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Steam Treatment of Forest Ground Vegetation to Improve Tree Seedling Establishment and Growth

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SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES

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Abstract

Mechanical soil scarification is the commonly used site preparation technique in Sweden today and there is a need for alternative site preparation methods to fulfil some environmental goals in Swedish forestry. Thermal vegetation control could be an alternative method that reduces the competing forest ground vegetation with minimal disturbance to the mineral soil and ground floor. The aim with this work has been to investigate if it is possible to control forest ground vegetation by steam treatment as an alternative site preparation method before planting or seeding. Studies were conducted on four sites, each representing main Swedish forest vegetation types, i.e. the ground vegetation was dominated by crowberry (*Empetrum hermaphroditum* Hagerup), bilberry (*Vaccinium myrtillus* L.), heather (*Calluna vulgaris* (L.) Hull) and wavy hair grass (*Deschampsia flexuosa* (L.) Trin.). Steam generally controlled recolonisation of vegetation on all investigated sites for a longer time than soil scarification. Especially in controlling grass vegetation steam treatment was much more effective than soil scarification. The establishment and growth of seeded Scots pine seedlings also improved after vegetation control by steam treatment compared to that in intact vegetation. For all sites, both steam treatment and soil scarification improved seedling height growth compared to seedlings planted in intact vegetation. In the bilberry and heather dominated sites seedling growth in steam treated plots was even better than for seedlings planted in mechanical soil scarified plots. Further, key biological soil processes such as microbial activity and mycorrhizal colonisation were not negatively affected by steam treatment. The conclusion made from these studies is that steam treatment has the potential to be used as an alternative site preparation method especially on sites dominated by ericaceous vegetation. However, the method requires some further technical development before it may be used on an operational scale.

Keywords: Calluna vulgaris, Deschampsia flexuosa, Empetrum hermaphroditum, Norway spruce, Scots pine, soil scarification, thermal vegetation control, *Vaccinium myrtillus*

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Contents

Appendix

Papers I-V

The present thesis is based on the following papers, which will be referred to by their Roman numerals.

I. Zackrisson, O., Norberg, G., Dolling, A., Nilsson, M-C., and Jäderlund, A. 1997. Site preparation by steam treatment- effects on forest vegetation control and establishment, nutrition and growth of seeded Scots pine. Canadian Journal of Forest Research 27: 315-322.

II. Norberg, G., Jäderlund, A., Zackrisson, O., Nordfjell, T., Wardle, D. A., Nilsson, M-C., and Dolling, A. 1997. Vegetation control by steam treatment in boreal forests: A comparison with burning and soil scarification. Canadian Journal of Forest Research 27: 2026-2033.

III. Jäderlund, A., Norberg, G., Zackrisson, O., Dahlberg, A., Demel Teketay, Dolling, A., and Nilsson, M-C. 1998. Control of bilberry vegetation by steam treatment: effects on seeded Scots pine and associated mycorrhizal fungi. Forest Ecology and Management 108: 275-285.

IV. Norberg, G., Dolling, A., Jäderlund, A., Nilsson, M-C., and Zackrisson, O. 2000. Control of heather (*Calluna vulgaris* (L.) Hull) by steam treatment – effects on establishment and early growth of Scots pine. Submitted manuscript.

V. Norberg, G. 2000. Steam treatment as a vegetation management method on grass dominated clearcuts. Manuscript.

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Introduction

Background

The silvicultural objective of vegetation management is to directly control competing vegetation in order to increase resources availability for tree seedlings that either exist or will be established (Oliver 1998). In Sweden, ground vegetation management for forest regeneration purpose is primarily accomplished using mechanical site preparation which involves removal of vegetation and humus layer before planting and seeding or natural regeneration from seedtrees. Today, mechanical site preparation is applied to approximately 160 000 ha per year, which represents about 75% of the total clearcut area (Anon. 2000a). Disc trenching is the most commonly used method together with mounding (for definitions see Örlander *et al.* 1990). The clearcutting silvicultural system used today in Sweden came into practice at the beginning of the 1950's. At this time prescribed burning was the most common site preparation method. In 1960's mechanical site preparation methods were introduced, at the same time as prescribed burning came under environmental criticism (Bäckström 1986). Today, concerns are being expressed about the environmental effects of the excessive soil disturbance caused by mechanical soil scarification (Rosén and Lundmark-Thelin 1986; Johansson 1994; Humphrey *et al.* 1995). There are also concerns raised about the destruction of ancient remains by mechanical soil scarification (Anon. 2000b).

Over the past 40 years several different types of mechanical soil scarification methods have been tested, and increased soil temperature and soil moisture are often mentioned as the main factors important for successful tree seedling establishment and growth (Söderström 1974; Bäcke *et al.* 1986; Örlander 1995). Further, there are few experiments conducted in boreal forests where competition from the ground vegetation is reduced without mechanical disturbance. However, experiments where a herbicide has been used to control forest ground vegetation have resulted in an enhanced rate of seedling establishment and growth (Munson *et al.* 1993; Örlander *et al.* 1996). This would indicate that the ground vegetation might be more important for tree seedling establishment and growth than earlier thought. Herbicide-use to control the forest ground vegetation is not a viable alternative in Swedish forestry where by tradition herbicides are not used to the same extent as in other parts of the world (Stewart *et al.* 1984). In North America where herbicides are frequently used in forestry, public opposition to their use is becoming more common (Freedman *et al.* 1993; Wagner *et al.* 1998).

Alternative site preparation methods that are environmentally acceptable and also meet production goals are needed. On sites where the ground vegetation is the main problem for the establishment of new tree seedlings excessive mechanical soil disturbance can be avoided by using a thermal vegetation control method as steam treatment.

Steam – a thermal vegetation control method

Thermal vegetation control is an alternative vegetation management method and a generic term for various methods that use high temperatures or radiation to control unwanted vegetation (Ascard 1988). Thermal vegetation control includes the use of flames, infrared radiation, hot water, steam, microwaves and different electrical treatments. The development of steam as a vegetation control method has emerged from the need to seek alternatives to the use of herbicides (Ascard 1988; Daar 1994; Storeheier 1996; Holgersen and Dam 2000; Kurfess and Kleisinger 2000). Steam treatment is preferable to herbicides because it only applies pure water to the ground and does not leave any foreign chemical substances in treated plants or in the soil. Further, the non-specificity of the steam method enables a large area of coverage, as opposed to many chemical herbicides, which are often specific to certain plant species. Steam has been shown to be at least as effective as herbicides in the control of ground vegetation, depending on the steam treatment duration (Daar 1994). Additionally steam treatment kills the vegetation immediately whereas herbicide treatment often takes longer (i.e. weeks) to attain maximum vegetation mortality (Daar 1994).

The aim of a thermal treatment is to apply sufficient heat to severely damage an enough amount of plant cells so that the plant will wither and die (Hoffmann 1985). When the plant tissue reaches a temperature between 50 to 70°C the proteins coagulate, then the cell membranes burst because of the increase in volume (Ellwanger *et al.* 1973; Hoffmann 1985). Plant cell temperatures of 100°C for 0.1 s are sufficient to destroy living cells (Hoffmann 1985).

The use of steam for soil sterilisation in greenhouses and on outdoor nurseries is a long established method (Schreiner and Lathrop 1912; Morris and Winspear 1957) that has been "reinvented" as an alternative to chemical pest control (Raats 1988; Belker 1990; Labowsky 1990). Steam has experimentally been used for vegetation control on railway embankments both in Canada and in Sweden (Torstensson and Lindholm 1988; Hansson *et al.* 1995). However, to receive a sufficient vegetation control the ground speed of the equipment has to be slow (about 0.5 km/h) which limit the practical use of steam to the railway stations. The ground speed on the railway has to be at least 4 km/h otherwise the regular train traffic is severely disturbed. The ground speed has also limited the use of steam for weed control in agricultural fields, however experiments with steam has been effectively performed to kill and dry growing crop (Philipsen 1970; Holmøy and Hoftun 1980). Small scale steam equipment for vegetation control in fruit orchards and public-use areas such as playgrounds, schoolyards, parks etc is available for commercial use (AquaHeat 1994; Daar 1994).

To date, steam has not been used to control forest ground vegetation. Although steam efficiently controls different types of weeds in agriculture and municipal settings, it has yet to be adequately tested in forest ecosystems.

Objectives of the thesis

The overall aim of the study was to investigate if the steam treatment technique could be suitable as a tool for forest ground vegetation control from both a management and an environmental perspective. Specifically, I investigated *i*) the effects of steam treatment on ground vegetation in relation to the effects of traditional soil scarification and spot burning methods and *ii*) the growth and survival of planted and seeded Scots pine and Norway spruce seedlings in steam treated, soil scarified and spot burned plots and in intact vegetation. Soil microorganisms and specifically mycorrhiza can be adversely effected by high temperatures and in particular steam heat. Therefore studies were also conducted to assess the effects of steam treatment on soil microbiological activity and mycorrhizal colonisation of tree seedling roots.

Materials and methods

Study sites

A number of experiments were conducted on four distinct clearcuts in Sweden (Figure 1). The sites were all dominated by some of the most common forest ground vegetation types for each region including:

- crowberry (*Empetrum hermaphroditum* Hagerup; I),
- bilberry (*Vaccinium myrtillus* L.; II and III),
- heather (*Calluna vulgaris* (L.) Hull; IV), and
- wavy hair-grass (*Deschampsia flexuosa* (L.) Trin.; V).

Regeneration failures are sometimes reported from these vegetation types (Björkman 1970; Ebeling 1979; Gimingham 1994) and some of the sites were already unsuccessfully regenerated.

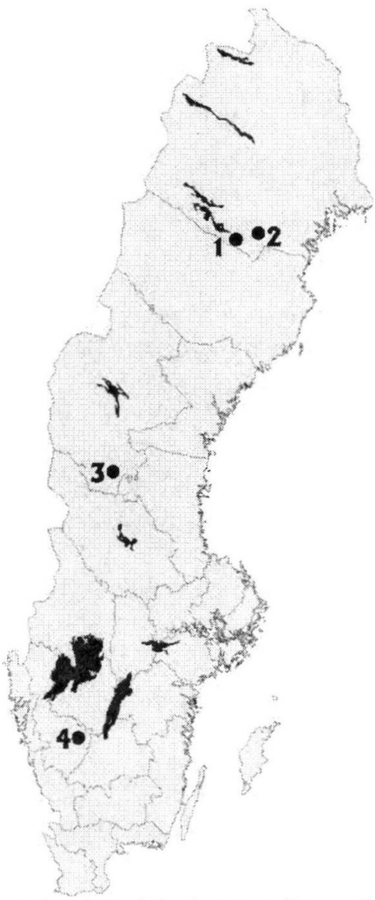

Figure 1. Location of the study sites: 1 Ledvattnet (Paper I); 2 Skavliden (Paper II and III); 3 Tandsjöborg (Paper IV); 4 Fänneslunda (Paper V).

Steam equipment

Steam generators manufactured by O. Malmkvist AB, Alvesta, Sweden, were used in all studies. Two models were used i.e. BINI 510 and BINI 610 (Figure 2). These steam generators produce boiling water, which is transformed to steam when it leaves the boiler. A new type of steam generator (WR-Damp, Hedehusene, Denmark) was additionally tested in a small pilot study (see discussion under *Practical considerations*) that produces slightly superheated steam, which means that the water is heated to steam inside the boiler. Technical data about the equipment is presented in Table 1.

Table 1. Technical data on the equipment used for steam treatment.

Type of steam generator	Boiling water	Boiling water	Superheated steam
Manufacturer and model	O. Malmkvist AB, Alvesta, Sweden BINI 610	O. Malmkvist AB, Alvesta, Sweden BINI 510	WR-Damp, Hedehusene, Denmark
Used in study:	I, II, III	IV, V	Pilot study
Pressure (bar)	5-6	6-7	4-7
Temperature (°C)	120-130	130-140	150-170
Energy output ($kJ \cdot kg^{-1}$ steam)	500	550	2700
Water consumption ($l \cdot s^{-1}$)	0.109	0.062	0.028

Experimental design

On the experimental sites 2, 3 and 4, planting experiments were established in steam treated vegetation plots, in soil scarified plots, in spot burned plots (only in site 2) and in intact vegetation. At site 1, 2 and 3 seeding experiments were also established in plots subjected to steam treatment and in intact vegetation. Steam was applied as a spot treatment in 0.6×0.6 m plots using a open aluminium box (0.6×0.6 m and 0.4 m high) to reduce loss of steam laterally and to clearly define the treated area. The steam held a temperature of about 100°C when it left the application nozzle and since the steam was applied to the vegetation from above, the aboveground vegetation was exposed to this temperature (Figure 3). Plots used for planting and seeding experiments were treated with steam for two minutes. Soil scarification was performed by manual removal of vegetation and humus layer in plots of the size 0.6×0.6 m. Spot burning was performed by combusting the ground vegetation and litter using a propane-burner inside the same aluminium box used for steam treatment. Untreated control plots were comprised of 0.6×0.6 m intact vegetation. One, 1-1½ year old, seedling was planted in the centre of each plot. In the three northern sites Scots pine were used (I, II, III and IV) and in the southern site Norway spruce was planted (V).

Experiments were also established to study ground layer vegetation response to different length of steam exposure time. Temperature measurements during steam treatment were also performed in order to evaluate the distribution of plant lethal temperatures in the soil. In order to receive a measure of the efficiency of steam as a vegetation control method, vegetation response to all treatments was evaluated and compared by recording species composition and percent cover of the ground vegetation in the plots. Then tree seedling performance and establishment success including mycorrhizal colonisation of seedling short roots and soil microbial activity (based on SIR and BR) were recorded in the study sites.

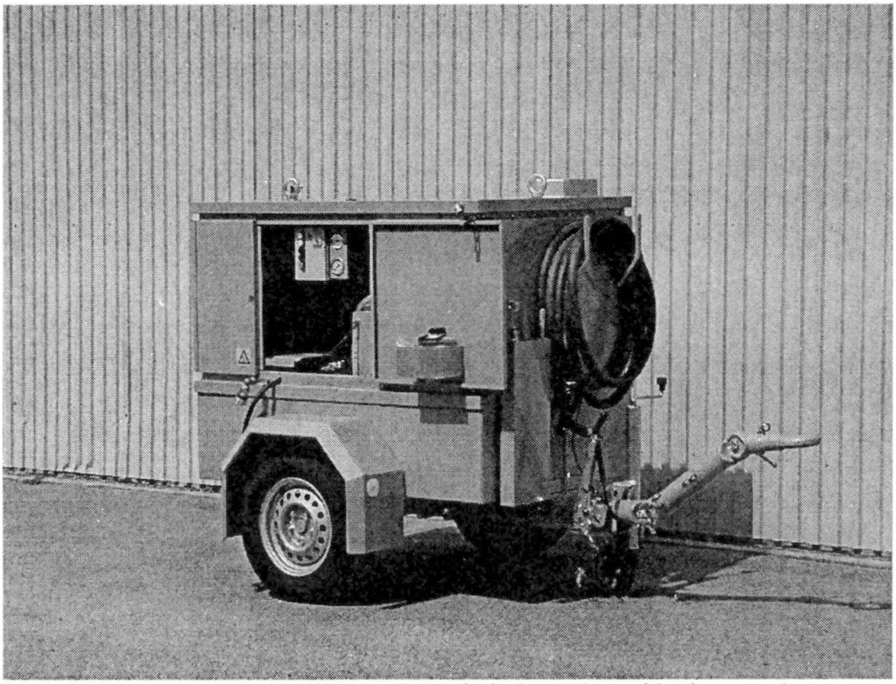

Figure 2. Steam generator (BINI 610; O. Malmkvist AB) used in the experiments.

Figure 3. Application of steam using an open aluminium box (0.6×0.6 m and 0.4 m high). The steam held a temperature of about 100°C when it left the application nozzle.

Results and discussion

Effects of steam treatment on vegetation

Directly after steam treatment the vegetation turned slightly darker green in colour and after 12-24 hours the vegetation, irrespectively of species, desiccated and became reddish-brownish in colour. Recolonisation of vegetation following treatment was slow and occurred mainly by rhizomes from the edges of the treated plots. Establishment of seed dispersed species was scarce within steam treated plots likely as a result of the dense ground surface cover by withering vegetation which was unfavourable for seed germination of most forest plants.

The cover of field layer vegetation in the sites dominated by ericaceous species was reduced to less than 20% of that in intact control plots up to five years after treatment (I, II, III and IV). In comparison to soil scarified and prescribed spot burned plots, steam is as effective in reducing ground vegetation (II). In study V in which the effects of steam treatment on grass (*Deschampsia*) vegetation was investigated, steam reduced the total ground vegetation cover to less than 20% of that in the intact control plots and resulted in that the cover of *Deschampsia* was only 6% two years after treatment. Steam treatment was also much more effective than soil scarification in reducing grass vegetation. Two years after steam treatment of *Deschampsia* dominated vegetation the steam treated plots had less than 40% vegetation cover of that in soil scarified plots (19% and 51% total vegetation cover respectively).

The effect of steam treatment in general remained for several years, therefore one may conclude that the belowground parts of plants (i.e. roots and rhizomes) were severely affected by the steam treatment. The rhizomes of *Vaccinium* spp. and *Deschampsia flexuosa* are known to be killed by a heat exposure in the temperature range of 55-59°C when the exposure occurs for 10 min (Schimmel and Granström 1996). However, the correlation between lethal temperature in the humus and death of vegetation was weak in my studies (II and V). Temperature measurements in the *Vaccinium* site (II) and in the *Deschampsia* site (V) were conducted during and after steam treatment in the humus layer, five cm under the soil surface, where most of the rhizomes were present. Results from these temperature measurements showed that the vegetation was strongly reduced even if the temperatures in the humus layer did not exceeded a temperature that is known to be lethal to roots and rhizomes (55-60°C). However, little is known about heat transfer in living tissue (Hungerford *et al.* 1991) and it is also suggested that high, but otherwise not lethal temperatures, can be harmful if the exposure time is long enough (Wright 1970), i.e. when the heat is kept in the soil for several hours after the treatment (V). Another plausible explanation is that the whole plant desiccates through increased transpiration when the protective wax layers (or cuticle) are destroyed (AquaHeat 1994; Kurfess and Kleisinger 2000).

Tree seedling establishment and growth

Seeding experiments

Vegetation control by steam treatment showed a positive effect on both tree seed germination, seedling establishment and growth compared to the intact plots. This was particular true for the *Calluna* vegetation (IV), but in the *Empetrum* and *Vaccinium* sites (I, III) no differences in seed germination and seedling establishment between steam treatment and intact vegetation were found. Growth of seeded seedlings was strongly improved by the reduction of competing vegetation by steam in all sites (I, III, IV). For example, a 275% increase in biomass was recorded after four years for seedlings grown in steam treated *V. myrtillus* vegetation compared to intact vegetation (III).

Planting experiments

The overall survival of planted tree seedlings was improved by steam treatment and soil scarification compared to intact vegetation in all study sites. For all sites, both the steam treatment and soil scarification improved seedling height growth compared to seedlings planted in intact vegetation. In the ericaceous sites seedlings in steam treated plots were significantly taller (total seedling height) than seedlings grown in soil scarified plots four to five years after planting. In the *Calluna* site (IV) seedlings planted in soil scarified plots were subjected to frost heaving, which may explain some of the improved biomass growth of seedlings in steam treated plots. The intact humus layer left after a steam treatment reduces the degree of soil temperature fluctuations (II), and therefore reduce the degree of freezing and thawing. In sites known to be susceptible to frost heaving the recommendation is to leave the humus layer intact (Goulet 2000), this recommendation is also supported by study V. Steam is therefore also suggested as an alternative to soil scarification on frost heaving susceptible sites.

In the grass dominated site in southern Sweden spruce seedling height growth was greatest in the soil scarified plots. This enhanced growth can not be explained by reduced competition from ground vegetation since the steam treatment reduced the vegetation cover to a greater extent than soil scarification. However, on this grass dominated site the abundance of pine weevil was frequent. Despite repeated insecticide treatments the seedlings were exposed to numerous pine weevil attacks during the first growing season. Seedlings however, tended to be less frequently attacked when growing in soil scarified plots (von Sydow 1997) compared to seedlings grown in intact vegetation and steam treated plots which could have contributed to the observed results. Although seedlings in steam treated plots were more frequently attacked by pine weevil, the seedlings in these plots survived to the same extent as the seedlings grown in soil scarified plots, however pine weevil attacks may have caused some growth reductions.

Mycorrhiza - Microbial activity

Key biological soil processes such as soil microbial activity and mycorrhizal colonisation were not negatively affected by the steam treatment. The microbial activity (measured as soil basal respiration (BR) and substrate-induced respiration (SIR)) were significantly reduced in steam treated plots immediately (2 weeks) after treatment, but six weeks after treatment the microbial activity was equally high as in undisturbed control plots (II). This implies that the steam treatment (applied during 2 minutes) heats the soil to microbial-lethal temperatures (Dunn *et al.* 1985), but that there is rapid recolonisation of microorganisms (Diaz-Ravina *et al.* 1996). There was no observed negative effect of steam treatment on mycorrhizal colonisation of pine roots as almost all the fine-roots of seeded Scots pines were colonised by mycorrhizal fungi at the time of harvest (4 years after sowing). No significant differences in species richness and abundance of ectomycorrhizal taxa between seedlings grown in steam treated plots and intact vegetation were found (III).

Practical considerations

In my studies I used a common but simple type of steam generator, in Sweden this equipment is often used to melt ice in road drains. Boiling water inside the generator is transformed to steam when it is released into the open air, and thereafter the steam condenses to water again and heat energy is released. However, it is more energy efficient if the water is transformed to steam inside the boiler, since every gram of water then can be loaded with more energy (superheated steam). This leads to a considerable reduced water consumption and a more efficient use of energy (Table 1). Energy calculations based on the technique used in study II (BINI 610) showed that the energy consumption for steam treatment was much higher than for mechanical soil scarification (i.e. harrowing). When using superheated steam it is possible to reduce the energy consumption, although further studies are required to investigate this. However, since at least the water consumption is reduced to 20% by using superheated steam compared to using boiling water, it would be possible to develop a steam treatment system for forest ground vegetation control of commercial interest. Additionally, the vehicle carrying the steam equipment could be considerably smaller and lighter compared to those used for mechanical soil scarification which would further minimise soil disturbance.

However, before it is possible to use this method at a greater operational scale there are some technical aspects that must be considered. Leaking of steam leads to a considerable loss of heat and energy and therefore a careful design of the application technique is required before using this method in practical scale. An optimal application method would include: (a) some kind of hood or cover to reduce the loss of steam during the steam application (Labowsky 1990; Storeheier 1996); and (b) some kind of insulation applied to the plot after treatment to keep the heat on the treated plot for a longer time (Kurfess and Kleisinger 2000). In study V, a layer of insulating mineral wool was placed on the steam treated plot directly after treatment, but some kind of insulating foam that are self-destructing (Rajamannan 1996; Kurfess and Kleisinger 2000) would be more suited to this purpose from a practical perspective. It is also crucial to establish data on the optimal combination of temperature and exposure time required killing specific vegetation types. High temperature and a short exposure time has been suggested to be the most energy efficient treatment (Storeheier 1996).

When these technical difficulties are overcome, the steam method can be considered as an alternative to mechanical soil scarification at least on sites dominated by ericaceous vegetation. The method is probably also useful on other vegetation types as long as pine weevil attacks is considered to be a minor problem. The steam method could also be preferable on sites that are highly susceptible to frost heaving and soil erosion.

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