; and scalps S, 0.30.

Table 1. Mean WTL (± SD) during growing season from 2007 to 2009 indicated as depth below soil surface (cm) according to site and microsite type. N = Northend, S = Southend.

	WTL
N, control	30.2 ± 14.9
N, scalps	8.7 ± 9.3
N, mounds	41.8 ± 9.0
S, control	41.2 ± 9.6
S, scalps	11.7 ± 15.8
S, mounds	51.6 ± 13.3

Seedlings survived significantly better in mounds than scalps and unprepared microsites **(Table 2)**. In scalps, seedling survival was especially poor. In regards to seedling height after three growing seasons in field conditions, those planted in mounds and unprepared microsites grew equally well and thus did not significantly differ from each other overall **(Table 2)**. Seedlings planted in scalps, however, were significantly shorter than those growing in the other two microsite types.

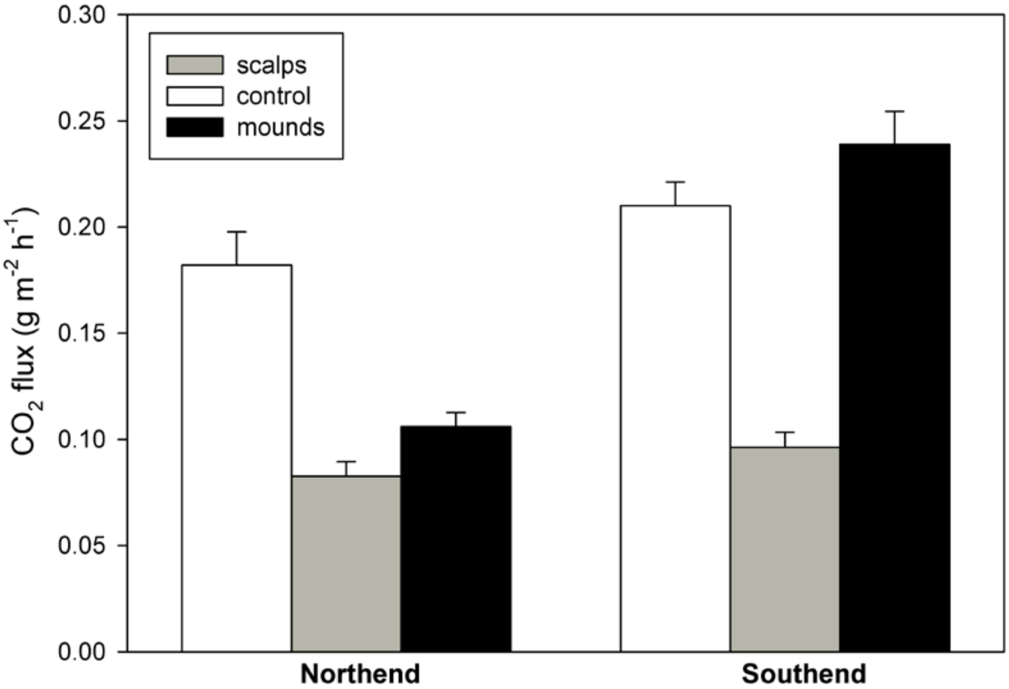

Figure 1. Mean heterotrophic peat soil respiration rate (± SE) over three growing seasons (2007-2009) in the three treatments according to site.

Table 2. Mean survival rate and height (± SD) of containerized Scots pine seedlings three summers after planting according to site and subsite. Survival rate relative to initial planting density of 2000 seedlings ha^{-1}. Height based on total number of seedlings found alive. N = Northend, S = Southend.

site / subsite	survival rate (%)	height (cm)
N, control	60 ± 10	41.5 ± 8.2
N, scalped	50 ± 44	26.8 ± 8.0
N, mounded	93 ± 12	42.0 ± 11.2
S, control	53 ± 32	46.5 ± 8.6
S, scalped	17 ± 15	32.2 ± 13.2
S, mounded	87 ± 6	45.9 ± 14.8

DISCUSSION

Soil preparation created a wide range of soil moisture conditions which were reflected in both respiration from peat decomposition and regeneration success **(Fig. 1, Tables 1 and 2)**. In complete contrast with our first hypothesis, neither mounding nor scalping increased heterotrophic soil respiration relative to the control. Particularly scalps suffered from waterlogged soil and the consequent lack of oxygen which in effect restricted microbial respiration. Given that the surface of scalps was situated approximately 10 cm below the original surface of the drained peatland, their ability to disperse and/or percolate surplus water was limited and slow compared to other microsite types during periods of excess rainfall and high WTLs. Additionally, the fairly slow hydraulic conductivity and high water retention capacity of the moderately decomposed *Carex-Sphagnum* peat (Päivänen, 1982**)** only compounded the hydrological debacle. Water tables have also been shown to control the emission of CO_2 by regulating the O_2 supply to decomposer microflora in soils with thick organic layers at high latitudes (e.g., Moore and Dalva, 1993; Davidson *et al.*, 1998). On the same site type as ours, Mäkiranta *et al.* (2010) similarly concluded that clearcutting reduced the decomposition rate of peat soil due to a rise in the WTL.

Most profoundly, mounding, which as an intensive method of soil preparation has long been revered for improving tree seedling growth and soil conditions (including decomposition) especially in peatlands, either reduced (Northend) or negligibly influenced (Southend) peat decomposition relative to the control. This finding is akin to that of Mojeremane (2009) from afforestation sites on peaty gley soils. When considering the location of the most readily decomposable organic matter relative to the WTL from the aspect of aerobic fungi and bacteria, this result is not however so surprising. In pure, unmixed peat mounds, the best quality substrate for microbial decomposition is actually buried underneath. Conversely, the upper portion of mounds consists of more decomposed organic matter, i.e., old recalcitrant carbon. Hogg *et al.* (1992) found that old, deeper peats are resistant to decay despite exposure to warmer, aerobic conditions; this would also appear to be the case in the mounds studied here. Additionally, burying of the newer carbon into a low oxygen environment close to the water table at the bottom of mounds may explain why mounding did not accelerate decomposition relative to the unprepared treatment; the newer carbon in unprepared plots enjoyed better soil aeration. Mojeremane (2009) previously identified a low oxygen situation at the bottom of mounds which restricted decomposition. Furthermore, Smith *et al.* (2003) stressed the importance of soil aeration and water content in controlling the diffusion of CO_2 through soil into the atmosphere. In our case, CO_2 had to travel from the poorly aerated mound bottom through the denser, recalcitrant peat summit. Hence, the conditions for gas diffusion were less than ideal.

In this study, regeneration success depended strongly on planting spot position and its distance to the WTL. Although regeneration was most successful in mounds based on survival and growth, it nonetheless failed to accelerate pine seedling growth relative to unprepared planting spots. Thus, our findings challenge the widely held presumption (i.e., the motive for applying mounding) in peatland forestry, that mounding accelerates seedling growth compared to leaving soil unprepared (Mannerkoski, 1975; Kaunisto, 1984). The elevation of unprepared planting spots (Roy *et al.*, 1999) together with surrounding transpiring vegetation (Verry, 1988) may have determined whether WTL became a survival and/or growth inhibiting factor or not in the control treatment. In any case, the regeneration situation there did not present itself as being troublesome since seedlings of both natural and artificial origin (former not surveyed) complemented each other. In fact, the lack of differences in height between seedlings growing in mounds and unprepared spots would seem to indicate relatively equal growing conditions. Careful consideration of microrelief, peat characteristics, species, and local climate prior to planting may improve the survival rate in unprepared peatland forest regeneration sites as suggested by Roy *et al*. (1999). The tragic regeneration situation encountered in scalps, which was clearly worse than in the control microsites, was primarily due to excess moisture as alluded to earlier. The results of this study confirm the all too familiar dangers associated with insufficient drainage in clearcut peatland forest regeneration areas. Soil preparation to promote stand regeneration, like scalping, is far from cost-effective if surplus water cannot be expelled, thus identification of vulnerable sites is an absolute necessity if the intention is to continue practicing forestry in deep-peated forest regeneration areas in the future. As a soil preparation method on peat soils, scalping clearly needs further development aimed at reducing susceptibility to “watering up”. By adjusting scalp depth and inclination (and planting position), for instance, it may be possible to prevent scalps from becoming death pools.

CONCLUSIONS

The observations made in this study conflict quite radically with the prevailing conceptions regarding the impacts of soil preparation on peat soils. Compared to leaving soil unprepared, soil preparation through mounding and scalping increased neither the decomposition rate of peat soil nor the growth of planted Scots pine seedlings over three growing seasons. In light of these findings, any further studies on this topic are well worth undertaking.

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