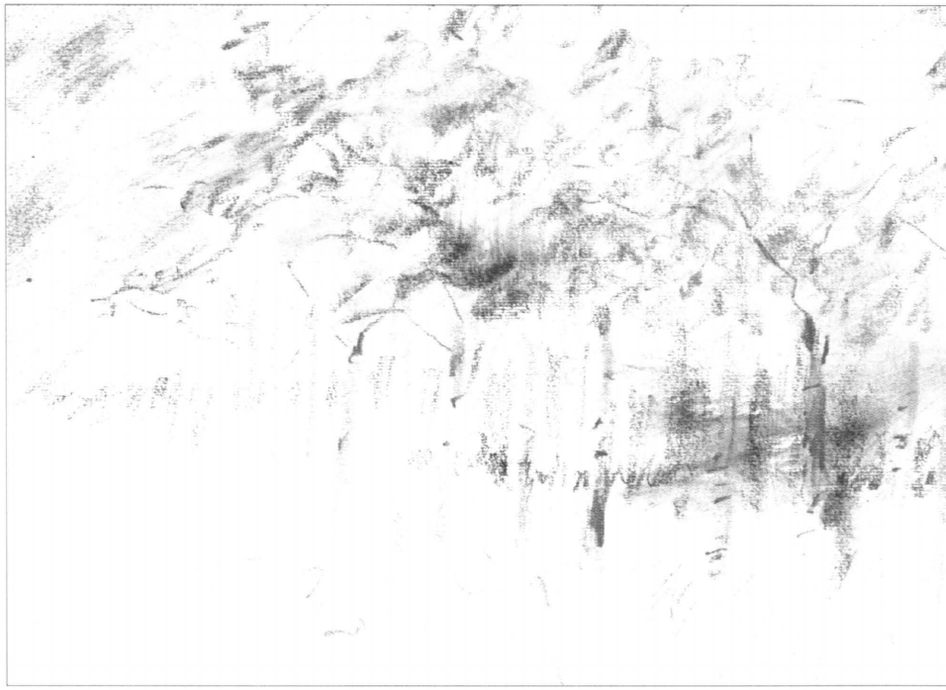
ACTA FORESTALIA FENNICA



Eero Kubin and Lauri Kemppainen

Effect of Soil Preparation of Boreal Spruce Forest on Air and Soil Temperature Conditions in Forest Regeneration Areas

244 · 1994

ACTA FORESTALIA FENNICA

Publishers The Finnish Society of Forest Science
The Finnish Forest Research Institute

Editors Editor-in-chief Eeva Korpilahti
Production editors Tommi Salonen, Seppo Oja

Editorial Office Unioninkatu 40 A, FIN-00170 Helsinki, Finland
Phone +358 0 857 051, Fax +358 0 625 308, E-mail silva.fennica@metla.fi

Managing Board Erkki Annila (The Finnish Forest Research Institute), Jari Kuuluvainen (The Finnish Forest Research Institute), Esko Mikkonen (University of Helsinki), Lauri Valsta (The Finnish Forest Research Institute), Harri Vasander (University of Helsinki), and Seppo Vehkamäki (University of Helsinki).

Editorial Board Per Angelstam (Grimsö Wildlife Research Station, Sweden)
Julius Boutelje (Swedish University of Agricultural Sciences, Sweden)
Finn H. Brække (Norwegian Forest Research Institute, Norway)
J. Douglas Brodie (Oregon State University, USA)
Raymond L. Czaplewski (USDA Forest Service, USA)
David Ford (Lancaster University, United Kingdom)
George Gertner (University of Illinois, USA)
Martin Hubbes (University of Toronto, Canada)
William F. Hyde (Virginia Polytechnic Institute and State University, USA)
Jochen Kleinschmit (Lower Saxony Forest Research Institute, Germany)
Michael Köhl (Swiss Federal Institute for Forest, Snow and Landscape Research, Switzerland)
Noel Lust (University of Gent, Belgium)
Bo Långström (Swedish University of Agricultural Sciences, Sweden)
William J. Mattson (USDA Forest Service, USA)
Robert Mendelsohn (Yale University, USA)
Hugh G. Miller (University of Aberdeen, United Kingdom)
John Pastor (University of Minnesota, USA)
John Sessions (Oregon State University, USA)
Jadwiga Sienkiewicz (Environment Protection Institute, Poland)
Richard Stephan (Federal Research Centre for Forestry and Forest Products, Germany)
Elon S. Verry (USDA Forest Service, USA)
S.E. Vompersky (Russian Academy of Sciences, Russia)
A.G.D. Whyte (University of Canterbury, New Zealand)
Claire G. Williams (North Carolina State University, USA)

Aim and Scope Acta Forestalia Fennica publishes monographs in forest science. These may be original research articles or comprehensive reviews aiming at a synthesis of knowledge in a particular topic. The series covers all aspects of forest science, both basic and applied subjects. Manuscripts are subject to peer review.

ACTA FORESTALIA FENNICA

244 · 1994

Eero Kubin and Lauri Kemppainen

Effect of Soil Preparation of Boreal Spruce Forest on Air and Soil Temperature Conditions in Forest Regeneration Areas

The Finnish Society of Forest Science — The Finnish Forest Research Institute

Kubin, E. & Kemppainen, L. 1994. Effect of soil preparation of boreal spruce forest on air and soil temperature conditions in forest regeneration areas. Acta Forestalia Fennica 244. 56 p.

The effect of scarification, ploughing and cross-directional plouhing on temperature conditions in the soil and adjacent air layer have been studied during 11 consecutive growth periods by using an unprepared clear-cut area as a control site. The maximum and minimum temperatures were measured daily in the summer months, and other temperature observations were made at four-hour intervals by means of a Grant measuring instrument. The development of the seedling stand was also followed in order to determine its shading effect on the soil surface.

Soil preparation decreased the daily temperature amplitude of the air at the height of 10 cm. The maximum temperatures on sunny days were lower in the tilts of the ploughed and in the humps of the cross-directional ploughed sites compared with the unprepared area. Correspondingly, the night temperatures were higher and so the soil preparation considerably reduced the risk of night frost. In the soil at the depth of 5 cm, soil preparation increased daytime temperatures and reduced night temperatures compared with unprepared area. The maximum increase in monthly mean temperatures was almost 5 °C, and the daily variation in the surface parts of the tilts and humps increased so that excessively high temperatures for the optimal growth of the root system were measured from time to time. The temperature also rose at the depths of 50 and 100 cm.

Soil preparation also increased the cumulative temperature sum. The highest sums accumulated during the summer months were recorded at the depth of 5 cm in the humps of cross-directional ploughed area (1127 dd.) and in the tilts of the ploughed area (1106 dd.), while the corresponding figure in the unprepared soil was 718 dd. At the height of 10 cm the highest temperature sum was 1020 dd. in the hump, the corresponding figure in the unprepared area being 925 dd.

The incidence of high temperature amplitudes and percentage of high temperatures at the depth of 5 cm decreased most rapidly in the humps of cross-directional ploughed area and in the ploughing tilts towards the end of the measurement period. The decrease was attributed principally to the compressing of tilts, the ground vegetation succession and the growth of seedlings. The mean summer temperature in the unprepared area was lower than in the prepared area and the difference did not diminish during the period studied. The increase in temperature brought about by soil preparation thus lasts at least more than 10 years.

Keywords: boreal spruce forest, forest regeneration, soil preparation, soil temperature, air temperature.

Authors' addresses: *Eero Kubin*, Finnish Forest Research Institute, Muhos Research Station, FIN-91500 Muhos, Finland, *Lauri Kemppainen*, Department of Biophysics, University of Oulu, FIN-90570 Oulu, Finland.

Accepted December 21, 1994

ISBN 951-40-1409-X
ISSN 0001-5636
Tampere 1994, Tammer Paino Oy

Contents

1 Introduction

Temperature conditions in boreal and sub-arctic regions are significant for both forest growth and regeneration. This is particularly emphasized in areas of fine-grained soils with predominantly spruce forests. The coolness of the soil together with the shading effect of the trees makes decomposition slower and results in the formation of a thick layer of raw humus (Sirén 1955, Havas and Kubin 1983). Although the humus layer levels out the daily variation in temperature, it considerably slows down the warming effect during the growing season, as has been demonstrated in various investigations in which humus has been removed from above the mineral soil (e.g. Homén 1896, Ronge 1928, Ångström 1936–1937).

From the 1950's onwards special attention has been paid to mechanical soil preparation. The first experiments involving more than scarification were carried out on mineral soils with open-ditch ploughs developed for peatland draining (Huikari 1954). In 1964 the first experiments with forest ploughing on mineral soil by means of modern equipment were carried out in state forests in northern Finland, so that the total ploughed area was 112 100 ha by the end of 1970 (Turtiainen and Valtanen 1970). The ploughing of forest soils was seen as able to solve the problems of practical reforestation (Huikari 1964, Autio 1965, Halonen 1965, Puukko 1965), although actual investigations into these aspects were not carried out at that time.

At the time when the ploughing of forest soils was at its very beginning in northern Finland Scots pine plantations met with a serious setback when large numbers of saplings died, particularly on reaching the snow limit (Valtanen 1970a). The most significant direct reason for this was the die-back of Scots pine (*Gremmeniella abietina*), which mainly attacked stands planted on fine-grained moist soils (Valtanen 1970b, Norokorpi 1971). On these areas attempts had been made to replace old Norway spruce stands with Scots pine before the time of extensive forest ploughing. The damage was so extensive and had such far-reaching effects that closer investigation into its reasons was considered necessary (Leikola 1979). The extensive series of experiments was initiated for this purpose under the leadership of Prof. Risto Sarvas (Metsänviljelytutkimuksen ... 1970) and the experimental field of present investigation, Kivesvaara, belongs to this.

The soils of fine grain-size fractions were found to be detrimental to the condition of seedling stands (Lähde 1974). The attention was thus at first focused on the physical conditions, especially the moisture and temperature of the soil. It became immediately clear that the mineral soil exposed by preparation warmed up in the tilts in particular and that the soil was coldest beneath the insulating humus layer (Turtiainen and Valtanen 1970, Pohtila 1970, 1977, Leikola 1971, Mälkönen 1972). Later measurements confirmed this and indicated that the soil temperature increased for the growing season especially in tilts and mounds (Leikola 1974, Kauppila and Lähde 1975, Lähde 1978, Ritari and Lähde 1978). Parallel studies were intensified also in Sweden at the same time as in Finland (Kohh 1970), and the most notable rises in temperature conditions were measured there, too, in the tilts and mounds (Söderström 1974, 1975), with corresponding results also obtained later by Lundmark (1988) and Örlander and Gemmel (1989). Temperatures in the tilts nevertheless rose sometimes so high that it was also assumed to harm the root system of the young seedlings (Mälkönen 1972, Örlander 1987).

The aim of this study is to clarify the effects of different soil preparation methods on soil and air temperatures and to examine the changes of temperature conditions during the following 11 growing seasons. The study forms part of a programme of intensified research into forest regeneration in northern Finland, and especially in the Kivesvaara research area since the 1970's.

2 Material and Methods

The experimental area Kivesvaara (64°27'N, 27°33'E) is situated in the mid-boreal part of the northern coniferous forest zone (Ahti et al. 1968). The annual mean temperature according to the climatical data of Finland is in this area 1–2 °C and the mean temperature sum 900–1000 dd. (Helminen 1987). The age of the cut stand in 1974 was 139 years and the growing stock 116 m^3/ha. The dominant tree was spruce, *Picea abies*, which accounts for 95 %, the rest being mainly birch, *Betula pubescens* (Kubin 1977). The soil at the site is a fine sandy till covered by a humus layer of approx. 7 cm (Table 1). The thickness of the A horizon was 11 cm and that of the B horizon 24 cm.

The experimental area was divided into strips after clear-cut and the various soil preparation methods were assigned to these at random. There were five replicates (sectors I–V) of which three were used for temperature measurements (Figure 1). The soil was prepared in the autumn of 1974. Ploughing was performed with a reforestation plough drawn by a Caterpillar tractor (Figure 2). The same equipment was used for cross-directional ploughing, where the furrows were made side by side and after that crosswise so that the soil in every place would really be turned over (Figure 3). The soil did not contain big stones, which would have hampered soil preparation, but some large stumps caused roughness in the tilts. Scarification was carried out by means of a tractor-drawn "Sinkkilä" scarifier. The various soil preparation techniques were compared with an unprepared clear-cut strip in which the planting patches were made by hand, and an area of uncut forest. The comparison between clearcut reference site and uncut forest has been reported formely (Kubin and Kemppainen 1991) and done at the same time and by the same methods as the present investigation.

Scots pine was planted on sectors I and V and broadcast sown on sector II in 1976 which were also used for the soil temperature measurements. The sectors III and IV were only regenerated with Scots pine (Figure 1). Seedling inventories were carried out in the summer of 1982 and after the temperature measurements had ended in the summer of 1986. In addition to the inventory of seedling survival, the spatial distribution of the seedlings was examined at the points where the temperature sensors were located.

Temperature measurements were initiated every year after the melting of snow at the end of May and continued until September. Five continuously operating thermographs situated at the height of 2 m in standard weather screens and controlled by direct glass maximum/minimum and

Table 1. Location of the experimental forest and general features of the climate and soil. Climatic data after Kolkki (1966) and Helimäki (1967), soil properties from Kubin (1975).

Variable	Value
Location	64°28'N, 27°33'E
Height above sea level	200–210 m
Mean annual temp.	Kajaani 1.9 °C, Vaala 2.2 °C
Effective temp. sum	Kajaani 1033 dd., Vaala 1051 dd.
Growing season	Kajaani 149 days, Vaala 149 days
Rainfall	Kajaani 564 mm, Vaala 525 mm
Soil	Fine sandy till
Soil type	Podsol
— Raw humus	6.7 cm
— Eluvial horizon	11.3 cm
— Illuvial horizon	23.7 cm
Depth of root penetration	0–70 cm

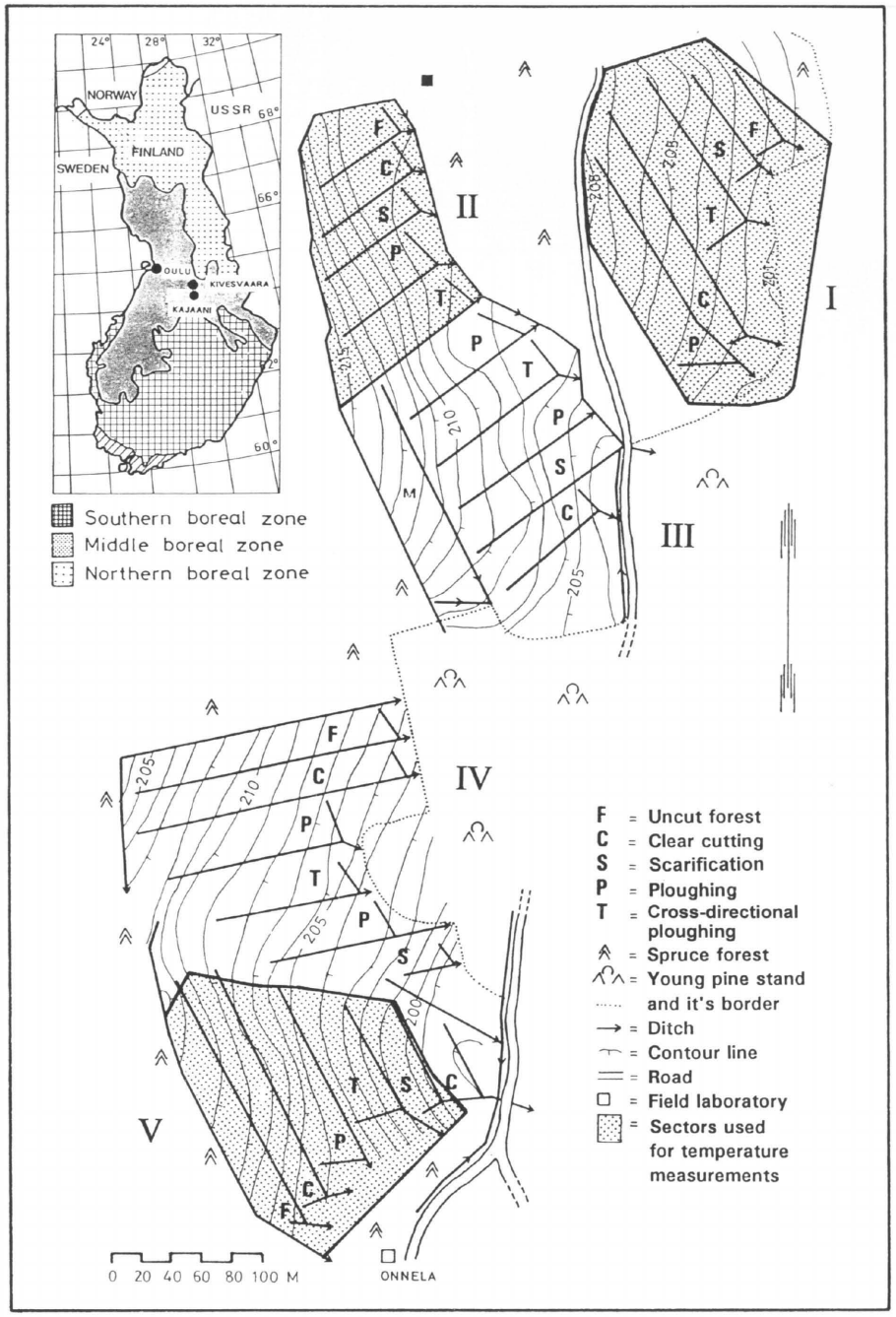


Figure 1. The phytogeographical zonation for Finland and the location of the experimental forest of Kivesvaara. Clearcutting was done in 1973–74 and soil preparation in 1974. Sectors I and V were planted and sector II sowed in 1976 and used for temperature measurements. Sector III was planted in 1975 and also sector IV excluding ploughing and cross-directional ploughing which were sowed in the same year.

Figure 2. The reforestation plough and the caterpillar tractor used for shoulder ploughing and cross-directional ploughing.

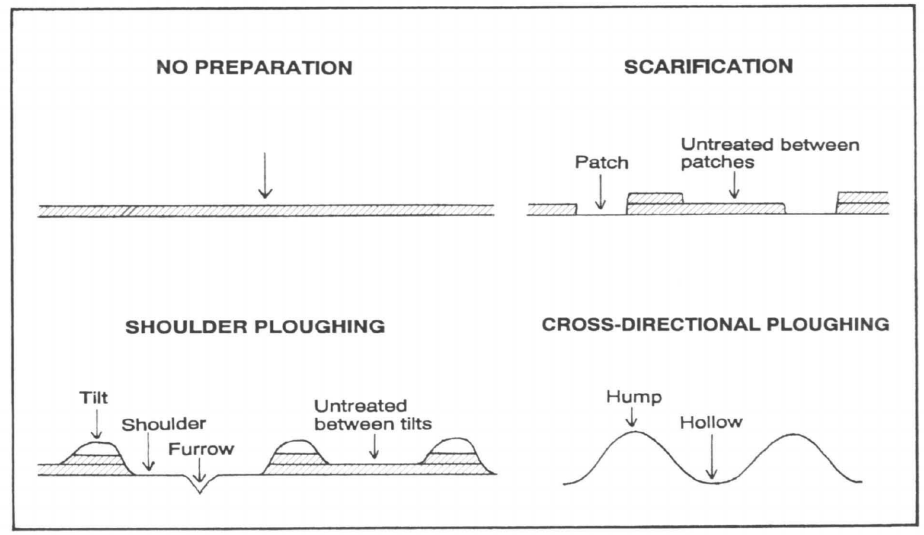


Figure 3. Schematic representation of the site preparation tracks. The arrows indicate the points where the temperature measurements from 10 cm above the ground level to 100 cm into the soil were done.

"normal" thermometers were used for air temperature measurements. At the height of 10 cm from ground level daily maximum and minimum temperatures by using maximum/minimum thermometers were started to measure at the unprepared clearcut area, on the shoulders and on the humps and added later on the tilt, on the hollow and on the scarified patches (Figure 3). Thus it was not

possible to obtain a full series of readings for all the sites. In addition some of the results had to be rejected on account of meter errors.

Soil temperature was recorded by using the Grant measuring instrument in which the resistance of the sensor changes according to the temperature. In addition of glass max/min meters this was also used at the height of 10 cm. The boundary between the live and dead part of the moss layer in the uncut forest was originally selected as a ground level for the measurements and the same point was also used in the clear cut areas where the original humus layer was left. In the areas where the mineral soil was made bare the sensors were put on the soil surface and protected with a thin layer of soil from the direct sun shine. The other measurings were done at the depths of 5, 50 and 100 cm. Four sensors were placed at each measurement point and level except the depth of 100 cm with one sensor and the mean value was recorded on paper tape at four-hour intervals daily from 4 a.m onwards during the whole measuring period (Figure 4). The distance between single sensors was from one to four meters in each 147 measurement points excluding those at the depth of 100 cm. The total number of sensors was 570. Because of the selected measuring system (Figure 4) the statistical differences between the sectors cannot be calculated in spite of the great number of sensors.

The spacing of the planted saplings and stocking by natural regeneration around the sensors and thermometers were examined as a factor affecting the temperature conditions at the end of the measurement period. The melting time of the soil frost and the thickness of the frost layer were measured (Kubin and Poikolainen 1982) by the method of Gandahl (1956).

Temperature observations were recorded manually from the paper tape on computer forms and stored at first by means of punched cards and later on computer tapes. The results were processed on an IBM 3083 computer employing programs written for the purpose in Fortran, separate sorting programs and SAS software at the University of Oulu.

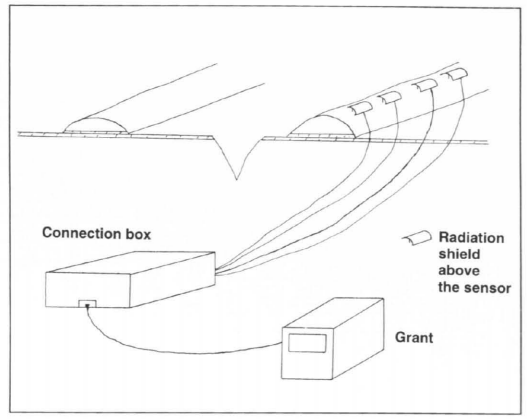


Figure 4. Schematic representation of temperature measurement system (+10 cm) with the Grant device. The plotter registers the mean value of each four sensors from connection box on the temperature scale.

Temperature sums were calculated on the day-degree principle with a threshold value of +5 °C. The distribution of daily temperature amplitude was described by subtracting the minimum temperature of each day from the maximum one and arranging the resulting figures in order of magnitude starting from the lowest and plotting them on a system of co-ordinates. Only the days in June, July and August were included. The distributions were divided into suitable intervals in connection with the tabulation and expressed as percentages. Distribution curves for each year can be drawn relatively accurately on a system of co-ordinates on the basis of the data in the tables if required.

In addition to the daily temperature amplitude the distributions of the temperature values were also obtained by arranging all the observations from June, July, and August in order of magnitude starting from the highest and plotting them on a system of co-ordinates. The distributions were again divided into suitable intervals in connection with the tabulation and expressed as percentages.

3 Results

3.1 Effect of Soil Preparation on Air and Soil Temperatures

3.1.1 Daily Maximum and Minimum Temperatures at the Height of 10 cm

Daily maximum and minimum temperatures at the height of 10 cm will be first examined in terms of three sample years, 1976, 1980 and 1985 (Figure 5). Maximum temperatures in the humps of the cross-directional ploughing area were at first usually 3–8 °C lower compared with unprepared reference but minimum temperatures were higher by the same margin at night. Weather conditions affected the differences so that when the variation in daily temperature was small the differences between the unprepared site and the humps were also small. Four years later in 1980 maximum temperatures were still 1–4 °C lower in the humps and minimum temperatures correspondingly higher compared with the unprepared site. Again the weather affected further the extent of the differences. The differences in maximum temperatures had levelled out almost completely by 1985, while the minimum temperatures were 1–3 °C higher on the humps of cross-directional ploughing than in the unprepared site in mid and late summer.

The temperature fell below zero and below five degrees most frequently on the unprepared site during the summer months. Night frosts occurred there 3–19 times every summer, whereas no night frost occurred in the humps in two summers and the maximum number was only 8 in 1982 (Table 2). There were three summers during which the temperature did not fall below zero in the ploughing shoulder, and also in 1982 the maximum number of the occurrences of below-zero temperatures was 10. The temperature fell below zero 0–14 times per summer on the scarified site in 1977–1985, again most frequently in 1982.

Considerable variation was also detected in the

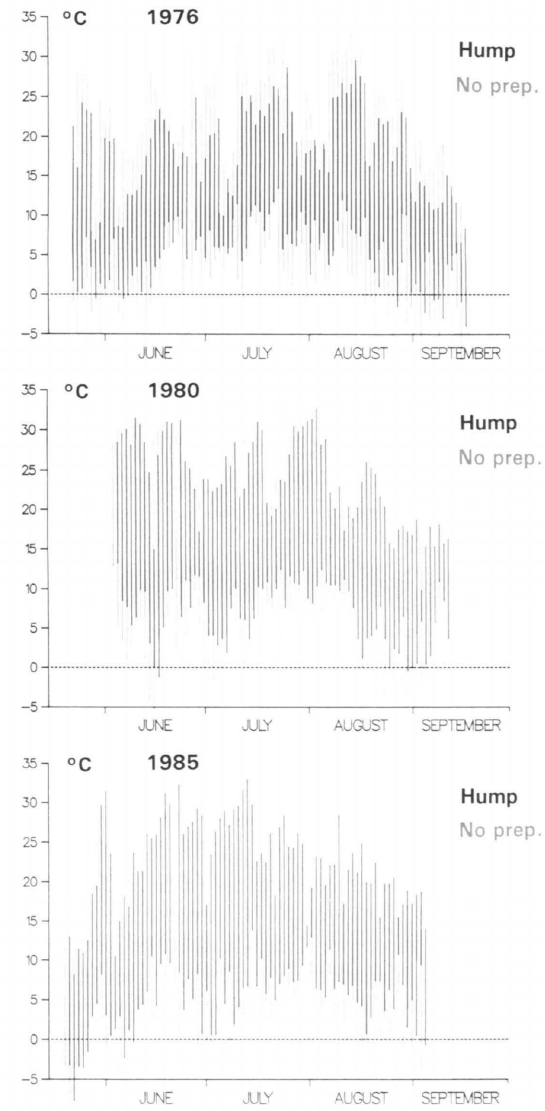


Figure 5. Daily minimum and maximum temperatures at a height of 10 cm in the unprepared area (red column) and in the humps of cross-directional ploughed area (black column) in the summers 1976, 1980 and 1985.

Table 2. Numbers of occasions during the summer months on which daily maximum temperatures exceeded 30 °C and 25 °C and minimum temperatures fell below 5 °C and 0 °C at height of +10 cm. Ploughing is shoulder ploughing where S is shoulder and T is tilt. C-ploughing is cross-directional ploughing where Hu is hump and Ho is hollow. See Figure 2.

Year	No prep.	Patch	Ploughing S	Ploughing T	C-ploughing Hu	C-ploughing Ho	No prep.	Patch	Ploughing S	Ploughing T	C-ploughing Hu	C-ploughing Ho
	Daily maximum above 30 °C						Daily maximum above 25 °C					
1975	10	–	2	–	2	–	22	–	16	–	14	–
1976	11	–	0	–	0	–	31	–	13	–	10	–
1977	9	6	1	–	4	–	21	6	10	–	10	–
1978	10	10	4	–	5	–	27	27	20	–	23	–
1979	5	3	0	–	3	–	37	25	16	–	25	–
1980	18	14	11	–	12	–	37	42	31	–	32	–
1981	1	2	0	–	1	–	22	19	9	–	15	–
1982	5	5	5	–	5	–	25	26	20	–	22	–
1983	6	2	3	–	6	–	25	23	21	–	22	–
1984	3	1	3	–	5	–	24	23	23	–	24	–
1985	3	1	0	–	4	–	23	14	15	–	26	–
	Daily minimum below 5 °C						Daily minimum below 0 °C					
1975	24	–	25	–	23	–	6	–	0	–	0	–
1976	41	–	25	–	24	–	13	–	3	–	3	–
1977	42	37	30	–	24	–	16	10	4	–	3	–
1978	32	29	26	–	23	–	6	3	0	–	3	–
1979	34	33	17	14	13	16	3	0	0	0	0	0
1980	29	24	19	17	18	18	9	7	3	3	2	3
1981	26	25	17	14	16	16	5	5	4	3	3	3
1982	53	53	38	35	34	34	19	14	10	6	8	6
1983	32	32	24	21	23	23	14	13	6	4	3	4
1984	33	33	29	21	23	23	13	12	7	5	7	5
1985	35	34	28	22	22	23	8	7	5	1	2	3

daily maximum temperatures (Table 2). Temperature records of over 30 °C occurred more frequently on the unprepared site at the beginning of the measurement period (1975–1980), and slightly more frequently in the humps than on the unprepared site at the end (1984–1985). High temperature records occurred in the shoulders of the ploughed site less often than in the humps. Temperature records of over 30 °C occurred more frequently on the scarified patches than on the shoulders of the ploughed area or on the humps of the cross-directional ploughing at the beginning of the period, but the situation was reversed at the end of it.

3.1.2 Daily Temperatures at the Height of 10 cm and in the Soil

3.1.2.1 Scarification

The differences in the temperature at the height of 10 cm between the scarified patches and the unprepared control area were fairly small in 1976 (Figure 6). The day temperatures were slightly higher and night temperatures slightly lower on the unprepared site than in the scarified patches throughout the summer. The differences remained similar in 1980 (Figure 7) and 1985 (Figure 8).

The daily temperature amplitude at the zero level

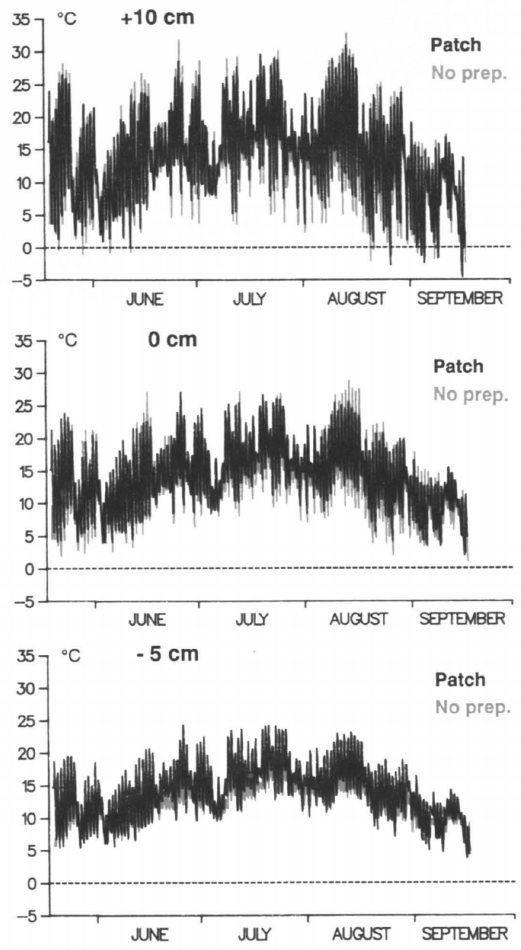


Figure 6. Daily temperatures at the levels of +10 cm, +0 cm and –5 cm in the unprepared area (red line) and the scarified patch (black line) in the summer of 1976.

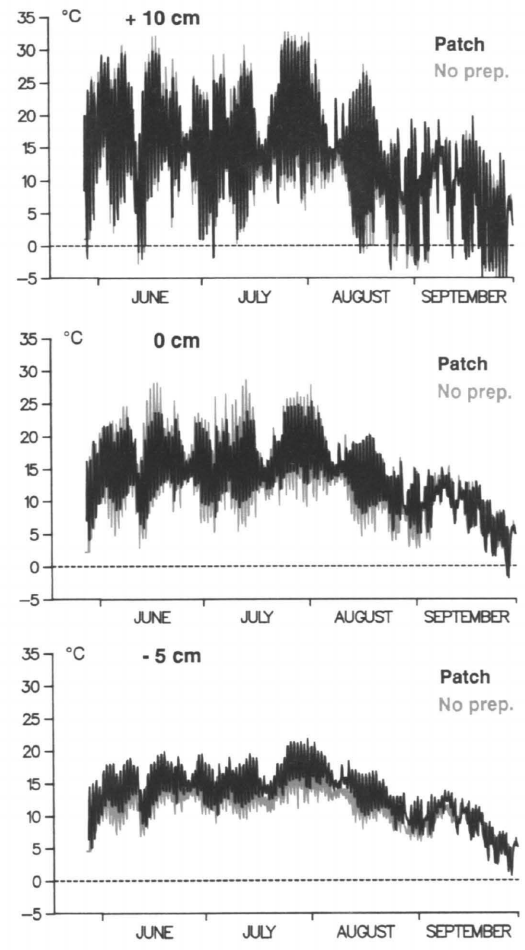


Figure 7. Daily temperatures at the levels of +10 cm, +0 cm and –5 cm in the unprepared area (red line) and the scarified patch (black line) in the summer of 1980.

in the patches and the unprepared site was smaller than at the height of 10 cm (Figure 6). Temperature differences between these two sites were small in 1976 and in 1980 (Figure 7) with the exception of warm periods. The differences increased in 1985, however, when temperatures were regularly higher on the unprepared site (Figure 8).

Daily temperatures at a depth of 5 cm were constantly higher in the patches than on the unprepared area in 1976 (Figure 6). The night temperatures were similar in early summer, being somewhat higher in the patches in July and August. The patches were colder at night in September. Day temperatures continued to be higher on the patches in 1980 (Figure 7). The night temperatures were lower on the unprepared site with the exception of September, when the soil was colder in the patches. The temperature patterns were similar in both areas in 1985 (Figure 8).

The air between the scarified patches on the untreated areas at the height of 10 cm was warmer during the day and colder at night than at the same height above the patches (Figure 9). The corresponding differences at the zero level were small,

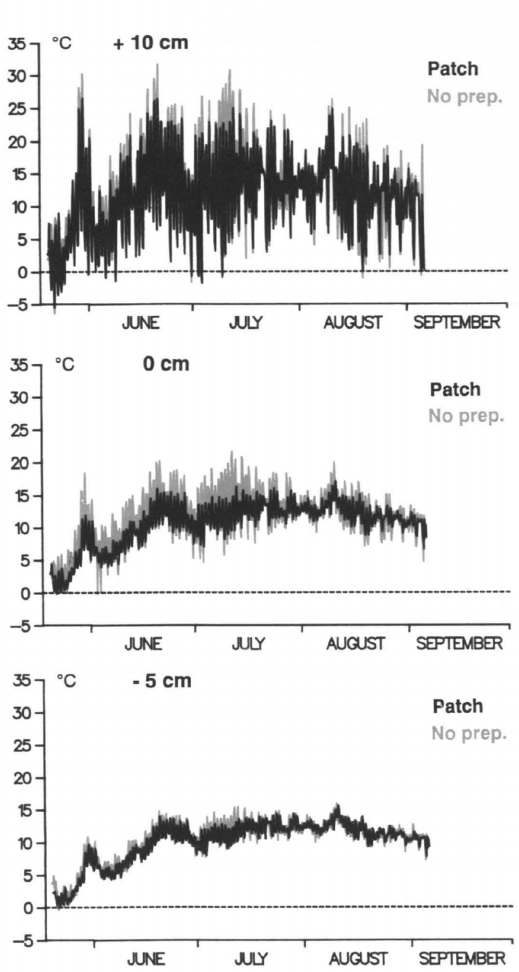


Figure 8. Daily temperatures at the levels of +10 cm, +0 cm and –5 cm in the unprepared area (red line) and the scarified patch (black line) in the summer of 1985.

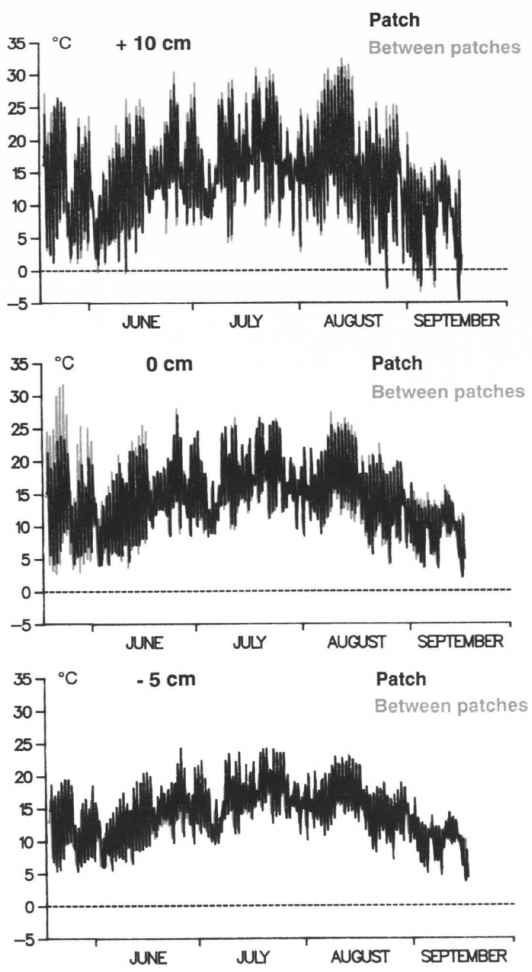


Figure 9. Daily temperatures at the levels of +10 cm, +0 cm and –5 cm in the area between the scarified patches (red line) and in the scarified patch (black line) in the summer of 1976.

but the soil at a depth of 5 cm was warmer in the patches during the day and slightly colder at nighttime.

3.1.2.2 Ploughing

The day temperature at the height of 10 cm above the shoulder was lower than that in the unprepared area, and the night temperature was higher respectively (Figure 10). The differences in temperature remained similar almost throughout the summer. Day temperatures at the depth of 5 cm were approx. 5 °C higher than those in the unprepared area. Night temperature was slightly lower, respectively. The temperature differences between the ploughing shoulder and the tilt were small at +10 cm (Figure 11), while day temperatures were higher and night temperatures lower at –5 cm in the tilt than in the shoulder, a difference that persisted throughout the summer.

Day temperature records at 10 cm above the ploughing tilt were lower than those on the unprepared site, and the respective night temperatures were higher at the beginning of the measurement period (Figures 12 and 13), but the differences

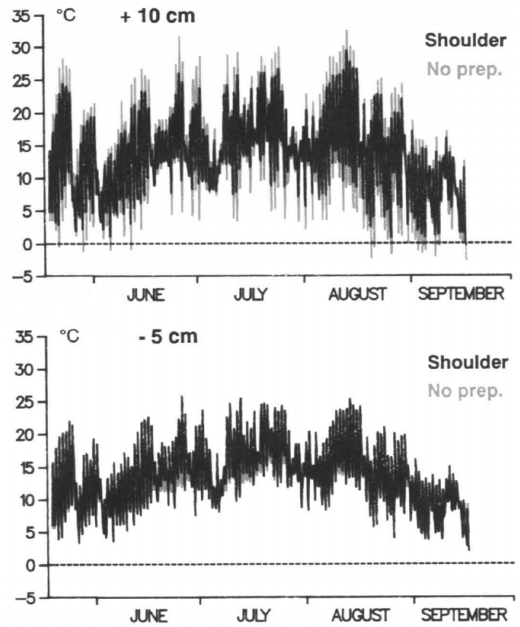


Figure 10. Daily temperatures at the levels of +10 cm and –5 cm in the unprepared area (red line) and the shoulder of the ploughed area (black line) in the summer of 1976.

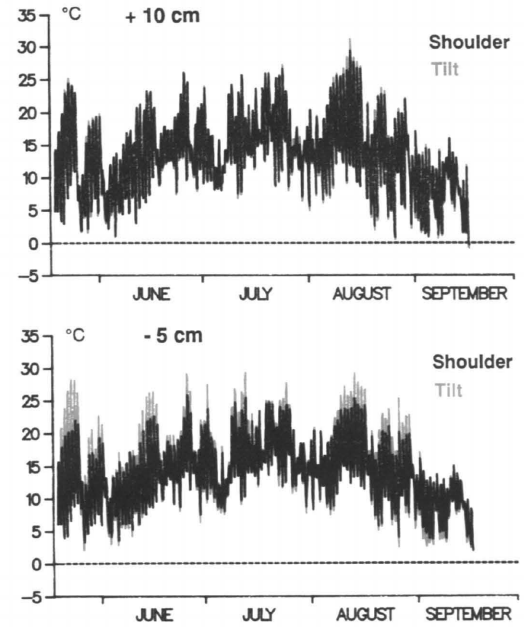


Figure 11. Daily temperatures at the levels of +10 cm and –5 cm in the tilt (red line) and shoulder of the ploughed area (black line) in the summer of 1976.

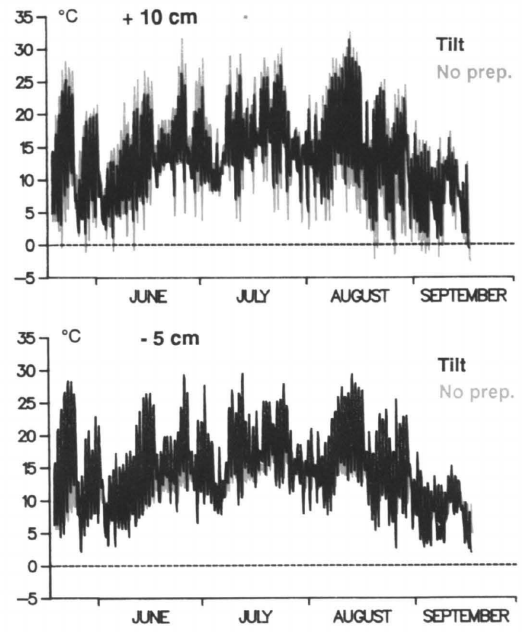


Figure 12. Daily temperatures at the levels of +10 cm and –5 cm in the unprepared area (red line) and in the tilt in the ploughed area (black line) in the summer of 1976.

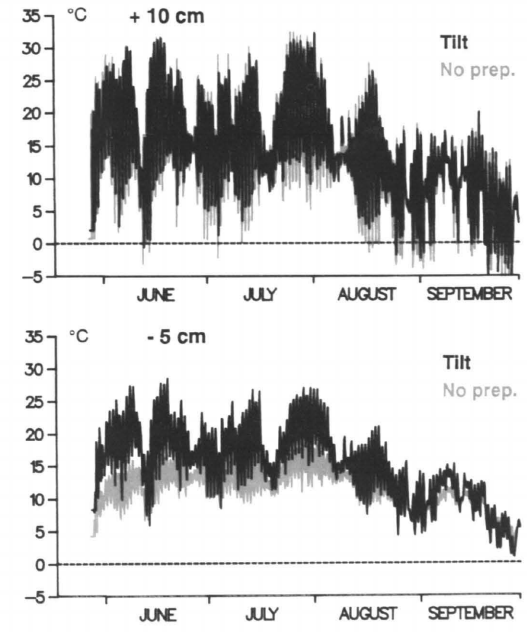


Figure 13. Daily temperatures at the levels of +10 cm and –5 cm in the unprepared area (red line) and in the tilt in the ploughed area (black line) in the summer of 1980.

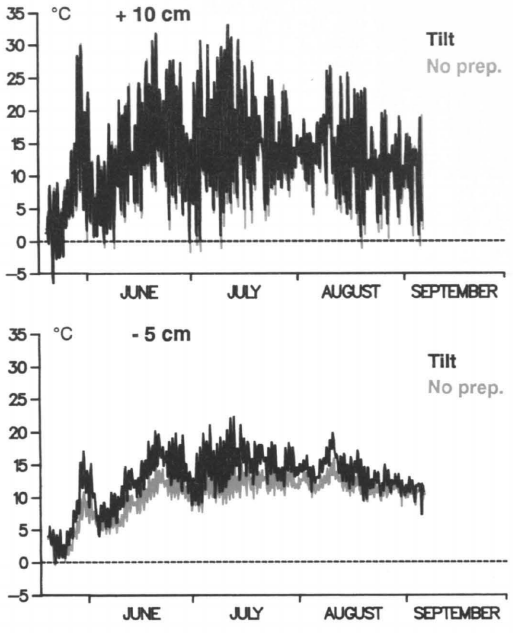


Figure 14. Daily temperatures at the levels of +10 cm and –5 cm in the unprepared area (red line) and in the tilt of the ploughed area (black line) in the summer of 1985.

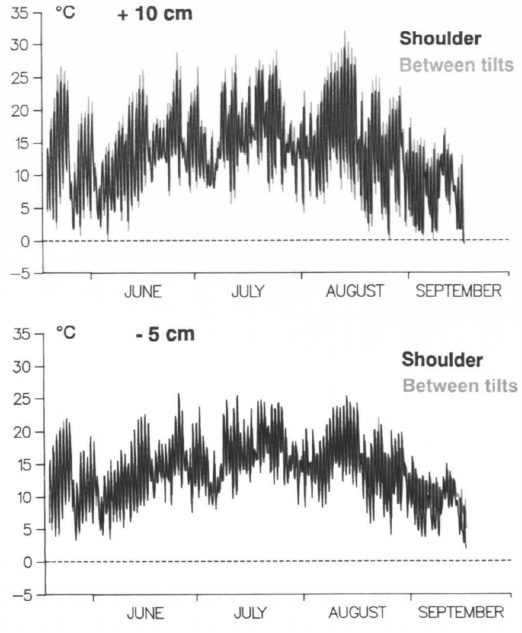


Figure 15. Daily temperatures at the levels of +10 cm and –5 cm between the tilts (red line) and in the shoulder of the ploughed area (black line) in the summer of 1976.

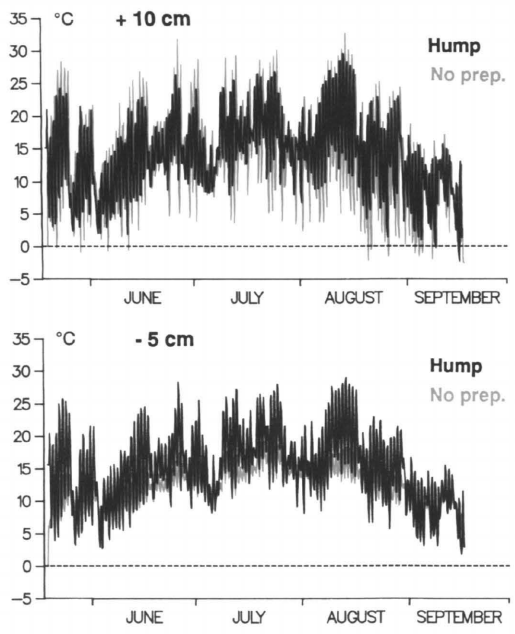


Figure 16. Daily temperatures at the levels of +10 cm and –5 cm in the unprepared area (red line) and in the hump of the cross-directional ploughed area (black line) in the summer of 1976.

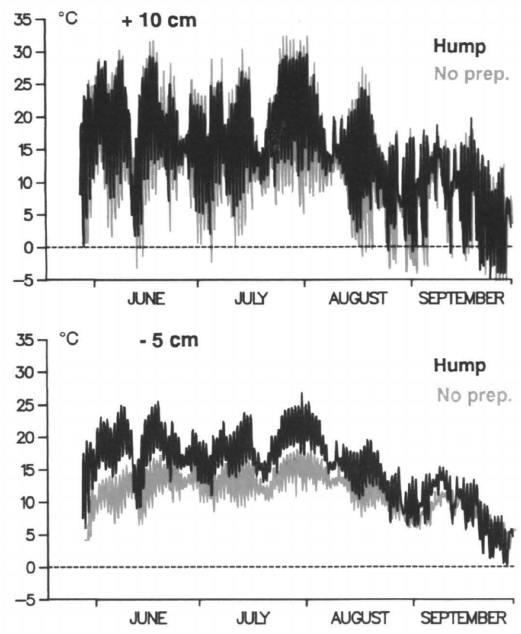


Figure 17. Daily temperatures at the levels of +10 cm and –5 cm in the unprepared area (red line) and in the hump of the cross-directional ploughed area (black line) in the summer of 1980.

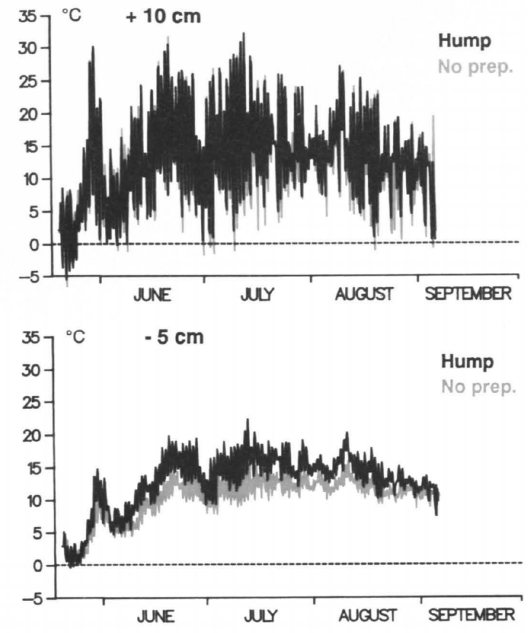


Figure 18. Daily temperatures at the levels of +10 cm and –5 cm in the unprepared area (red line) and in the hump of the cross-directional ploughed area (black line) in the summer of 1985.

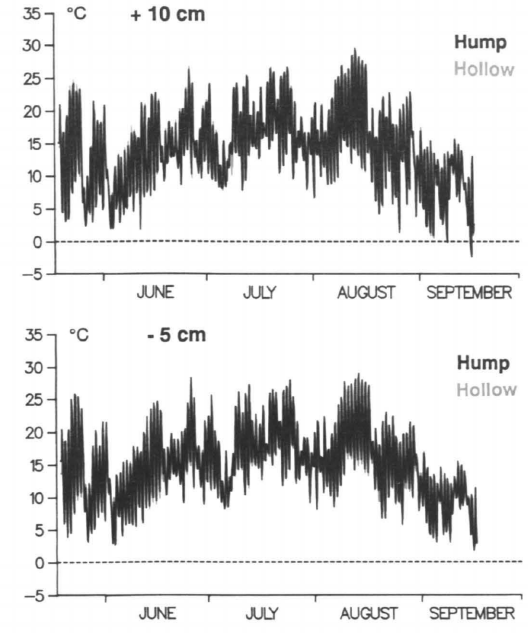


Figure 19. Daily temperatures at the levels of +10 cm and –5 cm in the hollow (red line) and in the hump of the cross-directional ploughed area (black line) in the summer of 1976.

were small nine years later (Figure 14). Day temperature records at the depth of 5 cm in the tilt were higher than those in the unprepared area throughout the period (Figures 12, 13 and 14). Night temperature records were at first lower, but the situation was reversed in 1985 (Figure 14). Although the temperature in the tilts was higher than in the unprepared areas in summer, the tilts cooled down rapidly in early September.

The temperature conditions at the height of 10 cm on the untreated areas between the tilts were more extreme than those above the shoulders (Figure 15). The day temperature was 1–2 °C higher and night temperature correspondingly lower throughout the summer. No frost nights occurred at this height between the tilts unlike the unprepared control area (see Figure 6). The soil temperature at the depth of 5 cm in the shoulder was warmer by day and colder by night than in the untreated area between the tilts.

3.1.2.3 Cross-Directional Ploughing

On cross-directional ploughed areas the variation of the temperature above the humps at the height of 10 cm was throughout the summer naturally smaller than on the unprepared control area (Figure 16). No night frosts were observed on the humps during the summer months and both night and day temperatures were, depending on the type of the weather, 3–5 °C higher compared to the control area. At the depth of 5 cm the day temperatures were also higher in the humps than in the unprepared area but the night temperatures could be, depending on the type of the weather and certainly in September, even lower in the hump than in the unprepared area.

Four years later the daily variation of the temperature above the humps was similar but inside the hump it had diminished (Figure 17). Especially the night temperatures inside the humps were smaller than on the unprepared area.

At the end of the measuring period in 1985, 11 years after the site preparation, the variation of

Table 3. Monthly mean temperatures at a height of +10 cm. C-plough is cross-directional ploughing.

Year	June	July	Aug.	June	July	Aug.	June	July	Aug.	June	July	Aug.
	No preparation			Patch			Between patches			Plough tilt		
1976	13.3	16.0	14.3	13.1	16.6	15.2	13.3	16.7	15.4	12.7	15.8	15.0
1977	15.3	17.3	13.9	15.0	17.4	13.8	15.6	16.7	13.1	15.3	17.2	14.3
1978	14.0	16.9	11.9	14.3	15.7	11.4	14.3	15.6	11.0	14.1	17.3	12.0
1979	14.8	15.8	13.7	15.6	16.4	14.3	15.7	16.4	14.0	15.3	16.1	14.3
1980	16.9	16.1	12.0	16.9	16.5	13.1	17.0	16.2	12.5	17.3	16.8	12.8
1981	11.4	16.6	12.5	11.5	16.7	12.8	11.5	16.7	12.6	11.4	16.8	12.7
1982	9.3	15.4	12.0	9.2	15.1	12.1	9.4	15.4	12.1	9.3	16.3	12.6
1983	12.6	15.7	11.4	12.6	15.2	11.3	12.7	15.4	11.3	12.8	15.9	11.8
1984	12.7	14.5	11.4	12.2	14.3	11.0	12.5	14.6	11.3	13.3	14.8	11.8
1985	13.0	14.6	12.3	11.4	13.4	12.4	12.1	14.2	12.6	13.3	15.4	12.9
	Plough shoulder			Between tilts			C-plough hump			C-plough hollow		
1976	12.7	15.7	14.7	13.0	15.8	14.5	13.0	16.5	16.1	13.2	16.5	16.0
1977	15.1	17.1	13.9	14.9	17.2	14.0	14.8	17.0	13.2	14.6	16.0	13.0
1978	13.8	17.0	11.8	13.9	16.9	11.8	14.3	16.0	11.5	14.2	15.8	11.4
1979	14.7	15.9	14.2	15.0	16.2	14.1	15.9	16.6	14.7	15.9	16.6	14.5
1980	16.9	16.5	12.6	17.1	16.5	12.6	17.5	17.2	13.6	17.3	16.9	13.4
1981	11.4	16.6	12.6	11.1	16.2	12.2	11.9	17.1	12.8	11.6	17.0	12.7
1982	9.1	15.7	12.3	8.9	15.3	11.8	9.9	16.4	12.8	9.5	16.1	12.5
1983	12.3	15.3	11.3	12.3	14.9	11.0	13.0	16.2	11.9	12.7	15.9	11.7
1984	12.4	14.2	11.2	12.3	14.0	10.9	13.2	14.9	11.8	12.8	14.3	11.5
1985	12.6	14.4	12.3	13.2	14.8	12.6	12.9	15.5	13.5	12.3	14.8	13.1

the temperature above the humps and on the unprepared area was similar, that is, the differences had diminished (Figure 18). However, at the depth of 5 cm the differences had remained and the temperatures were during the summer months about 5 °C higher than in the unprepared soil and came down to the same level only in September.

A comparison of the temperatures between the humps and hollows (Figure 19) 10 cm above the soil surface at the beginning of the measuring period indicates that the differences were very small throughout the summer. The daily soil temperatures at the depth of 5 cm in the humps were approx. 5 °C higher than those in the hollows, which corresponds approximately to the difference between the shoulders and the tilts at the ploughed area at the same depth (cf. Figure 11).

3.1.3 Monthly Mean Temperatures

The differences in the mean air temperatures for June between the various years were considerable at the height of 10 cm in all prepared areas (Table 3), while the respective differences between the treatments within the same year were small. The highest June mean temperature (17.5 °C) was measured in a hump in 1980 and the lowest (8.9 °C) between the tilts on the ploughed area in 1982. In July the mean temperature did not vary annually as much as that for June. The highest value was recorded on the scarified patch in 1977 and the lowest also in the same area in 1985. The differences between the preparations were small. In August the mean temperatures did not vary annually as much as those for June. The highest value occurred above a hump in 1976 and respectively the lowest above the untreated area between the tilts of the ploughed site in 1984.

Table 4. Monthly mean temperatures at ground level (±0 cm). C-plough is cross-directional ploughing.

Year	June	July	Aug.	June	July	Aug.	June	July	Aug.	June	July	Aug.
	No preparation			Patch			Between patches			C-plough hollow		
1976	13.0	15.7	14.6	13.3	16.7	15.2	13.4	16.4	15.2	13.7	16.8	15.2
1977	15.4	16.9	14.4	14.8	17.4	14.4	14.2	16.4	13.4	14.4	16.9	13.9
1978	–	–	–	14.9	16.5	13.2	15.3	16.2	12.1	15.6	17.9	13.4
1979	15.0	16.2	14.1	14.9	16.4	14.6	14.8	16.2	14.6	17.5	18.5	15.9
1980	15.6	15.7	12.8	15.5	16.0	13.7	15.8	16.2	13.7	17.9	18.3	15.1
1981	11.8	16.3	13.5	11.4	16.1	13.6	11.9	16.6	13.9	13.1	17.9	14.2
1982	9.7	14.5	12.0	9.9	14.5	12.3	9.9	14.7	12.4	11.4	17.0	13.6
1983	12.2	15.0	11.9	12.2	14.6	12.1	12.4	14.8	12.1	13.8	16.4	12.8
1984	12.3	14.2	11.9	11.7	13.6	11.9	12.2	14.1	12.0	13.6	14.9	12.1
1985	10.9	13.3	12.4	9.4	12.3	12.2	10.1	12.8	12.5	11.6	14.3	12.1

The differences between different soil preparation methods were relatively small at the ground level while those between the years were considerable (Table 4). The mean temperatures for June varied most, the lowest being in the unprepared area in 1982. The mean temperatures for July also varied most in the same area, while in August the variation was greatest in the hollows of the cross-directional ploughing area.

At the depth of 5 cm soil preparation affected considerably the average soil temperature for all summer months and the differences between the years were also large (Table 5). The lowest mean temperature for June (8.5 °C) occurred in the unprepared site in 1982, and the highest (18.6 °C) in the tilts of the ploughed site in 1980. The maximum difference among the mean soil temperature records for June was 5.8 °C between the unprepared site and the tilts in 1980.

The lowest mean temperature for July (11.8 °C) was in a scarified patch in 1985 and the highest (18.8 °C) in a tilt in the ploughed site in 1978. The maximum difference in mean July temperature values, 4.9 °C, occurred between the untreated areas in the scarification and the humps on the cross-directional ploughing in 1978. The lowest mean temperature in August (11.5 °C) occurred in the unprepared site in 1982, 1983 and 1984 and the highest (17.0 °C) in the hump in 1976.

Differences in monthly mean temperatures also occurred between the various methods at the depth of 50 cm, but also between consecutive years with the same preparation method (Table 6). The maximum mean temperatures for June (13.6 °C) and July (16.0 °C) were observed in the hump in 1980 and 1976 and the minimum for June (6.5 °C) and July (9.3 °C) in the unprepared site in 1985.

At the depth of 100 cm the mean temperatures for the summer months were highest in August (Table 7), especially in the cross-directional ploughed area. The lowest temperatures were usually measured in the unprepared site. The differences between the years with each preparation method were relatively small, with the exception of the mean temperatures for June in 1985, which were lower than in the previous years. Generally speaking, the monthly mean temperatures at the depths of 50 and 100 cm were highest in the tilts of the ploughed site or in the humps and the lowest in the unprepared site.

3.1.4 Distributions of Daily Temperature Amplitude

The difference between the daily maximum and minimum temperatures at the height of 10 cm in 1976 was largest at the unprepared area (Figure 20), the arithmetic mean of temperature amplitude being 16.8 °C (Table 8). Amplitudes of over 20 °C accounted for 29 % of the total variation, and the observed maximum daily amplitude, 26.8 °C, also occurred in the unprepared area. The daily amplitude at this height was also large between the scarified patches, but the distributions on the tilt and shoulder at the ploughed

Table 5. Monthly mean temperatures at a depth of –5 cm. C-plough is cross-directional ploughing.

Year	June	July	Aug.	June	July	Aug.	June	July	Aug.	June	July	Aug.
	No preparation			Patch			Between patches			Plough tilt		
1976	11.5	14.6	13.8	13.5	16.7	15.6	12.1	15.7	15.1	14.2	17.0	16.1
1977	12.9	15.6	14.2	14.0	16.2	12.1	12.8	15.6	13.8	16.7	18.1	14.9
1978	12.3	15.7	12.0	13.9	15.6	12.4	11.9	13.9	11.7	15.8	18.8	13.2
1979	11.6	14.0	12.9	14.3	16.0	14.6	12.8	15.0	14.0	16.8	17.6	15.8
1980	12.8	13.5	12.0	14.9	15.6	13.8	13.3	14.4	13.3	18.6	18.1	14.4
1981	10.1	14.6	12.9	11.3	15.9	13.8	10.6	15.2	13.6	13.2	18.1	14.3
1982	8.5	12.9	11.5	9.6	14.0	12.0	9.0	13.3	11.8	11.1	17.2	13.9
1983	10.5	13.6	11.5	11.6	14.0	11.9	11.4	13.8	11.9	13.7	16.5	13.1
1984	10.9	13.0	11.5	11.2	13.3	11.8	11.2	13.3	11.8	14.0	15.6	13.0
1985	9.4	12.0	11.9	8.9	11.8	12.0	8.9	11.9	12.2	12.5	15.2	13.8
	Plough shoulder			Between tilts			C-plough hump			C-plough hollow		
1976	13.4	16.3	15.0	12.3	15.6	14.9	14.2	17.5	17.0	13.6	16.9	15.8
1977	15.1	17.5	14.9	13.9	16.3	14.9	15.7	17.6	14.2	14.5	17.0	13.9
1978	15.8	19.4	14.7	12.4	15.7	12.3	16.1	17.9	13.7	15.1	17.2	13.1
1979	15.0	16.5	14.9	12.7	15.1	13.9	16.8	17.9	15.9	16.2	17.4	15.6
1980	16.4	16.7	13.8	13.6	14.5	13.0	18.3	18.2	15.2	17.0	17.4	14.8
1981	12.1	16.9	13.8	10.6	15.2	13.6	13.1	18.0	14.5	12.4	17.1	14.0
1982	10.2	15.8	13.1	8.8	13.5	12.1	11.1	17.1	13.8	10.5	16.0	13.1
1983	12.7	15.4	12.4	11.2	14.0	12.0	13.8	16.7	13.2	13.1	15.8	12.6
1984	12.9	14.5	12.3	11.2	13.5	12.1	13.8	15.5	12.9	13.0	14.5	12.3
1985	11.2	13.8	12.7	9.7	12.6	12.5	12.1	15.4	14.2	11.1	14.0	13.1

and on the hump at the cross-directional ploughed areas did not differ to any significant extent.

An examination of the daily temperature amplitude at +10 cm at the unprepared site from 1976 onwards (Appendix 1) indicates that the arithmetic mean value varied annually, but no distinct upward or downward trend could be detected. The maximum mean value for the whole period was 17.7 °C, in 1982, and the minimum 13.4 °C, in 1981. The arithmetic mean of daily amplitude in the ploughed and cross-directional ploughed areas also varied annually, the highest value in the tilt being 15.4 °C in 1982 and the lowest value 11.4 °C in 1977 and the corresponding figures for the hump 14.8 °C in 1982 and 10.7 °C in 1976. A slight upward trend occurred in the arithmetic mean in both areas.

Examination of the occurrence of high values at the height of 10 cm in the unprepared area indicates that daily amplitudes of over 20 °C occurred every year (Appendix 1) of which most cases, 40 %, occurred in 1982 and the fewest, 11 %, in 1978. Comparable amplitudes did not occur every year on the tilt or on the hump although peaks of 23 % and 15 % respectively did occur in 1985.

The daily amplitude at the ground level was similar on the unprepared site and the scarified patch (Figure 20), but smaller in the hollow. The amplitude at the depth of 5 cm was greatest in the tilt of the ploughed area, the arithmetic mean being 11.4 °C and the maximum 22.8 °C. 1 % of the days had amplitudes of over 20 °C, and 17 % over 15 °C (Table 8). The daily amplitudes in the hump also exceeded 15 °C in 5 % of cases, and the maximum value was 16.3 °C. The amplitude was by far the lowest in the unprepared area, where the maximum was only 6.5 °C and arithmetic mean 4.1 °C.

Table 6. Monthly mean temperatures at a depth of –50 cm. C-plough is cross-directional ploughing.

Year	June	July	Aug.	June	July	Aug.	June	July	Aug.	June	July	Aug.
	No preparation			Patch			Between patches			Plough tilt		
1976	9.0	12.0	12.6	9.9	12.9	13.6	10.9	13.8	14.6	10.6	13.8	14.0
1977	9.6	12.5	13.2	–	–	–	9.4	12.4	12.5	11.2	14.4	14.3
1978	8.2	12.0	10.9	8.6	11.3	11.0	8.6	11.2	10.6	9.9	14.1	12.3
1979	7.4	10.9	11.3	10.7	13.1	13.1	11.6	14.3	13.7	10.3	13.5	13.5
1980	9.0	10.8	11.7	10.7	11.8	12.4	9.5	11.6	12.2	11.2	13.4	13.2
1981	8.3	12.2	12.2	8.3	12.3	12.6	8.1	12.1	12.5	9.2	13.6	13.3
1982	7.0	10.1	10.2	7.0	10.4	10.3	6.9	10.3	10.2	7.5	11.9	11.6
1983	8.6	11.5	11.1	8.3	10.4	10.7	8.7	11.1	10.9	9.7	12.6	11.9
1984	8.9	11.0	10.8	8.6	10.6	10.8	8.7	10.6	10.9	9.8	12.1	11.9
1985	6.5	9.3	10.4	5.9	9.2	10.6	6.2	9.3	10.7	7.5	10.8	11.6
	Plough shoulder			Between tilts			C-plough hump			C-plough hollow		
1976	10.6	13.6	14.0	9.5	12.8	13.5	12.4	16.0	16.3	11.4	14.7	15.1
1977	11.4	14.7	14.7	10.3	13.5	14.2	12.8	15.6	13.7	11.2	14.2	13.4
1978	9.6	13.6	11.8	9.0	12.5	10.4	12.1	14.8	13.5	10.8	13.8	12.3
1979	10.7	13.8	13.5	9.0	12.9	12.9	13.3	15.6	15.1	12.0	14.3	13.9
1980	11.5	13.5	13.2	9.7	12.2	12.7	13.6	15.3	15.0	12.3	14.3	14.2
1981	9.3	13.6	13.2	8.5	12.6	13.1	10.6	15.2	14.3	9.6	14.1	13.5
1982	7.9	12.2	11.7	7.0	10.7	11.1	8.9	13.7	12.8	8.2	12.8	11.9
1983	9.9	12.7	11.9	9.0	11.8	11.7	11.3	14.3	13.0	10.4	13.2	12.1
1984	10.1	12.1	11.9	9.1	11.5	11.7	11.7	13.7	12.9	10.6	12.2	11.8
1985	7.7	10.9	11.5	6.7	10.1	11.4	8.8	12.8	13.2	7.8	11.5	12.1

Table 7. Monthly mean temperatures at a depth of –100 cm. C-plough is cross-directional ploughing.

Year	June	July	Aug.	June	July	Aug.	June	July	Aug.	June	July	Aug.
	No preparation			Patch			Between tilts			C-plough hollow		
1976	7.9	10.6	11.8	9.2	12.1	13.3	9.0	11.9	13.3	9.8	13.2	14.4
1977	8.2	10.8	12.0	8.0	10.8	11.4	9.5	12.2	13.1	10.2	13.2	13.1
1978	6.3	10.1	9.7	9.5	11.7	12.3	9.0	12.8	11.5	9.5	12.9	12.4
1979	6.1	9.7	11.1	9.2	12.3	12.9	12.1	14.9	14.3	10.0	12.9	13.3
1980	6.8	9.3	10.4	8.2	10.7	11.9	8.2	10.8	12.0	10.1	13.1	14.0
1981	6.9	10.3	11.6	7.4	11.0	12.1	7.2	11.1	12.4	9.0	12.9	13.4
1982	6.5	9.1	9.6	6.5	9.4	9.9	6.2	9.5	10.3	8.0	12.0	12.2
1983	7.2	9.7	10.1	7.4	9.6	10.1	7.8	10.6	11.1	10.1	12.8	12.8
1984	7.4	9.4	10.3	7.3	9.5	10.2	8.0	10.2	11.2	10.1	11.8	12.4
1985	6.1	9.0	10.8	4.4	7.6	9.4	5.1	8.6	9.0	7.7	11.3	12.1

Table 8. Distribution of daily temperature amplitude during the summer months in 1976 as percentages of total observations in different temperature classes. The minimum, maximum and mean ($\bar{x}$) values of amplitude during the same period are also presented.

Level	Site preparation	Temperature classes °C							Temperatures °C		
		0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	$\bar{x}$	min	max
+10 cm	No preparation	1	3	16	7	12	32	29	16.8	3.0	26.8
	Patch	0	7	15	14	22	35	7	13.8	3.1	24.2
	Between patches	0	3	20	5	14	32	26	15.5	3.5	28.0
	Plough tilt	1	8	28	20	17	26	0	11.6	2.2	19.5
	Plough shoulder	1	9	25	23	20	22	0	11.4	2.3	18.2
	Between tilts	1	5	20	13	14	37	10	13.8	2.8	22.3
	C-plough hump	1	10	30	24	23	12	0	10.7	2.2	18.9
	C-plough hollow	1	9	29	25	24	12	0	10.7	2.3	18.4
0 cm	No preparation	2	4	29	14	24	27	0	12.0	2.9	19.7
	Patch	2	3	35	34	22	4	0	10.3	2.7	16.3
	Between patches	2	5	31	24	25	13	0	10.9	2.6	18.1
	C-plough hollow	0	4	25	24	25	22	0	11.9	3.1	17.8
–5 cm	No preparation	20	57	23	0	0	0	0	4.1	1.0	6.5
	Patch	3	13	68	16	0	0	0	7.7	2.4	12.4
	Between patches	16	47	37	0	0	0	0	4.6	1.4	8.1
	Plough tilt	1	4	32	25	20	17	1	11.4	3.0	22.8
	Plough shoulder	2	5	47	33	11	2	0	9.6	2.7	16.1
	Between tilts	7	24	67	2	0	0	0	6.1	1.4	11.1
	C-plough hump	1	5	39	26	24	5	0	10.3	2.6	16.3
	C-plough hollow	3	9	57	28	3	0	0	8.5	2.5	13.0

The arithmetic mean of the daily temperature amplitude at the depth of 5 cm in the tilt ranged from 11.4 °C in 1976 (Table 8) to 4.3 °C in 1985 (Appendix 1), and the maximum from 22.8 °C in 1976 to 8.7 °C in 1985, the corresponding mean values for the hump being 10.3 °C and 3.8 °C and the maxima 16.3 °C and 7.6 °C, which indicates that the daily variation at these measurement points shows a distinct downward trend.

The average daily amplitude at the depth of 5 cm on the unprepared area ranged from 5.6 °C in 1978 to 2.9 °C in 1985 and was very much lower than in the prepared areas. The amplitude diminished towards the end of the measurement period. Daily amplitudes of over 20 °C at this depth (Table 8, Appendix 1) occurred only in the tilt in 1976 (1 %) and 1978 (1 %), but amplitudes of over 15 °C occurred both in the tilts and in the humps in the early years. Amplitudes of over 10 °C were still relatively rare in the unprepared area, occurring only in 1978 (1 %) and 1979 (1 %).

3.1.5 Distributions of Temperature Observations

Soil preparation affected the distributions of the observations to some extent at the height of 10 cm (Figure 21, Appendix 2). Temperatures of over 25 °C accounted for 9 % of observations between the patches and 4 % in the tilt and shoulder of the ploughed area and in the hollow in 1976 (Table 9). Low temperatures were most frequent in the unprepared area and rarest in the cross-directional ploughing. Temperatures below 5 °C accounted for 10 % of all observations at

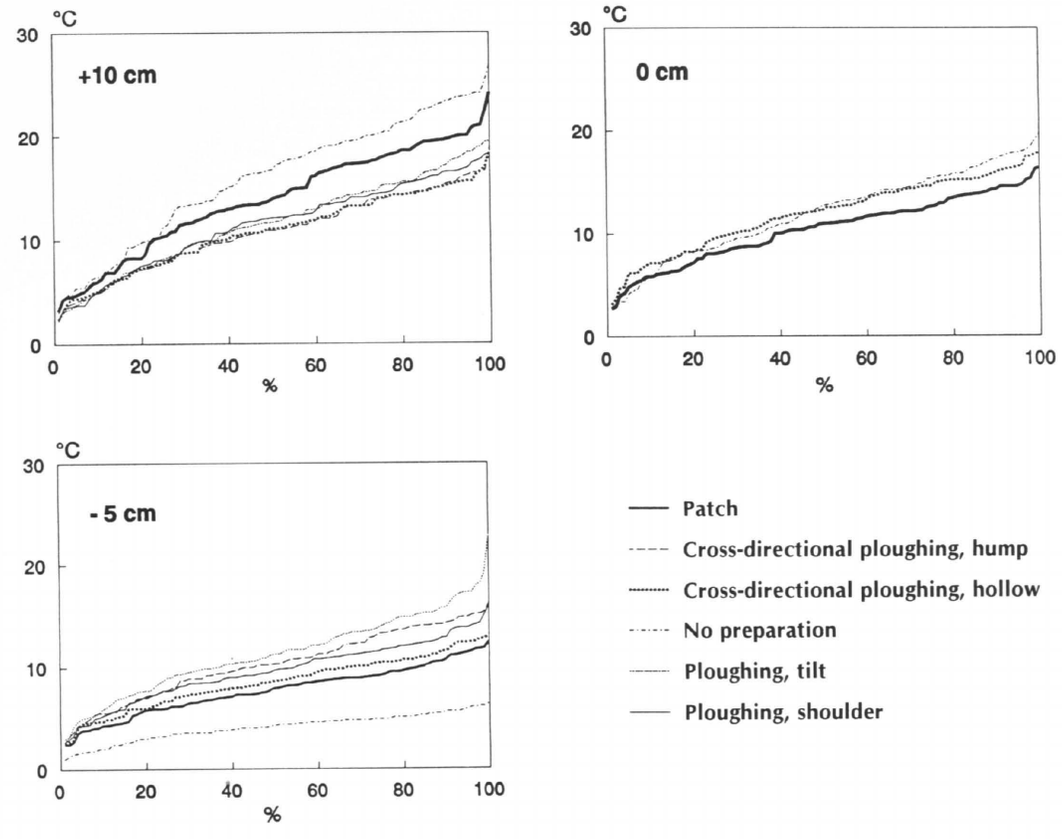


Figure 20. Distributions of daily temperature amplitude at the levels of +10 cm, +0 cm and –5 cm at the different preparations during the summer months of 1976.

the height of 10 cm in the unprepared area and 3 % in the humps and hollows, but temperatures below 0 °C occured only in the unprepared and scarified areas. The means of the temperature observations ranged from 14.4 °C in the shoulder of the ploughed to 15.3 °C in the hollow of the cross-directional ploughing in 1976.

Differences in the distributions of the temperatures at the depth of 5 cm between the unprepared and prepared soils were large instead, particularly in the case of the high temperatures. Temperatures exceeding 25 °C occurred only in the tilt, in the shoulder and in the hump, and did not even exceed 20 °C at this depth in the unprepared area. Temperatures of over 20 °C accounted for 21 % in the tilt and 24 % in the hump. Temperatures below 5 °C occurred at the depth of 5 cm only in the tilt and shoulder and in the hump and in the hollow in 1976 (Table 9). Low temperatures occurred least often between the scarified patches, where only 8 % of the readings were below 10 °C. The mean values at this depth ranged from 13.3 °C in the unprepared site to 16.3 °C in the hump. The maximum 29.5 °C and the minimum of 2.7 °C both occurred in the tilt, the corresponding values for the hump being very similar.

The influence of soil preparation to the distributions of temperature observations could also be observed clearly deeper in the soil. Temperatures did not exceed 15 °C at all at the depth of 50 cm in the unprepared area, but 56 % of the temperature values in the hump did so. The distribution in the unprepared area was similar to that in the space between the tilts of the ploughed site. Temperatures exceeding 10 °C accounted for 56 % of the readings at the depth of 100 cm in the unprepared soil and 81 % in the hollow of the cross-directional ploughing site.

Table 9. Distribution of observations during the summer months in 1976 as percentages of total observations in different temperature classes. The minimum, maximum and mean ($\bar{x}$) values of observations during the same period are also presented.

Level	Site preparation	Temperature classes °C								Temperatures °C		
		<0	0–5	5–10	10–15	15–20	20–25	25–30	>30	$\bar{x}$	min	max
+10 cm	No preparation	1	9	16	29	23	14	7	1	14.6	–2.0	32.9
	Patch	1	5	17	28	27	15	7	0	15.0	–2.8	30.9
	Between patches	1	6	17	27	26	14	7	2	15.2	–3.1	32.3
	Plough tilt	0	4	17	36	25	14	4	0	14.5	0.8	31.5
	Plough shoulder	0	4	17	37	25	13	4	0	14.4	0.9	29.4
	Between tilts	0	6	17	35	22	14	6	0	14.5	0.0	31.9
	C-plough hump	0	3	15	31	31	15	5	0	15.2	1.4	29.6
	C-plough hollow	0	3	15	32	31	15	4	0	15.3	1.9	29.3
0 cm	No preparation	0	2	18	38	27	12	3	0	14.4	2.2	28.9
	Patch	0	1	13	35	36	13	2	0	15.1	3.9	27.0
	Between patches	0	2	13	36	34	12	3	0	15.0	3.5	27.9
	C-plough hollow	0	2	15	33	31	14	5	0	15.3	2.8	28.9
–5 cm	No preparation	0	0	12	62	26	0	0	0	13.3	6.6	19.3
	Patch	0	0	10	38	40	12	0	0	15.3	5.5	24.3
	Between patches	0	0	8	48	42	2	0	0	14.3	5.9	21.1
	Plough tilt	0	1	12	33	33	14	7	0	15.8	2.7	29.5
	Plough shoulder	0	1	13	39	32	14	1	0	14.9	3.5	25.8
	Between tilts	0	0	10	49	35	6	0	0	14.3	4.9	22.5
	C-plough hump	0	1	10	30	35	17	7	0	16.3	2.7	29.0
	C-plough hollow	0	1	10	34	41	14	0	0	15.5	4.0	25.0
–50 cm	No preparation	0	0	26	74	0	0	0	0	11.2	7.7	14.0
	Patch	0	0	17	83	0	0	0	0	12.2	8.0	15.5
	Between patches	0	0	10	74	16	0	0	0	13.1	8.3	15.5
	Plough tilt	0	0	15	69	16	0	0	0	12.8	8.4	17.3
	Plough shoulder	0	0	14	74	12	0	0	0	12.8	8.4	16.0
	Between tilts	0	0	21	78	1	0	0	0	12.0	8.0	16.7
	C-plough hump	0	0	6	38	56	0	0	0	14.9	9.4	19.6
	C-plough hollow	0	0	10	60	30	0	0	0	13.8	8.6	17.2
–100 cm	No preparation	0	0	44	56	0	0	0	0	10.1	6.8	13.1
	Patch	0	0	25	75	0	0	0	0	11.6	6.4	13.9
	Between tilts	0	0	27	73	0	0	0	0	11.4	7.8	14.7
	C-plough hollow	0	0	19	74	7	0	0	0	12.5	8.4	15.6

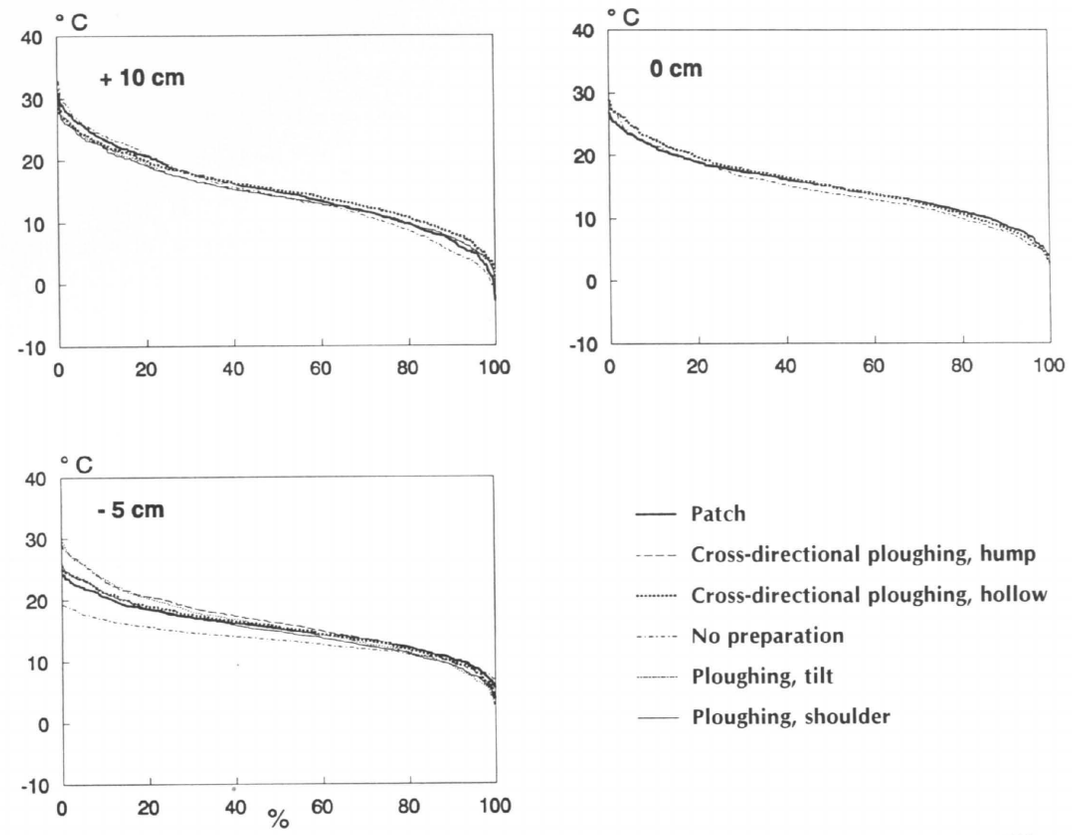


Figure 21. Distributions of temperature observations at the levels of +10 cm, +0 cm and –5 cm at the different preparations during the summer months of 1976.

3.2 Effect of Soil Preparation on Temperature Sums in the Air and in the Soil

Differences in the temperature sums for June at the height of 10 cm between the soil preparation types were fairly small in each year throughout the period. The various years differed considerably (Table 10). The lowest sum was 135 dd in the untreated area between tilts in 1982 and the highest in the hump of cross-directional ploughing site 376 dd in 1980. The differences measured at the ground level were also small, while in the depth of 5 cm the soil preparation types differed in each year considerably. The highest temperature sum, 407 dd, measured during the whole period occurred in the tilt in 1980 and the lowest, 107 dd, at the unprepared site in 1982. At the depth of 50 cm sums ranged from 39 dd to 259 dd, the maximum occurring in the hump in 1980 and the lowest in the scarified patches in 1982. The values for the humps were consistently higher than those for the tilts. The temperature sum for the hollow was highest at the depth of 100 cm almost throughout the period.

The temperature sums for July were usually higher than those for June at the same height or depth (Table 11). Differences between the soil treatments in the air near the soil surface were small, while in the soil the temperature sums were higher at all depths in prepared areas compared with the unprepared site or untreated areas in scarification or ploughing.

The temperature sums for August were smaller at the height of 10 cm and at the ground level compared with the values for July, but deeper in the soil the sums for August were higher (Table 12). Differences between the sites for August were small in the air and at the ground level, but dif-

Table 10. Cumulative effective temperature sums of June. I = no preparation, II = patch, III = between patches, IV = ploughing tilt, V = ploughing shoulder, VI = between tilts, VII = cross-directional ploughing; hump and VIII = cross-directional ploughing; hollow.

	+10 cm								0 cm			
Year	I	II	III	IV	V	VI	VII	VIII	I	II	III	VIII
1976	250	244	250	232	233	241	241	246	241	248	252	262
1977	310	299	289	309	308	302	295	289	319	296	274	282
1978	270	277	278	276	266	269	281	277	–	296	308	318
1979	294	320	321	311	290	299	327	326	301	296	294	375
1980	358	358	360	370	359	364	376	369	319	316	323	387
1981	193	198	197	196	195	185	209	201	204	193	208	244
1982	144	137	142	146	138	135	157	147	142	146	147	191
1983	230	227	231	234	220	219	240	232	216	217	223	264
1984	232	215	226	248	224	222	247	233	219	200	218	259
1985	241	193	215	251	229	248	239	222	179	133	152	199

	–5 cm							
Year	I	II	III	IV	V	VI	VII	VIII
1976	194	255	213	275	251	218	276	258
1977	239	271	235	354	303	270	322	285
1978	218	267	207	325	324	223	334	302
1979	199	280	235	355	300	232	355	335
1980	235	298	248	407	342	259	400	361
1981	152	190	166	248	212	168	244	222
1982	107	137	121	185	156	114	184	166
1983	166	198	193	262	231	188	264	245
1984	178	187	186	271	237	187	266	241
1985	131	117	117	225	187	140	212	183

	–50 cm								–100 cm			
Year	I	II	III	IV	V	VI	VII	VIII	I	II	VI	VIII
1976	121	148	176	168	170	136	223	193	88	128	120	144
1977	135	–	132	178	185	156	234	185	92	89	130	155
1978	96	109	107	147	139	119	213	173	40	134	121	136
1979	72	171	197	159	172	120	251	209	42	125	214	151
1980	120	172	135	187	194	141	259	220	60	96	98	154
1981	101	99	233	125	129	106	167	140	58	71	67	119
1982	61	62	58	76	86	62	118	96	45	46	37	91
1983	109	98	112	142	146	120	190	162	64	73	83	154
1984	116	108	109	145	154	124	201	167	72	69	91	153
1985	51	39	43	77	82	56	114	85	39	12	21	82

Table 11. Cumulative effective temperature sums of July. I = no preparation, II = patch, III = between patches, IV = ploughing tilt, V = ploughing shoulder, VI = between tilts, VII = cross-directional ploughing; hump and VIII = cross-directional ploughing; hollow.

	+10 cm								0 cm			
Year	I	II	III	IV	V	VI	VII	VIII	I	II	III	VIII
1976	341	361	363	334	332	335	358	359	331	363	354	367
1977	378	384	364	374	370	376	371	342	360	386	356	370
1978	369	332	329	380	373	371	342	321	–	357	347	400
1979	336	354	353	344	339	347	361	361	349	353	349	418
1980	345	355	349	366	356	358	377	370	331	340	347	414
1981	359	362	362	366	359	348	376	371	349	344	358	399
1982	323	314	323	349	330	321	355	344	297	296	301	374
1983	331	316	324	339	319	309	347	338	311	297	304	354
1984	294	290	300	304	285	280	306	290	284	268	281	306
1985	297	259	287	323	293	304	326	303	259	226	244	288

	–5 cm							
Year	I	II	III	IV	V	VI	VII	VIII
1976	299	363	331	371	352	331	389	369
1977	317	347	329	397	387	342	393	373
1978	333	328	277	427	447	333	402	378
1979	279	342	311	390	358	312	401	386
1980	265	328	291	407	365	295	409	384
1981	296	339	316	406	369	317	402	374
1982	246	279	256	378	334	266	374	343
1983	268	278	275	358	323	280	362	335
1984	249	258	259	328	294	264	325	296
1985	217	210	214	316	274	235	322	280

	–50 cm								–100 cm			
Year	I	II	III	IV	V	VI	VII	VIII	I	II	VI	VIII
1976	218	245	274	272	268	243	341	302	175	220	215	254
1977	226	–	230	286	308	259	329	285	167	179	224	256
1978	217	196	192	281	266	231	305	272	159	208	243	246
1979	182	252	289	264	272	245	330	288	147	226	306	246
1980	178	212	205	261	264	223	320	290	134	178	180	250
1981	221	226	221	267	269	236	316	281	163	187	188	247
1982	158	168	164	215	224	178	272	241	127	137	139	217
1983	202	168	189	236	240	211	287	253	148	144	173	241
1984	187	175	174	220	220	201	269	225	138	141	161	211
1985	134	131	134	180	183	159	242	202	122	81	113	194

Table 12. Cumulative effective temperature sums of August. I = no preparation, II = patch, III = between patches, IV = ploughing tilt, V = ploughing shoulder, VI = between tilts, VII = cross-directional ploughing; hump and VIII = cross-directional ploughing; hollow.

	+10 cm								0 cm			
Year	I	II	III	IV	V	VI	VII	VIII	I	II	III	VIII
1976	289	317	324	309	302	294	345	342	297	318	318	318
1977	283	274	252	294	285	283	255	250	294	292	260	276
1978	213	198	185	217	210	209	203	211	–	255	221	261
1979	268	287	280	289	284	284	300	294	282	299	298	339
1980	222	252	232	242	237	237	267	261	242	271	270	315
1981	234	242	236	238	234	224	243	239	265	268	277	286
1982	217	220	219	236	227	212	242	232	217	227	230	268
1983	201	195	197	210	196	187	214	208	213	222	221	243
1984	199	188	196	211	194	185	211	202	214	213	218	221
1985	228	230	235	244	226	237	264	252	229	224	233	220

	–5 cm							
Year	I	II	III	IV	V	VI	VII	VIII
1976	274	328	314	344	311	308	373	336
1977	289	221	271	309	310	308	286	275
1978	218	231	207	256	300	227	268	252
1979	247	297	280	334	306	277	339	330
1980	218	273	257	292	272	247	318	304
1981	246	272	268	289	274	268	296	280
1982	200	218	211	276	250	220	273	252
1983	203	214	215	251	230	219	253	236
1984	203	210	211	248	226	219	245	226
1985	213	216	222	273	239	233	285	252

	–50 cm								–100 cm			
Year	I	II	III	IV	V	VI	VII	VIII	I	II	VI	VIII
1976	234	266	299	279	278	264	349	314	210	256	257	291
1977	256	–	234	288	303	286	270	259	218	198	250	252
1978	182	187	172	227	212	167	263	226	145	226	203	229
1979	194	250	270	263	263	246	313	276	190	245	288	258
1980	208	229	224	254	254	239	312	285	167	213	219	279
1981	224	236	94	258	254	250	289	263	204	222	231	260
1982	161	165	163	203	207	188	241	216	144	154	163	225
1983	189	177	184	215	214	207	248	221	159	159	190	242
1984	181	181	182	215	214	208	246	212	163	162	192	229
1985	169	173	178	205	201	199	255	220	181	136	128	220

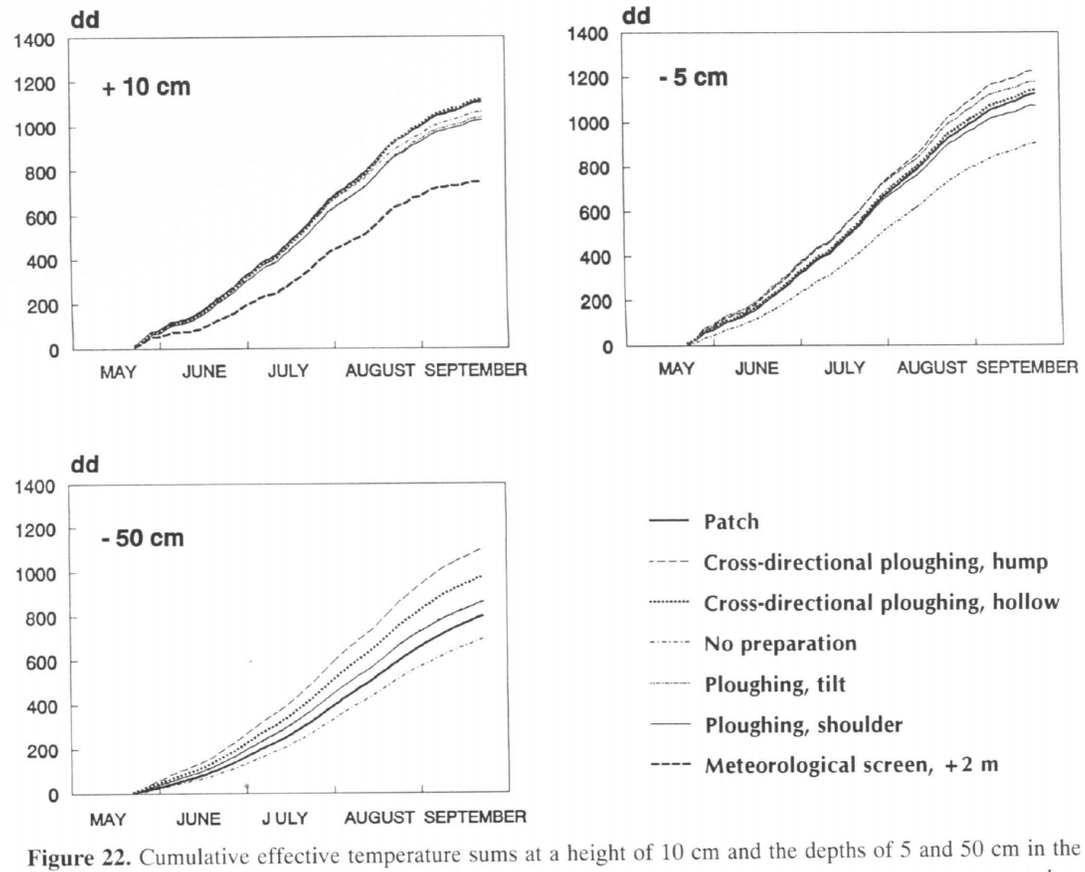


Figure 22. Cumulative effective temperature sums at a height of 10 cm and the depths of 5 and 50 cm in the unprepared and preparated areas in the summer of 1976. Calculation of the temperature sums was started on the 19th of May.

fered markedly in the soil as also in July. The highest temperature sum of 373 dd at the depth of 5 cm was measured in the hump in 1976 and the lowest, 200 dd, at the unprepared site in 1982. Correspondingly the highest value at the depth of 50 cm was 349 dd (1976) also in the hump and at the depth of 100 cm 291 dd (1976) in the hollow. In both depths the lowest sums were in the unprepared area.

The cumulative temperature sum from the end of May to the end of August is clearly higher at the height of 10 cm compared with the meteorological screen at the height of 2 m (Figure 22). The difference was about 200 dd. There were, however, very small differences between the treatments and they remained similar throughout the period (Table 13) as was also observed in the monthly sums. The temperature sum was generally highest in the hump of the cross-directional ploughing and lowest between the tilts of the ploughed site. The annual difference between the highest and lowest temperature sums was 70–100 dd.

At the depth of 5 cm the lowest temperature sum for the three summer months (Figure 22) was recorded in the unprepared area and it increased markedly as a result of soil preparation. The difference to the hump was approx 300 dd. During the hole measuring period the maximum difference, 409 dd, was in 1980.

Soil preparation also affected the temperature sum at the depth of 50 cm to a significant extent, the figure for the hump being highest throughout the period, and that for the unprepared soil usually the lowest, with a maximum difference between them of 446 dd in 1979 and a minimum differ-

Table 13. Cumulative effective temperature sums during summer months. I = no preparation, II = patch, III = between patches, IV = ploughing tilt, V = ploughing shoulder, VI = between tilts, VII = cross-directional ploughing; hump and VIII = cross-directional ploughing; hollow.

Year	+10 cm								0 cm			
	I	II	III	IV	V	VI	VII	VIII	I	II	III	VIII
1976	880	922	937	875	867	870	944	947	869	929	924	947
1977	971	957	905	977	963	961	921	881	973	974	890	928
1978	852	807	792	873	849	849	826	809	–	908	876	979
1979	898	961	954	944	913	930	988	981	932	948	941	1132
1980	925	965	941	978	952	959	1020	1000	892	927	940	1116
1981	786	802	795	800	788	757	828	811	818	805	843	929
1982	684	671	684	731	695	668	754	723	656	669	678	833
1983	763	738	752	783	735	715	801	778	740	736	748	861
1984	725	693	722	763	703	687	764	725	717	681	717	786
1985	766	682	737	818	748	789	829	777	667	583	629	707

Year	–5 cm							
	I	II	III	IV	V	VI	VII	VIII
1976	767	946	851	990	914	857	1038	963
1977	845	839	835	1060	1000	920	1001	933
1978	769	826	691	1008	1071	783	1004	932
1979	725	919	826	1079	964	821	1095	1051
1980	718	899	796	1106	979	801	1127	1049
1981	694	801	750	943	855	753	942	876
1982	553	634	588	839	740	600	831	761
1983	637	690	683	871	784	687	879	816
1984	630	655	656	847	757	670	836	763
1985	561	543	553	814	700	608	819	715

Year	–50 cm								–100 cm			
	I	II	III	IV	V	VI	VII	VIII	I	II	VI	VIII
1976	573	659	749	719	716	643	913	809	473	604	592	689
1977	617	–	596	752	796	701	833	729	477	466	604	663
1978	495	492	471	655	617	517	781	671	344	568	567	611
1979	448	673	756	686	707	611	894	773	379	596	808	655
1980	506	613	564	702	712	603	891	795	361	487	497	683
1981	546	561	548	650	652	592	772	684	425	480	486	626
1982	380	395	385	494	517	428	631	553	316	337	339	533
1983	500	443	485	593	600	538	725	636	371	376	446	637
1984	484	464	465	580	588	533	716	604	373	372	444	593
1985	354	343	355	462	466	414	611	507	342	229	262	496

Table 14. Planted and sowed pine seedlings, observed damages and naturally regenerated seedlings (no/ha) and height (cm) in 1982 and 1986. Pine seedlings were planted on sectors I and V in 1976 and seeds sowed on sector II in the spring of 1976. Planting density is calculated as the sum of living and dead seedlings in the inventory of 1982.

Variable	No preparation		Scarification		Ploughing		Cross-directional pl.	
	1982	1986	1982	1986	1982	1986	1982	1986
SECTORS I AND V								
Planted pines								
Planting density 1976	2158	–	2617	–	3184	–	3466	–
Living	1910	743	2335	1061	2476	849	2688	1097
Mean height (cm)	102	199	111	197	142	242	131	258
Damaged by snow blight	1415	354	1592	460	2370	142	2512	319
Replacement of main stem	920	106	885	36	1273	177	1203	36
Naturally regenerated								
Pine	106	36	142	213	708	849	1273	1415
Spruce	13405	12379	7569	7463	6473	7392	2830	4704
Deciduous trees	6260	6756	8488	7994	10398	9656	11389	11282
SECTOR II								
Sowed pines								
Living	34236	5659	35934	6508	40178	10752	27941	10610
Mean height (cm)	34	102	30	94	35	114	36	264
Dead pines	6508	354	2829	424	1698	2051	1768	2193
Damaged by snow blight	13298	778	3678	707	4527	2900	354	2476
Replacement of main stem	9337	283	6791	495	5942	1627	2476	990
Naturally regenerated								
Pine	0	354	849	71	0	424	0	212
Spruce	16977	11884	1981	2688	5376	3395	3537	5659
Deciduous trees	3395	3395	9337	5730	3395	3890	1768	2829

ence of 226 dd in 1981. The temperature sum for the tilt was lower than that for the hump throughout the period. The highest temperature sum at the depth of 50 cm, 913 dd, was recorded in the hump in 1976 and the lowest, 343 dd, in the scarified patch in 1985. The temperature sum also increased at the depth of 100 cm, the highest values being in the hollows and lowest in the unprepared area.

3.3 Development of Seedling Stand and Changes in Temperature Conditions

3.3.1 Number of the Seedlings and the Spatial Distribution of the Seedling Stand

The desirable planting density, 2500 seedlings/ha, was not reached at the unprepared site, was slightly exceeded at the scarified patch and was exceeded by a good margin at the ploughed and cross-directional ploughed site (Table 14). This had however a minor effect on temperature condition at the beginning of the research period and

later the shading effect of the planted seedlings was not great because of the mortality. The survival decreased radically at all sites between 1982 and 1986, varying from the 700 seedlings/ha on the unprepared area to 1100 seedlings/ha on the cross-directional ploughing, and the number of sown seedlings also decreased considerably. The height of the sown plants in 1986 was approx. 1 m, and that of the planted seedlings from approx. 2 m to 2.5 m. The poor success of the planted seedlings was compensated for by the natural regeneration of spruce and birch, their numbers were over ten times those of the planted seedlings in 1986.

The sector I, where the bare-root pine seedlings were planted in the spring of 1976, was taken as an example to study the spatial distribution of sapling stand. The low number of planted seedlings is due to their high mortality during the measuring period (Table 14) and because they were not planted in the immediate vicinity of the sensors.

The spatial arrangement of seedlings on the unprepared site has been described respectively earlier (Kubin and Kemppainen 1991). The scarified area had a sparse covering of fairly short planted pine seedlings and birches (Figure 23). Small stocking by natural regeneration of spruce occurred evenly all over the circular sample plot, but the total number of seedlings was smaller than at the ploughed area (Figure 24), which was characterized by an abundance of birch growing on the mineral soil exposed. Birches over 2 m in height also occurred more frequently than on the scarified area. Small pubescent birches of seed origin occurred in large numbers on the furrows and shoulders of the ploughing, and naturally regenerated spruces were numerous in the untreated area between the tilts. The areas with no seedlings were considerably smaller here than in the scarified patch. The shading influence of the seedling stand was more significant in the ploughed area than in the scarified area, especially at the end of the measuring period. The situation was similar on the cross-directional ploughed area (Figure 25), where the larger number of planted seedlings can partly be explained by the greater planting density (Table 14). Small pubescent birches of seed origin were dense in places, but the number of spruce seedlings was small.

3.3.2 Changes in the Distribution of Daily Temperature Amplitude

Ploughing and cross-directional ploughing led to a considerable increase in daily temperature amplitude at a depth of –5 cm in the soil (Figures 12 and 16). The succession of the vegetation (Figure 26) and seedling stand (Table 14, Figures 24 and 25) and deformation of the tilts gradually levels out this variation and will finally result in the conditions prevailing before cutting (Kubin and Kemppainen 1991). Temperature conditions during the measurement period (1976–1985) will be discussed in the following by means of changes in the percentage of high amplitude, which is used here to refer to variation exceeding a selected threshold value as a percentage of all the days examined. The threshold value was selected in such a manner that the percentage of high amplitude was never zero during the period studied, but was still as small as possible.

The threshold values used were 20 °C at +10 cm in the unprepared area, 15 °C at +10 cm on the ploughing tilt and cross-directional ploughing hump, 10 °C at –5 cm in the ploughing tilt and cross-directional ploughing hump and 5 °C at –5 cm in the unprepared area. The value was constant at each measurement site throughout the period, and may be different or the same at different levels in the clearcut area and soil preparation areas depending on the differences in the daily temperature amplitude between these points.

The overall trend in the percentage of high daily amplitudes at +10 cm in the ploughing tilts and the cross-directional ploughing humps was a rising one in 1976–1982 (Figure 27), with a slight decrease after 1982. The trend in the unprepared area was an even one except for maxima in 1980 and 1982 and a minimum in 1981. There were thus fairly marked differences between the years.

The percentage of high amplitude days at –5 cm decreased radically in the ploughing tilts and cross-directional ploughing humps throughout the period studied, and increased in the unprepared area between 1976 and 1978, decreasing after that to the end of the period in the same manner as in the first-mentioned areas.

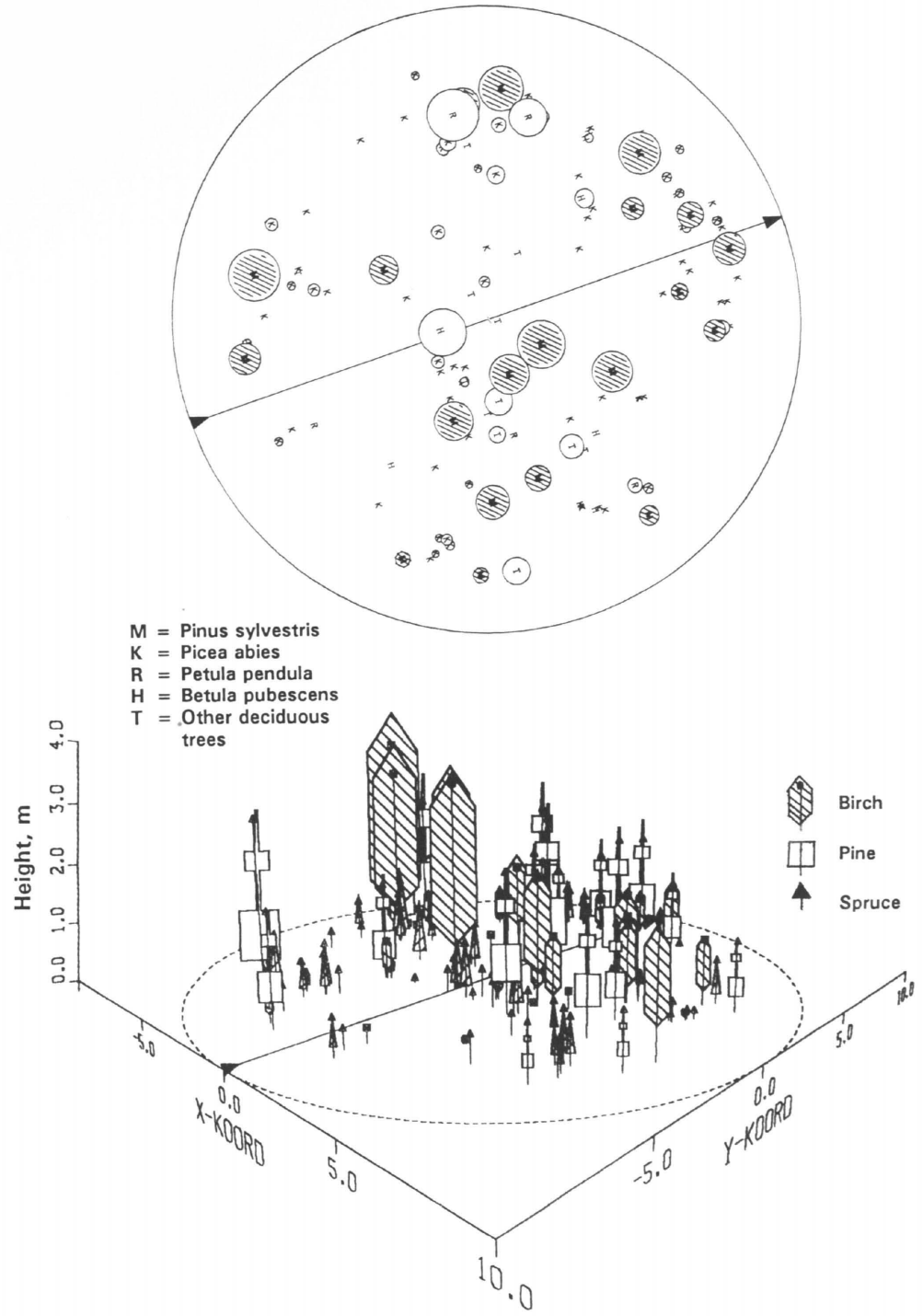


Figure 23. Distribution of the tree cover in 1986 around the measurement devices in the scarified area of sector I. Scots pine seedlings were planted in 1976. Trees are measured within a radius of 8.6 m.

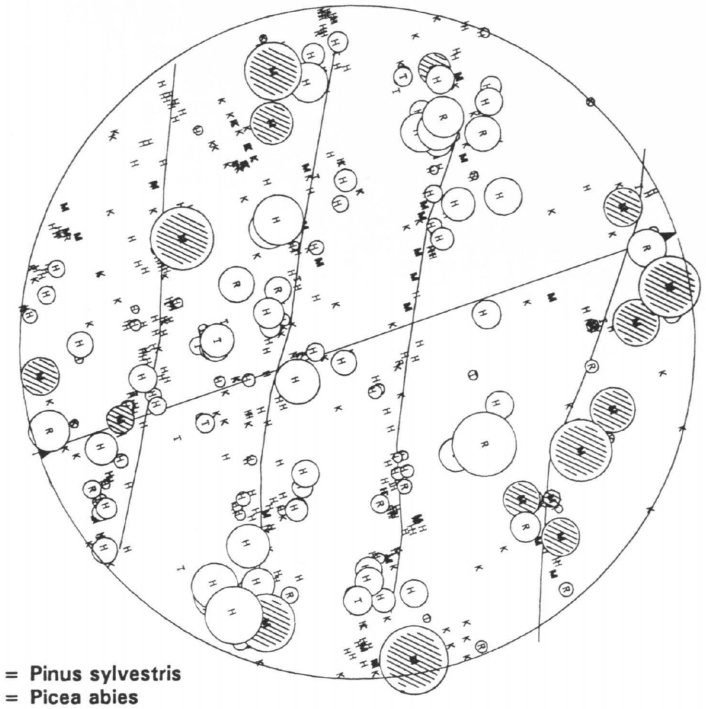


Figure 24. Distribution of the tree cover around the measurement devices in the shoulder ploughing area of sector I in 1986. Scots pine seedlings were planted in 1976. Trees are measured within a radius of 10.0 m. The lines indicate the bottoms of the furrows.

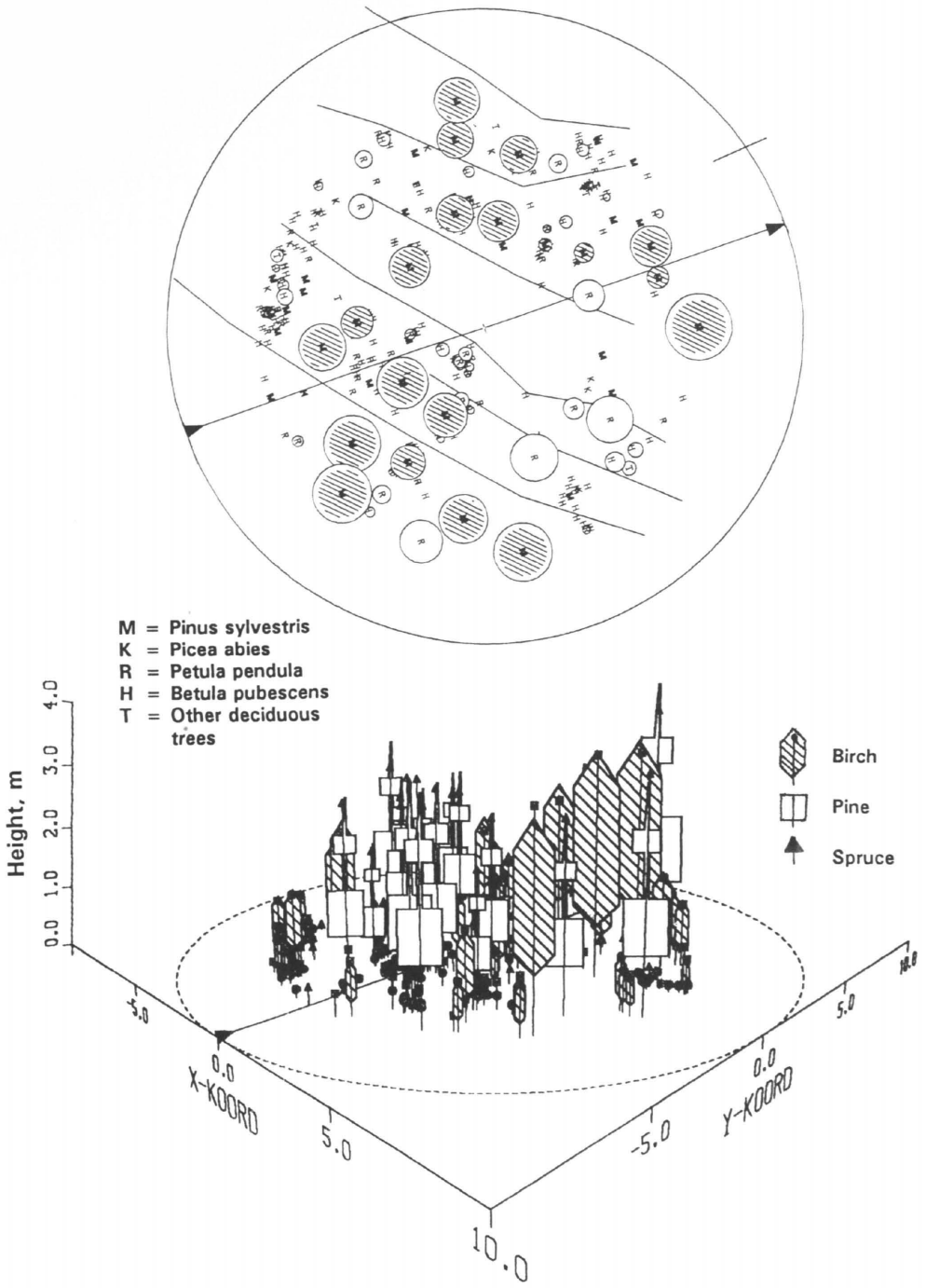


Figure 25. Distribution of the tree cover around the measurement devices in the cross-directional ploughed area of sector I in 1986. Scots pine seedlings were planted in 1976. Trees are measured within a radius of 7.6 m. The lines indicate the bottoms of the hollows, which are not the same as the ploughing furrows.

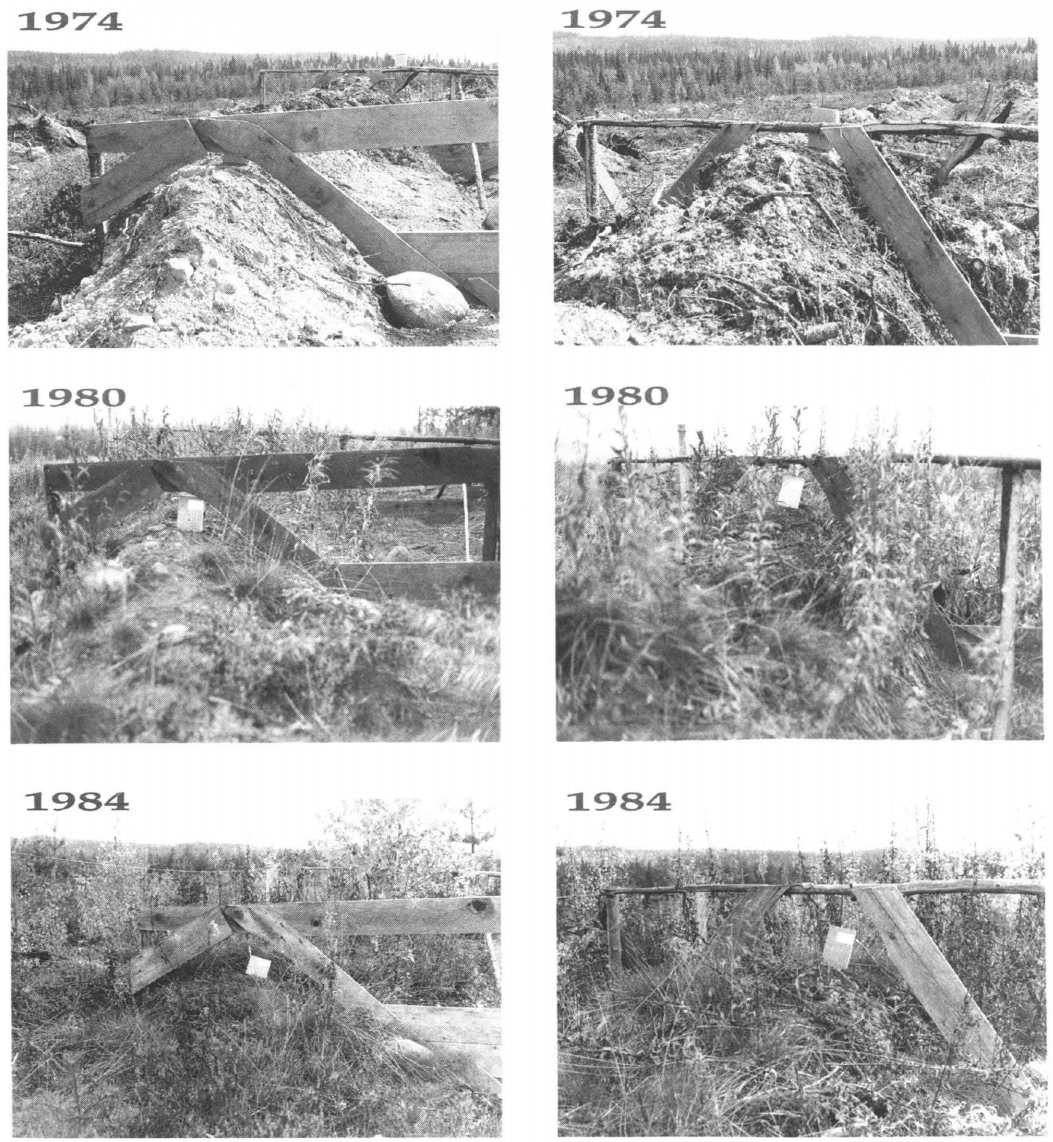
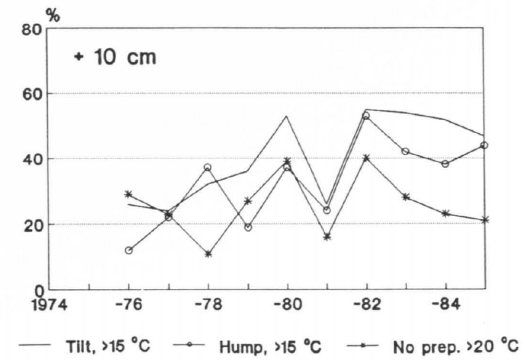


Figure 26. Sinking of ploughing tilts, photographed at the same places immediately after preparation in the autumn of 1974 (above), in the autumn of 1980 (centre) and in the autumn of 1984 (below). The left-hand pictures show a tilt with a high mineral soil content and the right-hand pictures one composed chiefly of raw humus.

3.3.3 Changes in the Distribution of Temperature Observations

Ploughing and cross-directional ploughing caused a considerable change also in the distribution of temperature observations at a depth of –5 cm in the soil (Figure 20). The description of the development is given in terms of the percentages of high and low temperatures. The percentage of high temperatures refers to those observations exceeding a selected threshold value and the percentage of low temperatures to those remaining under a lower level threshold. The threshold values were employed on the same principle as in



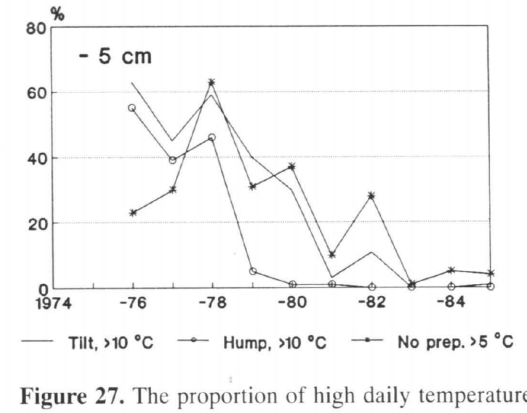
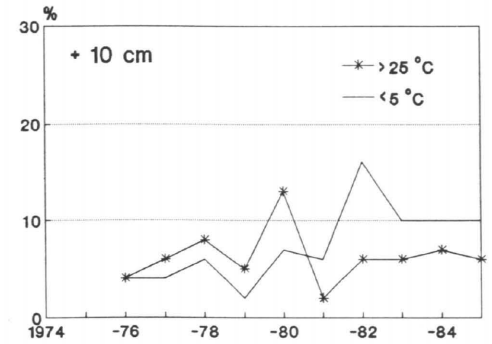


Figure 27. The proportion of high daily temperature amplitudes at the levels of +10 cm and –5 cm at different preprations in 1974–85.



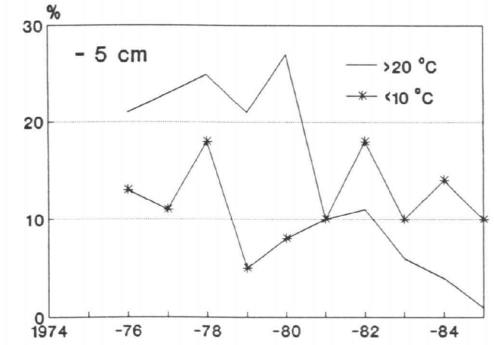


Figure 28. The proportions of high (>) and low (<) temperature observations at the levels of +10 cm and –5 cm in the tilt of the ploughed area.

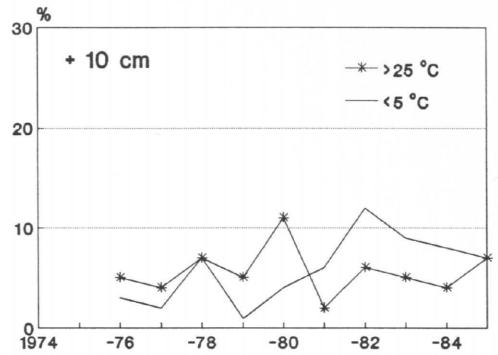
the examination of trends in the distribution of daily amplitude above and were selected to correspond to the temperature observations as follows: in the tilts and humps 25 °C at +10 cm and 20 °C at –5 cm for high temperatures; 5 °C at +10 cm and 10 °C at –5 cm for low temperatures.

The percentage of high temperatures remained broadly constant at +10 cm in the ploughing tilt throughout the period (Figure 28), with its maximum in 1980 and minimum in 1981, while that of low temperatures increased slightly and had its maximum in 1982. The proportion of high temperatures at –5 cm in the tilt was fairly even between 1976 and 1980, after which there was a considerable decrease, while that of low temperatures decreased in 1976–1979 and then started to increase, the maximum again occurring in 1982. The percentages of high and low temperatures in the hump were similar to those in the tilt at +10 cm (Figure 29), and only minor differences occurred at –5 cm, the most significant of these being at the beginning of the period.

3.3.4 Changes of Mean Summer Temperatures

Differences in mean summer temperature (June, July and August) between the tilts, the humps and the unprepared area were relatively small at +10 cm throughout the period (Figure 30), the mean temperatures themselves changing little between 1976 and 1980 but showing a considerable decrease between 1980 and 1982, after which the curve remains even.

The mean summer temperatures measured at –5 cm in the unprepared soil were markedly lower



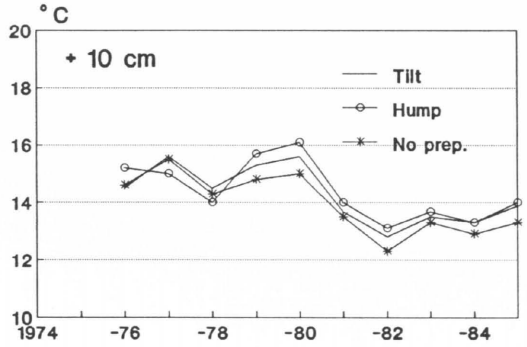
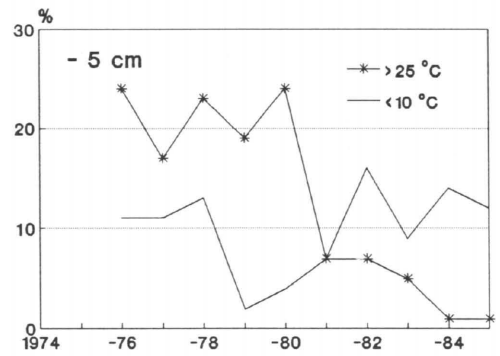


Figure 29. The proportions of high (>) and low (<) temperature observations at the levels of +10 cm and –5 cm in the hump of the cross-directional ploughed area.



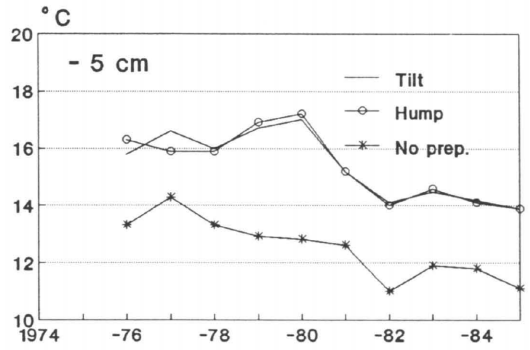


Figure 30. Mean summer temperatures at the heights of +10 cm and –5 cm at different preparations.

Table 15. Maximum soil frost depth (cm) in 1978–1985.

Winter	Uncut forest	Clearcut	Scarification		Shoulder ploughing			Cross-directional pl.	
			Patch	Between patches	Shoulder	Tilt	Between tilts	Hump	Hollow
1978–79	27	40	16	24	58	83	46	91	37
1979–80	7	5	4	2	13	51	9	46	5
1980–81	1	3	–	–	10	51	7	53	5
1981–82	1	2	1	0	11	48	8	50	5
1982–83	0	6	1	0	5	50	4	46	3
1983–84	1	4	3	1	6	47	4	48	8
1984–85	19	35	10	25	50	70	31	83	27

than those in the tilts and humps, and the difference did not change to any significant extent in the course of the period studied. The trend in mean temperatures at –5 cm was similar to that at +10 cm except for the year 1985, when temperatures at +10 cm were higher than in 1984 and those at –5 cm lower, as a result of a deeper than average soil frost layer the previous winter (Table 15). Soil frost was thick also in the winter 1978–1979, but it melted around mid-May.

4 Discussion

All the site preparation methods increased soil day temperature and decreased night temperature most just below the soil surface. Day temperature in particular was clearly higher in the prepared than in the unprepared soil, as also found by Raulo and Rikala (1981), Örlander (1986) and Örlander and Gemmel (1989) at the depth of 10 cm in mounds. Söderström (1974, 1976) has found that scarification increases daily maximum temperatures at the depth of 5 cm and Bjor (1971) states that removal of the humus layer increases day temperatures at the ground surface. Night temperature has been observed to be lower in scarificated patches than in unprepared soil (Söderström 1974, Lundmark et al. 1978). In this study the night temperatures were also lower in the tilts and humps. Temperature conditions levelled out in the soil in the course of the measurement period and were fairly constant even in the prepared areas 11 years after soil preparation.

Soil preparation had also a considerable increase in mean soil temperatures as observed formely (Kauppila and Lähde 1975, Ritari and Lähde 1978). Ploughing caused the largest increase in daily amplitude and scarification the smallest, as also found by Turtiainen and Valtanen (1970). Kemppainen (1985) observed that the daily amplitude was, however, larger in the mounded than in the ploughed areas and the levelling out of temperature in prepared soil does not start until a few years after preparation, which was also the result in this study.

The early researches of site preparation emphasized particularly such changes in temperature which are favourable for the growth of seedlings (Valtanen 1970b, Söderström 1974). Experimental laboratory investigations had indicated that the optimal soil temperature for the growth and branching of the root system of Scots pine was 19 °C (Slankis 1949), which is more than soil temperature in northern regions. The 120-day growth chamber experiment of Söderström (1976) showed that the dry weight of the root system of Scots pine increased up to 30 °C, whereas a 30-day experiment indicated that a rise in temperature from 15 °C to 30 °C did not increase the weight of the roots. Ladefoged (1939) indicated that the physiological optimum for root growth in the spruce is approx. 26 °C and Söderström (1976) 20–25 °C. Aaltonen (1942) observed that the increase of soil temperature increased more the biomass growth of Scots pine than that of the Norway spruce.

According to Örlander (1985), the transpiration of Scots pine seedlings is highest when the soil temperature is 30 °C, and the corresponding temperature for the spruce is 20 °C. The high soil temperature can, however, increase the transpiration of water from pine seedlings in such a manner that the ratio of transpirated water for photosynthesis increases (Vogl et al. 1972), which results in an excessive consumption of water by the seedling. An increase in the proportion of temperatures over 25 °C may also have a harmful effect on the development of the root system (Slankis 1949) and the growth of mycorrhiza (Laiho 1970). Soil preparation also increased the proportion of temperatures below 5 °C, which may also hamper the mycorrhizal growth. The influence of soil temperature nevertheless depends on the stage in the growing season and is seen to be most significant in spring, since other factors also affect root growth in summer (Lyr and Hoffman 1967). On the other hand, the intensive root growth in northern conditions is at its greatest at the beginning of August (Heikinheimo 1942).

Values exceeding the optimum temperature for Scots pine as defined by Örlander (1985) and Söderström (1976) were rare in this study. The observed increase in mean temperature can be considered mainly favourable for the growth of Scots pine seedlings. The ecological significance of temperature that exceeds optimum values

should not be underestimated, however. It is important to notice that the high temperatures occurring during warm periods also have a serious draining effect on humps in particular (Kemppainen 1985, Örlander 1986). Since transpiration in seedlings also increases with a rise in soil temperature (Örlander 1985, Vogl et al. 1972), the water conditions may become critical for excess drying of tilts and humps. The influence of high temperatures on seedlings in various soil preparation areas requires further investigation.

The proportion of temperatures exceeding the optimum for the spruce is considerably higher than for pines (Örlander 1985, Söderström 1975, 1976). It is obvious that soil temperatures in the warmest parts of the tilts can be more harmful to the development of spruce seedlings during warm summer days than for pine seedlings. A fairly large proportion of the high temperature sums near the soil surface are due mainly to temperatures in excess of the optimum during warm days. High temperature sums were reported also in many earlier studies (Turtiainen and Valtanen 1970, Leikola 1974, Kauppila and Lähde 1975, Ritari and Lähde 1978, Heinonen and Lukkari 1987, Örlander and Gemmel 1989). If the effect of site preparation is assessed solely on the basis of mean temperatures or increases in the temperature sum, it can be mostly regarded as favourable for the growth of seedlings. The highest monthly mean temperatures in the prepared areas can just increase close to the optimum defined for the spruce and is far from the optimum for pine.

In addition to soil temperature the effects of soil preparation should also be examined from the point of view of the plant shoots, in which case attention must be paid to the occurrence of high and low temperatures above the ground surface. Soil preparation reduced near the soil surface the daily air maximum temperature and increased the minimum temperature, especially in the tilts and humps. These results correspond to earlier observations (e.g. Kohh 1970, Brække 1972, Lundmark 1985, 1988, Tolvanen and Kubin 1990). Temperatures of over 30 °C and below 0 °C were considerably more common in the unprepared clearcut area, although they occured also in the ploughed and cross-directional ploughed areas. Temperature rose at the height of 10 cm so high at times that it can be assumed to be harmful to the optimal growth of seedling shoots (Kozlowski et al. 1991). The results indicate that temperature records exceeding the optimum were considerably more frequent in the unprepared than in the prepared areas. Since soil preparation also reduced the risk of night frosts, plants enjoy better growth conditions in the prepared areas. Soil preparation increases the height increment of seedlings, but pine seedlings have also thicker branches and are more luxuriant in prepared areas (Kubin 1981, 1983), partly on account of the release of nitrogen (Kubin 1979, 1993).

In summary, it can be stated that soil preparation improves temperature conditions in the soil, but with certain reservations. Soil preparation increases temperatures in the surface soil of tilts, and optimal temperatures for the root system of the spruce in particular are frequently exceeded. The tilt can be too hot for optimal growth if the warm weather occurs at the adaptation stage after planting. The increase in temperature caused by soil preparation can be considered to have favourable effects in spring, when the soil is cold and wet, whereas in autumn prepared areas cool and freeze more rapidly than unprepared ones. The increase lasts for a minimum of 11 years, which was the period of the measurement in present investigation. Site preparation should therefore be developed in a manner that will ensure that temperature conditions are favourable for both the shoot and the root system and that other growth factors and environmental effects are also taken into account.

Acknowledgements

The Kivesvaara experimental field was established by Jukka Valtanen, director of the Muhos Forest Research Station, in 1972. Valuable help was obtained from Pertti Matila, engineer at the Department of Physics, University of Oulu, at the starting of the temperature measurements. The help provided by the land owner, Kajaani Oy (later United Paper Mills Ltd), was also of prime importance in the selection of the area and in the practical work in founding of the experimental field. In particular Olli Sarantola, the company's forest manager, and Risto Nederström, forestry manager, followed the progress of the investigation with interest at all stages. Professors Matti Leikola, Yrjö Vuokila, Gustaf Sirén, Erkki Lähde and Eero Paavilainen, who have been members of the steering committee for joint research between the Finnish Forest Research Institute and the land owner, also followed the investigation and contributed to its progress.

The work has been carried out by the Muhos Research Station of the Finnish Forest Research Institute. Eero Kubin has been responsible for the collection of the material and performing of the measurements. Lauri Kemppainen has processed the material and produced a preliminary report. Based on this, the report was written by both authors together. The manuscript was reviewed by prof. Matti Leikola. Merja Moilanen and Irene Murtovaara have helped in the processing of the report for publication and it was translated into English by Sirpa Vellonen and Malcolm Hicks. Financial support has also been obtained from the Academy of Finland. We wish to express our sincerest thanks to all those who supported the work at its various stages.

References

Ahti, T., Hämet-Ahti, L. & Jalas, J. 1968. Vegetation zones and their sections in northwestern Europe. Annales Botanici Fennici 5: 169–211.

Ångström, A. 1936–37. Jordtemperaturen i Bestånd av olika täthet. Meddelelser från Statens Skogsförsöksanstalt. Häft 29: 187–218.

Autio, K. 1965. Metsänviljelyaura — ase metsänuudistajan kädessä. Laajat kehitysnäkymät. Metsätaloudellinen aikakauslehti 82: 129–131.

Bjor, K. 1971. Forstmeteorologiske, jordbunnsklimatiske og spireøkologiske undersøkelser. Meddelelser fra det Norske Skogforsøksvesen 28: 429–526.

Brække, F. 1972. Vannehusholdning og mikroklima på ulike myrtyper. Meddelelser fra Det Norske Skogforsøksvesen 119. 134 p.

Gandahl, R. 1956. Tjälgränsmätare. Svenska Vägförening. Tidskrift. 2.

Halonen, S. 1965. Metsänviljelyaura — ase metsänuudistajan kädessä. Käsite "laikutus" pian aikansa elänyt. Metsätaloudellinen aikakauslehti 82: 131–132.

Heinonen, T. & Lukkari, T. 1987. Puulajien kasvupaikkavaatimukset. Alustavia tuloksia männyn, kuusen ja rauduskoivun viljelyn onnistumisesta Nurmeksessa. Metsäntutkimuslaitoksen tiedonantoja 283. 19 p.

Helimäki, U.I. 1967. Taulukoita ja karttoja Suomen sadeoloista kaudelta 1931–1960. Liite Suomen meteorologiseen vuosikirjaan 1966. Tables and maps of precipitation in Finland, 1931–1960. Supplement to the Meteorological Yearbook of Finland, 1966.

Helminen, V.A. 1987. Lämpöolot. Suomen kartasto. Vihko 131: 4–10. Maanmittaushallitus, Suomen maantieteellinen seura.

Homén, T. 1896. Über die Bodentemperatur in Mustiala. Acta Societatis Scientiarum Fennicae. Tom. XXI nro 9. 184 p. III Pl.

Huikari, O. 1954. Metsänhoitotöiden koneellistamisen nykyvaihde. Summary: A good start with the mechanisation of silvicultural tasks. Metsätaloudellinen Aikakauslehti 71(8): 303–306.

— 1964. Metsänhoidon perusteista. Metsä ja Puu (8): 280–282.

Kauppila, A. & Lähde, E. 1975. Koetuloksia maankäsittelyn vaikutuksesta metsämaan ominaisuuksiin Pohjois-Suomessa. Summary: On the effects of soil treatments on forest soil properties in North-Finland. Folia Forestalia 230. 29 p.

Kemppainen, L. 1985. Metsän avohakkuun ja maanmuokkauksen aiheuttamat muutokset maaperän lämpö- ja kosteusoloissa sekä niiden vaikutus männyntaimien kasvuun. Pro gradu -työ. Oulun yliopisto, Biofysiikan laitos. 102 p.

Kohh, E. 1970. Bidrag till frågan om skogsmarksplöjning. Sveriges Skogsvårdsförbunds Tidskrift. Häfte 2: 75–106.

Kolkki, O. 1966. Taulukoita ja karttoja Suomen lämpöoloista kaudelta 1931–1960. Liite Suomen meteorologiseen vuosikirjaan 1965. Tables and maps of temperature in Finland during 1931–1960. Supplement to the Meteorological Yearbook of Finland, 1965.

Kozlowski, T., Kramer, P. & Pallardy, S. 1991. The physiological ecology of woody plants. 657 p. Academic Press. San Diego, New York, Boston, London, Sydney, Tokyo, Toronto.

Kubin, E. 1975. VMT-kuusimetsän kasvipeitteestä, maan fysikaalisista ja kemiallisista ominaisuuksista Paltamon Kivesvaaralla, Kainuussa. Pro gradu. 81 p. Oulun yliopiston kasvitieteen laitos.

— 1977. Paljaaksihakkuun vaikutus kuusimetsän ravinnetilaan Pohjois-Suomessa (64°28'N). Summary: The effect of clear cutting upon the nutrient status of a spruce forest in northern Finland (64°28'N). Acta Forestalia Fennica 155. 40 p.

— 1979. Avohakkuun ja metsämaan aurauksen vaikutus tuoreen kangasmetsän maan ravinteisuuteen. Pro gradu. 78 p. Helsingin yliopiston metsänhoitotieteen laitos. Helsinki.

— 1981. Männyntaimien menestymiseen vaikuttaa muokkaustapa ja istutuskohta. Metsä ja Puu 2/1981: 24–26.

— 1983. Taimien elinympäristötutkimus Paltamon Kivesvaarassa. Metsäntutkimuslaitoksen tiedonantoja 119: 29–39.

— 1987. Site preparation and leaching of nutrients. IUFRO S1. 05-12 Symposium. Northern forest silviculture and management Rovaniemi and Finnish Lapland, 16–22.8.1987.

— & Poikolainen, J. 1982. Hakkaamattoman metsän sekä eri tavoin muokatun avohakkuualan routa- ja lumisuhteista. Summary: Snow and frost conditions in an uncut forest and open clear-cut areas prepared in various ways. Folia Forestalia 518. 24 p.

— & Kemppainen, L. 1991. Effect of clearcutting of boreal spruce forest on air and soil temperature conditions. Acta Forestalia Fennica 225. 42 p.

Ladefoged, K. 1939. Untersuchungen über die Periodizität im Ausbruch und Längenwachstum der Wurzeln bei einigen unserer gewöhnlichsten Waldbäume. Forstl. Forsøgsv. Danm. 16. 256 p.

Laiho, O. 1970. Paxillius involutus as a Mycorrhizal Symbiont of Forest Trees. Acta Forestalia Fennica 106. 72 p.

Leikola, M. 1971. Maan ja maanläheisen ilmakerroksen lämpöoloista. Metsäntutkimuslaitos Rovaniemen tutkimusaseman tiedonantoja 2: 12–15.

— 1974. Muokkauksen vaikutus metsämaan lämpösuhteisiin Pohjois-Suomessa. Summary: Effect of soil preparation on soil temperature conditions of forest regeneration areas in northern Finland. Communicationes Instituti Forestalis Fenniae 84(2). 64 p.

— 1979. Tutkimustoiminta Lapin metsien hoidon ja käytön suuntaajana. Summary: The role of forestry research in guiding forest policy and management in Finnish Lapland. Toim. M. Leikola. Silva Fennica 13(1): 31–34.

Lundmark, J-E. 1988. Skogsmarkens ekologi. Ståndortsanpassat skogsbruk. Del 2 — tillämpning. Jönköping. 319 p.

Lundmark, T. 1985. Temperaturens påverkan på plantor. Skogsfakta. Skogsskötsel i södra Sverige. Jönköping 16–17 Januari 1985. Konferens Nr. 751-54.

— , Odin, H. & Söderström, V. 1978. En orienterande studie av marktemperaturen på ett par lokaler inom Vindelns försöksparker. Institutionen för Skogsföryngring. Rapporter och uppsatser 97. 41 p.

Lyr, H. & Hoffmann, G. 1967. Growth rates and growth periodicity of tree roots. In Romberger, J.A. & Mikola, P. (eds.). International Review of Forestry Research. Vol. 2. p. 181–236.

Lähde, E. 1974. The effect of grain size distribution on the condition of natural and artifical sapling stands of Scots pine. Seloste: Maan lajitekoostumuksen vaikutus männyn luontaisten ja viljelytaimistojen kuntoon. Communicationes Instituti Forestalis Fenniae 84(3). 23 p.

— 1978. Maan käsittelyn vaikutus maan fysikaalisiin ominaisuuksiin sekä männyn ja kuusen taimien kehitykseen. Summary: Effect of soil treatment on physical properties of the Soil and on development of Scots pine and Norway spruce Seedlings. Communicationes Instituti Forestalis Fenniae. 94(5). 59 p.

Mälkönen, E. 1972. Näkökohtia metsämaan muokkauksesta. Some aspects concerning cultivation of forest soil. Folia Forestalia 137. 11 p.

Metsänviljelytutkimuksen työryhmän retkeily Pohjois-Suomessa 24.–29.8.1970. Metsäntutkimuslaitos. Rovaniemen tutkimusaseman tiedonantoja 1.

Mikola, P. 1950. Puiden kasvun vaihteluista ja niiden merkityksestä kasvututkimuksissa. Summary: On variations in tree growth and their significance to growth studies. Communicationes Instituti Forestalis Fenniae 38(5). 125 p.

Norokorpi, Y. 1971. Männyn viljelytaimiston tuhoista Pohjois-Suomessa. Metsäntutkimuslaitos. Rovaniemen tutkimusaseman tiedonantoja 2: 37–49.

Örlander, G. 1985. Plantetablering — en fråga om vattenupptagning. Skogsfakta 28: 1–4.

— 1986. Effect of planting and scarification on the water relations in planted seedlings of Scots pine. Studia Forestalia Suecica 173. 17 p.

— 1987. Effects of site preparation on the development of planted seedlings in Northern Sweden. IUFRO Working Party S1.05-12, Rovaniemi, Finland, 1987, 1–7.

— & Gemmel, P. 1989. Markberedning. Sveriges Skogsvårdsförbunds Tidskrift 3: 1–53.

Pohtila, E. 1970. Aurattujen alueiden metsänviljelymenetelmä. Metsä ja Puu (2): 14–17.

— 1977. Reforestration of ploughed sites in Finnish Lapland. Seloste: Aurattujen alueiden metsänviljely Lapissa. Communicationes Instituti Forestalis Fenniae 91(4). 98 p.

Puukko, O. 1965. Metsänviljelyaura — ase metsänuudistajan kädessä. Vesitalous voitava järjestää otolliseksi. Metsätaloudellinen aikakauslehti 82: 132–133.

Raulo, J. & Rikala, R. 1981. Istutettujen männyn,

kuusen ja rauduskoivun taimien alkukehitys eri tavoin käsitellyllä viljelyalalla. Summary: The development of Scots pine, Norway spruce and silver birch seedlings planted on a forestation site prepared in different ways. Folia Forestalia 462. 13 p.

Ritari, A. & Lähde, E. 1978. Effect of site preparation on physical properties of the soil in a thick-humus spruce stand. Communicationes Instituti Forestalis Fenniae 92(7). 36 p.

Ronge, E. 1928. Kort redogörelse för vissa skogliga försök, verkställda under åren 1914–1928 å Kramfors Aktiebolags skogar, och resultatens praktiska tillämpning i skogsbruket. Norrlands skogsvårdsförbunds tidskrift. p. 308–356.

Sirén, G. 1955. The development of spruce forest on raw humus sites in Northern Finland and its ecology. Lyhennelmä: Pohjois-Suomen paksusammalkankaiden kuusimetsien kehitykestä ja sen ekologiasta. Acta Forestalia Fennica 62. 408 p.

Slankis, V. 1949. Einfluss der temperatur auf das Wachstum der isolierten Wurtzeln von Pinus silvestris. Physiologia Plantarum 2: 131–137.

Söderström, V. 1974. Markberedning. Summary: Soil treatment. Sveriges Skogsvårdsförbunds Tidskrift 1: 157–166.

— 1975. Ekologiska verkningar av hyggesplogning. Summary: Ecological effects of ploughing mineral soil before planting on clearfelled areas. Sveriges Skogsvårdsförbunds Tidskrift 5: 443–472.

— 1976. Analys av markberedningseffekterna vid plantering på några färska hyggen. Summary: Analysis of the effects of scarification before planting conifers on some newly clearfelled areas in Sweden. Sveriges Skogsvårdsförbunds Tidskrifter 2–3: 59–333.

Tikkanen, E. 1985. Aurausalueen heikkokuntoisten männyntaimien ravinnetaloudesta Pohjois-Suomessa. Nutrient metabolism of weakened Scots pine saplings on a ploughed site in Northern Finland. Metsäntutkimuslaitoksen tiedonantoja 186. 23 p.

Tolvanen, A. & Kubin, E. 1990. The effect of clear felling and site preparation on microclimate, soil frost and forest regeneration at elevated sites in Kuusamo. Aquilo Ser. Botanica 29: 77–86.

Turtiainen, M. & Valtanen, J. 1970. Metsänuudistuksen vaikutus maan lämpötilaan. Metsä ja Puu (12): 10–13.

Uotila, A. 1988. Ilmastotekijöiden vaikutus männynversosyöpätuhoihin. Summary: The effect of climatic factors on the occurence of Scledorris cancer. Folia Forestalia 721. 23 s.

Valtanen, J. 1970a. Lapin männyntaimistojen kunnosta. Metsä ja Puu (4): 5–6.

— 1970b. Versosyöpä Lapin taimistojen kimpussa. Metsä ja Puu (4): 7–10.

— 1978. Tutkimustuloksia viljelymateriaalin ja viljelypaikan valinnasta metsäaurausalueella. Pyhäkosken tutkimusaseman tiedonantoja 17: 77–83.

Vogl, M., Polster, H. & Fuchs, S. 1972. Über den Einfluss der Bodentemperatur auf den Gaswechsel der Nadeln von Koniferenjungpflanzen. Biologisches Zentralblatt 91: 757–762.

Total of 64 references

Appendix 1. Distribution of daily temperature amplitude at different levels and sites of different preparation during the summer months in 1977–1985 as percentages of total observations distributed into temperature classes. Minimum, maximum and mean ($\bar{x}$) values for the amplitude during the same period are given on the right. C-plough is cross-directional ploughing.

Year 1977

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C $\bar{x}$	min	max
+10 cm	No preparation	1	3	16	14	15	28	23	15.1	2.2	27.6
	Patch	0	3	28	16	14	32	7	13.1	3.1	24.0
	Between patches	0	3	25	15	10	28	19	14.2	3.5	28.0
	Plough tilt	3	5	29	20	19	24	0	11.4	2.0	19.8
	Plough shoulder	3	5	27	25	21	19	0	11.0	2.1	18.2
	Between tilts	3	1	21	17	14	30	14	13.8	2.4	23.5
	C-plough hump	2	9	42	14	9	22	2	10.8	2.2	23.5
	C-plough hollow	1	2	34	20	24	16	3	11.8	2.7	23.2
0 cm	No preparation	1	5	28	21	21	13	11	12.3	2.3	23.4
	Patch	0	10	52	27	9	2	0	9.0	3.4	18.4
	Between patches	0	8	48	16	13	15	0	10.3	3.3	19.7
	C-plough hollow	2	3	37	16	23	19	0	11.1	2.6	19.9
–5 cm	No preparation	22	48	30	0	0	0	0	4.3	0.8	9.3
	Patch	7	17	64	12	0	0	0	6.9	1.4	11.7
	Between patches	25	43	32	0	0	0	0	4.2	1.4	7.4
	Plough tilt	3	11	41	21	11	13	0	9.8	2.0	19.3
	Plough shoulder	5	12	57	19	7	1	0	7.9	1.8	16.0
	Between tilts	24	49	23	3	1	0	0	4.6	0.8	13.0
	C-plough hump	5	11	45	24	12	3	0	8.8	2.1	16.2
	C-plough hollow	5	10	56	22	5	2	0	8.2	1.9	16.7

Year 1978

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C $\bar{x}$	min	max
+10 cm	No preparation	3	4	12	25	15	30	11	13.5	2.0	23.5
	Patch	2	5	17	7	14	24	31	15.4	1.8	28.4
	Between patches	2	4	11	10	13	26	34	16.5	2.4	29.8
	Plough tilt	7	4	24	15	19	24	7	12.4	2.0	21.9
	Plough shoulder	5	3	13	29	14	34	2	12.6	1.9	21.5
	Between tilts	3	5	14	20	19	28	11	13.5	2.0	24.5
	C-plough hump	3	7	23	13	17	33	4	12.8	2.0	21.5
	C-plough hollow	3	8	21	13	21	27	7	13.0	1.9	21.4
0 cm	No preparation	–	–	–	–	–	–	–	–	–	–
	Patch	5	7	32	28	19	9	0	9.8	1.0	18.0
	Between patches	1	5	17	15	12	35	15	14.3	2.1	25.3
	C-plough hollow	2	5	23	8	22	36	4	13.2	2.3	22.7
–5 cm	No preparation	14	23	62	1	0	0	0	5.6	1.1	10.4
	Patch	8	17	56	15	4	0	0	7.5	0.8	13.1
	Between patches	20	33	47	1	0	0	0	4.8	0.6	11.2
	Plough tilt	7	3	32	24	14	20	1	10.8	1.4	21.4
	Plough shoulder	8	8	41	26	13	4	0	9.1	1.5	16.0
	Between tilts	16	16	67	0	1	0	0	5.9	1.1	18.9
	C-plough hump	5	8	41	20	21	5	0	9.6	1.7	19.1
	C-plough hollow	7	5	39	29	16	4	0	9.4	1.0	17.1

Year 1979

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C x̄	min	max
+10 cm	No preparation	0	3	15	7	20	28	27	15.8	4.1	26.8
	Patch	0	4	14	16	10	45	11	14.5	3.8	24.5
	Between patches	0	2	13	11	13	28	33	16.4	4.2	28.5
	Plough tilt	0	5	17	23	19	34	2	12.7	3.4	20.3
	Plough shoulder	0	7	20	22	22	29	0	12.5	3.5	19.9
	Between tilts	0	3	14	9	17	34	23	15.5	4.1	25.6
	C-plough hump	0	8	25	19	29	19	0	11.8	3.2	19.8
	C-plough hollow	0	5	26	21	28	20	0	11.8	3.3	19.4
0 cm	No preparation	0	5	20	21	13	30	11	13.5	3.9	23.0
	Patch	4	10	59	23	3	1	0	8.3	2.6	15.4
	Between patches	0	8	43	28	17	4	0	9.9	3.3	16.8
	C-plough hollow	0	10	47	27	14	2	0	9.4	3.2	16.0
–5 cm	No preparation	23	46	30	1	0	0	0	4.4	1.2	10.3
	Patch	15	36	49	0	0	0	0	4.9	1.4	8.7
	Between patches	30	61	9	0	0	0	0	3.7	1.1	7.1
	Plough tilt	3	10	47	29	7	4	0	9.0	2.3	19.7
	Plough shoulder	7	15	68	7	3	0	0	7.3	2.3	14.1
	Between tilts	14	32	50	4	0	0	0	5.2	1.6	11.8
	C-plough hump	5	15	75	4	1	0	0	6.9	2.3	12.9
	C-plough hollow	7	16	73	4	0	0	0	6.5	2.1	12.0

Year 1980

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C x̄	min	max
+10 cm	No preparation	3	2	10	11	7	28	39	17.3	1.9	28.4
	Patch	4	3	13	8	12	33	27	15.7	1.9	25.2
	Between patches	2	5	8	10	8	26	41	17.1	2.4	27.1
	Plough tilt	2	4	16	9	15	40	14	14.4	1.8	23.1
	Plough shoulder	3	3	15	10	23	37	9	14.0	1.8	21.9
	Between tilts	2	3	11	9	8	30	37	16.9	1.9	27.1
	C-plough hump	5	4	17	16	20	38	0	12.5	1.7	19.7
	C-plough hollow	5	3	16	14	17	42	3	13.4	1.6	21.2
0 cm	No preparation	2	4	26	16	23	26	3	12.1	1.9	21.5
	Patch	5	8	49	37	1	0	0	8.6	1.2	13.2
	Between patches	4	5	24	17	30	20	0	11.7	1.7	19.2
	C-plough hollow	5	3	34	27	27	4	0	10.2	1.7	18.4
–5 cm	No preparation	17	46	37	0	0	0	0	4.4	1.1	7.2
	Patch	12	32	56	0	0	0	0	5.1	1.0	7.8
	Between patches	22	66	12	0	0	0	0	3.8	0.8	6.0
	Plough tilt	5	5	60	27	3	0	0	8.4	1.8	13.2
	Plough shoulder	7	11	66	16	0	0	0	7.5	1.6	12.2
	Between tilts	24	52	24	0	0	0	0	4.0	0.5	6.1
	C-plough hump	8	17	74	1	0	0	0	6.0	1.2	11.0
	C-plough hollow	8	16	75	1	0	0	0	6.2	1.3	12.0

Year 1981

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C x̄	min	max
+10 cm	No preparation	3	3	26	17	8	27	16	13.4	2.1	24.7
	Patch	3	4	30	14	11	27	11	12.7	2.0	23.8
	Between patches	3	3	25	10	12	24	23	14.2	2.2	25.3
	Plough tilt	4	7	35	14	14	23	3	11.2	2.2	21.1
	Plough shoulder	4	8	33	12	19	21	3	11.0	1.8	20.6
	Between tilts	3	4	28	16	8	30	11	12.9	1.9	24.3
	C-plough hump	3	8	35	14	16	20	4	11.0	1.9	22.1
	C-plough hollow	3	9	34	16	16	20	2	10.8	1.8	20.5
0 cm	No preparation	5	19	54	13	9	0	0	7.6	1.4	14.8
	Patch	16	26	53	5	0	0	0	5.9	1.0	12.1
	Between patches	8	16	47	21	8	0	0	7.8	1.3	14.5
	C-plough hollow	5	21	48	17	8	1	0	7.6	1.4	16.3
–5 cm	No preparation	60	30	10	0	0	0	0	2.9	0.6	7.9
	Patch	39	39	22	0	0	0	0	3.7	0.5	8.8
	Between patches	62	33	5	0	0	0	0	2.7	0.6	6.1
	Plough tilt	27	25	45	2	1	0	0	5.1	0.8	13.1
	Plough shoulder	22	32	43	3	0	0	0	5.1	1.0	12.2
	Between tilts	67	25	8	0	0	0	0	2.7	0.5	7.4
	C-plough hump	30	34	35	1	0	0	0	4.4	0.6	11.1
	C-plough hollow	19	30	48	3	0	0	0	5.3	0.5	12.3

Year 1982

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C x̄	min	max
+10 cm	No preparation	0	2	11	12	8	27	40	17.7	3.7	27.9
	Patch	0	1	13	13	11	35	27	16.5	4.2	25.5
	Between patches	0	1	10	11	9	22	47	18.6	5.0	29.0
	Plough tilt	0	3	16	12	14	36	19	15.4	3.6	27.2
	Plough shoulder	0	3	17	12	16	41	11	14.6	3.6	26.4
	Between tilts	0	3	11	10	9	26	41	17.5	3.6	29.3
	C-plough hump	0	4	19	13	11	36	17	14.8	4.1	25.6
	C-plough hollow	0	4	19	13	14	38	12	14.3	3.9	22.4
0 cm	No preparation	0	8	45	23	24	1	0	9.8	3.3	15.2
	Patch	4	26	67	3	0	0	0	6.6	2.0	10.3
	Between patches	1	9	51	27	12	0	0	9.1	2.6	14.7
	C-plough hollow	1	5	49	17	25	3	0	9.7	2.5	15.5
–5 cm	No preparation	27	45	28	0	0	0	0	3.9	1.2	6.5
	Patch	25	42	33	0	0	0	0	4.2	1.2	7.4
	Between patches	38	48	14	0	0	0	0	3.6	1.4	6.1
	Plough tilt	10	16	63	11	0	0	0	6.7	1.7	11.5
	Plough shoulder	9	20	69	2	0	0	0	6.2	1.8	10.1
	Between tilts	42	49	9	0	0	0	0	3.4	0.9	6.5
	C-plough hump	15	28	57	0	0	0	0	5.6	1.5	9.2
	C-plough hollow	4	24	65	7	0	0	0	6.6	1.9	10.5

Year 1983

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C x̄	min	max
+10 cm	No preparation	0	3	10	8	10	41	28	16.8	3.6	27.4
	Patch	0	5	10	9	14	47	15	15.5	3.3	24.2
	Between patches	0	2	10	8	10	40	30	17.0	3.9	26.7
	Plough tilt	0	5	11	9	22	43	10	14.7	3.3	23.7
	Plough shoulder	0	7	12	13	17	48	3	14.0	3.1	21.9
	Between tilts	0	3	10	7	14	41	25	16.4	3.9	24.9
	C-plough hump	0	5	13	13	26	39	4	13.7	3.3	20.9
	C-plough hollow	1	5	13	13	29	38	1	13.4	3.0	20.6
0 cm	No preparation	2	10	43	33	12	0	0	9.3	2.6	14.4
	Patch	12	20	68	0	0	0	0	5.6	1.4	9.7
	Between patches	3	10	73	14	0	0	0	7.9	2.1	12.3
	C-plough hollow	4	10	65	20	1	0	0	8.0	2.3	12.7
–5 cm	No preparation	41	58	1	0	0	0	0	3.2	0.7	5.4
	Patch	42	57	1	0	0	0	0	3.1	0.8	5.4
	Between patches	41	58	1	0	0	0	0	3.2	0.8	5.1
	Plough tilt	20	34	46	0	0	0	0	4.8	1.0	8.7
	Plough shoulder	24	28	58	0	0	0	0	5.2	1.3	8.7
	Between tilts	46	54	0	0	0	0	0	3.0	0.6	5.0
	C-plough hump	21	36	43	0	0	0	0	4.6	1.0	7.6
	C-plough hollow	11	24	65	0	0	0	0	5.5	1.3	8.8

Year 1984

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C x̄	min	max
+10 cm	No preparation	0	4	12	13	13	35	23	15.6	3.7	26.8
	Patch	0	3	15	12	15	36	19	14.9	3.9	25.7
	Betweem tilts	0	3	12	10	13	37	25	16.3	4.2	27.4
	Plough tilt	0	4	11	15	17	31	22	15.2	3.6	27.4
	Plough shoulder	1	3	21	14	22	30	9	13.7	2.9	23.2
	Between tilts	0	3	11	13	15	33	25	15.9	3.8	27.2
	C-plough hump	0	7	21	10	25	28	9	13.4	3.4	24.9
	C-plough hollow	1	7	22	14	23	25	8	12.9	2.9	21.9
0 cm	No preparation	4	9	64	19	4	0	0	8.1	2.1	13.9
	Patch	23	43	34	0	0	0	0	4.3	0.9	8.1
	Between patches	7	17	71	5	0	0	0	6.7	1.9	12.3
	C-plough hollow	5	19	66	9	1	0	0	6.8	1.8	13.1
–5 cm	No preparation	47	48	5	0	0	0	0	3.2	0.9	5.7
	Patch	66	33	1	0	0	0	0	2.6	0.8	5.1
	Between patches	48	48	4	0	0	0	0	3.1	0.7	6.0
	Plough tilt	27	34	39	0	0	0	0	4.6	1.3	10.0
	Plough shoulder	20	39	41	0	0	0	0	4.6	1.3	8.6
	Between tilts	58	40	2	0	0	0	0	2.8	0.8	5.2
	C-plough hump	32	41	27	0	0	0	0	4.1	1.0	8.1
	C-plough hollow	24	37	39	0	0	0	0	4.4	1.4	8.6

Year 1985

Level	Site preparation	Temperature classes °C 0–3	3–5	5–10	10–12.5	12.5–15	15–20	>20	Temperatures °C x̄	min	max
+10 cm	Site preparation	0	5	15	22	9	28	21	14.8	3.8	29.1
	Patch	0	1	25	19	14	33	8	13.3	4.6	23.4
	Between tilts	0	0	19	12	11	24	34	16.7	6.0	31.8
	Plough tilt	0	4	23	16	10	24	23	14.6	4.0	30.5
	Plough shoulder	0	7	29	14	12	26	12	13.0	3.7	27.3
	Between tilts	0	3	19	19	12	25	22	15.2	3.3	29.1
	C-plough hump	0	2	25	13	15	30	15	14.2	4.2	26.9
	C-plough hollow	0	5	25	16	15	34	5	13.1	4.1	24.9
0 cm	No preparation	5	23	57	12	3	0	0	7.1	1.4	13.4
	Patch	41	40	19	0	0	0	0	3.6	1.3	6.8
	Between patches	5	26	61	8	0	0	0	6.5	2.1	12.0
	C-plough hollow	7	16	53	15	4	5	0	7.9	2.5	19.8
–5 cm	No preparation	61	35	4	0	0	0	0	2.9	0.5	6.2
	Patch	83	17	0	0	0	0	0	2.1	0.6	3.9
	Between patches	56	42	2	0	0	0	0	2.8	0.7	5.4
	Plough tilt	37	32	30	1	0	0	0	4.3	0.9	10.6
	Plough shoulder	29	41	28	0	0	0	0	4.1	1.2	9.1
	Between tilts	61	32	7	0	0	0	0	2.7	0.8	6.2
	C-plough hump	41	31	28	0	0	0	0	3.8	1.1	8.4
	C-plough hollow	29	36	35	0	0	0	0	4.3	1.4	8.4

Appendix 2. Distribution of temperature observations at different levels and sites of different preparations during the summer months in 1979–1985 as percentages of total observations distributed into temperature classes. Minimum, maximum and mean ($\bar{x}$) values of observations during the same period are given on the right. C-plough is cross-directional ploughing.

Year 1977

Level	Site preparation	Temperature classes °C								Temperatures °C		
		<0	0–5	5–10	10–15	15–20	20–25	25–30	>30	$\bar{x}$	min	max
+10 cm	No preparation	1	7	13	28	26	17	5	3	15.5	–2.3	36.1
	Patch	0	3	18	30	27	16	4	2	15.4	3.3	34.5
	Between patches	0	6	18	30	25	14	4	3	14.8	2.5	35.1
	Plough tilt	0	4	12	32	31	15	4	2	15.6	1.9	33.7
	Plough shoulder	0	4	12	33	30	16	4	1	15.4	2.1	32.0
	Between tilts	0	7	13	28	28	17	5	2	15.4	–0.8	34.0
	C-plough hump	0	3	16	32	31	14	3	1	15.0	2.5	32.2
	C-plough hollow	0	5	18	33	26	14	3	1	14.6	2.8	32.0
0 cm	No preparation	0	1	15	33	33	14	3	1	15.6	3.2	35.2
	Patch	0	0	10	35	42	10	3	0	15.6	5.8	30.8
	Between patches	0	0	18	37	32	10	3	0	14.7	5.0	28.9
	C-plough hollow	0	0	18	33	32	13	3	1	15.1	4.8	31.9
–5 cm	No preparation	0	0	5	56	39	0	0	0	14.3	6.9	21.2
	Patch	0	0	14	47	32	7	0	0	14.1	4.8	24.5
	Between patches	0	0	7	55	38	0	0	0	14.1	7.1	20.1
	Plough tilt	0	0	11	27	39	17	5	0	16.6	4.4	34.2
	Plough shoulder	0	0	9	33	42	15	1	0	15.9	4.2	27.3
	Between tilts	0	0	3	48	47	2	0	0	15.1	6.6	23.7
	C-plough hump	0	0	11	33	39	13	4	0	15.9	5.4	30.9
	C-plough hollow	0	0	12	37	37	12	2	0	15.2	5.5	26.6
–50 cm	No preparation	0	0	18	82	0	0	0	0	11.8	6.9	14.8
	Patch	–	–	–	–	–	–	–	–	–	–	–
	Between patches	0	0	20	80	0	0	0	0	11.5	6.4	14.2
	Plough tilt	0	0	10	69	21	0	0	0	13.3	7.4	16.9
	Plough shoulder	0	0	10	63	27	0	0	0	13.7	7.2	17.9
	Between tilts	0	0	3	48	47	2	0	0	12.7	7.1	15.9
	C-plough hump	1	0	4	50	45	0	0	0	14.0	5.0	27.6
	C-plough hollow	0	0	10	83	7	0	0	0	12.9	6.4	15.8
–100 cm	No preparation	0	0	38	62	0	0	0	0	10.4	5.9	13.4
	Patch	0	0	42	58	0	0	0	0	10.1	5.5	13.0
	Between tilts	0	0	16	84	0	0	0	0	11.6	6.4	18.2
	C-plough hollow	0	0	13	87	0	0	0	0	12.2	6.6	19.6

Year 1978

Level	Site preparation	Temperature classes °C								Temperatures °C		
		<0	0–5	5–10	10–15	15–20	20–25	25–30	>30	$\bar{x}$	min	max
+10 cm	No preparation	1	8	21	30	16	16	8	0	14.3	–1.0	31.7
	Patch	2	7	22	30	19	12	7	1	13.8	–3.6	31.0
	Between patches	4	7	25	25	16	14	7	2	13.6	–5.0	33.0
	Plough tilt	0	6	21	33	17	15	7	1	14.5	–3.5	31.4
	Plough shoulder	0	7	22	33	18	13	7	0	14.2	–3.2	30.8
	Between tilts	0	7	23	31	16	15	7	1	14.2	–0.1	31.5
	C-plough hump	1	6	24	30	20	12	7	0	14.0	–4.5	30.2
	C-plough hollow	1	7	24	30	20	12	6	0	13.8	–4.5	30.5
0 cm	No preparation	–	–	–	–	–	–	–	–	–	–	–
	Patch	0	1	13	46	25	11	4	0	14.9	3.5	29.5
	Between patches	1	6	19	34	20	12	7	1	14.5	–1.2	31.8
	C-plough hollow	0	2	15	37	22	15	6	3	15.6	0.5	32.1
–5 cm	No preparation	0	0	20	51	26	3	0	0	13.3	4.0	21.3
	Patch	0	1	15	48	27	9	0	0	14.0	3.8	24.8
	Between patches	0	0	19	63	18	0	0	0	12.5	5.0	22.4
	Plough tilt	0	2	16	33	24	16	8	1	16.0	1.1	32.3
	Plough shoulder	0	0	6	34	36	16	8	0	16.6	3.7	29.6
	Between tilts	0	0	18	51	26	5	0	0	13.5	4.5	28.8
	C-plough hump	0	1	12	36	28	15	8	0	15.9	1.7	28.7
	C-plough hollow	0	1	15	40	26	12	6	0	15.1	1.8	28.7
–50 cm	No preparation	0	0	38	62	0	0	0	0	10.4	5.8	13.0
	Patch	0	0	33	66	1	0	0	0	10.3	6.5	15.5
	Between patches	0	0	41	58	1	0	0	0	10.1	6.5	15.5
	Plough tilt	0	0	22	70	8	0	0	0	12.1	7.3	16.1
	Plough shoulder	0	0	24	74	2	0	0	0	11.7	7.1	15.3
	Between tilts	0	0	43	57	0	0	0	0	10.6	5.1	16.2
	C-plough hump	0	0	4	70	26	0	0	0	13.5	9.6	17.4
	C-plough hollow	0	0	17	71	12	0	0	0	12.3	6.0	16.6
–100 cm	No preparation	0	2	66	32	0	0	0	0	8.7	3.8	12.4
	Patch	0	0	26	74	0	0	0	0	11.2	6.1	16.8
	Between tilts	0	0	30	70	0	0	0	0	11.1	7.0	15.0
	C-plough hollow	0	0	24	76	0	0	0	0	11.6	7.3	14.9

Year 1979

Level	Site preparation	Temperature classes °C <0	0–5	5–10	10–15	15–20	20–25	25–30	>30	Temperatures °C x̄	min	max
+10 cm	No preparation	1	8	15	30	21	18	6	1	14.8	–2.1	32.1
	Patch	0	5	13	32	25	19	6	0	15.4	–0.6	31.2
	Between patches	0	7	13	31	24	16	8	1	15.4	–1.4	33.5
	Plough tilt	0	2	16	33	27	17	4	1	15.3	2.7	31.5
	Plough shoulder	0	2	17	34	26	17	4	0	14.9	2.2	28.7
	Between tilts	0	6	15	32	22	16	8	1	15.1	–0.3	33.0
	C-plough hump	0	1	14	33	29	18	5	0	15.7	3.0	29.4
	C-plough hollow	0	1	14	35	28	18	4	0	15.7	2.8	29.4
0 cm	No preparation	1	1	17	33	27	16	4	1	15.1	–0.5	31.4
	Patch	0	0	6	44	39	11	0	0	15.3	6.0	26.0
	Between patches	0	0	11	40	36	13	1	0	15.2	5.6	26.7
	C-plough hollow	0	0	3	27	45	22	3	0	17.3	7.7	29.1
–5 cm	No preparation	0	1	11	70	18	0	0	0	12.9	3.6	18.5
	Patch	0	0	2	49	47	2	0	0	15.0	8.3	22.0
	Between patches	0	0	4	64	32	0	0	0	14.0	7.6	19.3
	Plough tilt	0	0	5	31	42	19	3	0	16.7	5.6	30.2
	Plough shoulder	0	0	5	42	43	10	0	0	15.5	5.7	25.4
	Between tilts	0	1	7	58	34	0	0	0	13.9	3.3	20.1
	C-plough hump	0	0	2	27	52	18	1	0	16.9	7.8	26.9
	C-plough hollow	0	0	1	32	54	13	0	0	16.4	7.9	25.2
–50 cm	No preparation	0	2	39	59	0	0	0	0	9.9	3.5	12.6
	Patch	0	0	12	88	0	0	0	0	12.3	6.6	14.8
	Between patches	0	0	7	87	6	0	0	0	13.2	8.1	16.1
	Plough tilt	0	0	16	83	1	0	0	0	12.5	6.6	15.3
	Plough shoulder	0	0	15	84	1	0	0	0	12.7	6.7	15.2
	Between tilts	0	1	20	79	0	0	0	0	11.6	3.7	14.2
	C-plough hump	0	0	0	50	50	0	0	0	14.7	9.5	17.7
	C-plough hollow	0	0	1	89	10	0	0	0	13.4	8.6	16.2
–100 cm	No preparation	0	6	51	43	0	0	0	0	9.0	1.5	12.3
	Patch	0	0	23	77	0	0	0	0	11.5	3.6	14.4
	Between tilts	0	1	8	65	26	0	0	0	13.8	4.7	17.4
	C-plough hollow	0	0	18	82	0	0	0	0	12.1	5.9	14.7

Year 1980

Level	Site preparation	Temperature classes °C <0	0–5	5–10	10–15	15–20	20–25	25–30	>30	Temperatures °C x̄	min	max
+10 cm	No preparation	3	8	17	25	18	14	12	3	15.0	–3.6	32.7
	Patch	2	7	14	29	19	18	9	2	15.5	–3.8	31.6
	Between patches	3	7	16	29	16	14	13	2	15.2	–2.9	32.6
	Plough tilt	1	6	15	30	20	15	11	2	15.6	–1.8	32.3
	Plough shoulder	1	6	16	30	20	17	10	0	15.3	–1.4	30.8
	Between tilts	2	7	17	27	17	16	11	3	15.4	–3.0	33.4
	C-plough hump	0	4	13	29	26	17	11	0	16.1	–0.6	29.9
	C-plough hollow	0	4	13	31	26	17	8	1	15.9	–0.8	31.1
0 cm	No preparation	0	2	19	33	27	15	4	0	14.7	2.8	28.6
	Patch	0	0	12	40	35	13	0	0	15.1	5.4	25.3
	Between patches	0	1	17	36	27	15	4	0	15.2	3.2	27.6
	C-plough hollow	0	0	7	30	36	21	6	0	17.1	4.9	32.9
–5 cm	No preparation	0	0	14	68	18	0	0	0	12.8	6.3	18.4
	Patch	0	0	5	49	43	3	0	0	14.8	7.3	21.8
	Between patches	0	0	6	67	27	0	0	0	13.7	7.8	19.2
	Plough tilt	0	1	7	26	39	21	6	0	17.0	4.3	28.5
	Plough shoulder	0	0	8	36	42	14	0	0	15.6	5.1	24.5
	Between tilts	0	0	7	64	29	0	0	0	13.7	6.7	18.8
	C-plough hump	0	0	4	22	50	23	1	0	17.2	6.3	26.8
	C-plough hollow	0	0	5	29	50	16	0	0	16.4	6.5	27.9
–50 cm	No preparation	0	0	31	69	0	0	0	0	10.5	6.6	17.4
	Patch	0	0	10	90	0	0	0	0	11.7	6.5	14.9
	Between patches	0	0	21	79	0	0	0	0	11.1	6.6	14.0
	Plough tilt	0	0	11	81	8	0	0	0	12.6	7.5	16.2
	Plough shoulder	0	0	10	81	9	0	0	0	12.7	8.1	16.2
	Between tilts	0	0	17	83	0	0	0	0	11.6	3.7	14.3
	C-plough hump	0	0	1	63	36	0	0	0	14.7	9.7	19.3
	C-plough hollow	0	0	3	81	16	0	0	0	13.6	8.3	18.1
–100 cm	No preparation	0	8	64	28	0	0	0	0	8.9	3.1	13.3
	Patch	0	0	34	66	0	0	0	0	10.3	5.2	14.1
	Between tilts	0	1	29	70	0	0	0	0	10.4	4.1	18.1
	C-plough hollow	0	0	15	81	4	0	0	0	12.4	6.2	16.7

Year 1981

Level	Site preparation	Temperature classes °C <0	0–5	5–10	10–15	15–20	20–25	25–30	>30	Temperatures °C x̄	min	max
+10 cm	No preparation	2	7	22	28	26	11	4	0	13.5	–4.5	30.4
	Patch	1	6	20	33	26	10	4	0	13.7	–4.6	29.1
	Between patches	2	6	22	31	23	11	5	0	13.6	–5.0	31.3
	Plough tilt	1	5	22	31	27	11	3	0	13.7	–4.4	29.2
	Plough shoulder	1	6	21	32	26	12	2	0	13.5	–4.3	28.9
	Between tilts	2	7	24	30	23	11	3	0	13.2	–4.8	30.7
	C-plough hump	1	5	20	32	28	12	2	0	14.0	–2.9	30.2
	C-plough hollow	1	5	21	32	27	12	2	0	13.8	–2.6	28.7
0 cm	No preparation	0	1	17	45	30	7	0	0	13.9	1.8	23.5
	Patch	0	1	15	50	30	4	0	0	13.7	2.9	22.8
	Between patches	0	1	14	47	30	8	0	0	14.2	1.4	24.6
	C-plough hollow	0	1	11	37	38	12	1	0	15.1	2.0	26.9
–5 cm	No preparation	0	0	20	62	18	0	0	0	12.6	5.1	21.0
	Patch	0	0	13	52	34	1	0	0	13.7	5.2	20.8
	Between patches	0	0	16	58	26	0	0	0	13.2	5.7	18.6
	Plough tilt	0	1	9	36	44	10	0	0	15.2	3.7	25.3
	Plough shoulder	0	1	14	40	40	5	0	0	14.3	3.4	23.5
	Between tilts	0	0	15	59	26	0	0	0	13.2	5.4	21.6
	C-plough hump	0	0	7	38	48	7	0	0	15.2	4.5	23.7
	C-plough hollow	0	0	12	42	41	5	0	0	14.5	3.8	23.4
–50 cm	No preparation	0	0	28	72	0	0	0	0	10.9	6.6	14.5
	Patch	0	0	28	72	0	0	0	0	11.1	6.8	13.8
	Between patches	0	0	29	71	0	0	0	0	10.9	6.6	13.8
	Plough tilt	0	0	25	74	1	0	0	0	12.1	7.1	15.6
	Plough shoulder	0	0	25	75	0	0	0	0	12.1	7.3	15.6
	Between tilts	0	0	27	73	0	0	0	0	11.4	6.7	14.1
	C-plough hump	0	0	15	51	34	0	0	0	13.4	8.4	16.5
	C-plough hollow	0	0	24	72	4	0	0	0	12.4	7.8	15.3
–100 cm	No preparation	0	0	47	53	0	0	0	0	9.6	5.0	12.5
	Patch	0	0	40	60	0	0	0	0	10.2	5.9	14.0
	Between tilts	0	0	40	60	0	0	0	0	10.3	5.1	13.0
	C-plough hollow	0	0	27	73	0	0	0	0	11.8	7.3	15.8

Year 1982

Level	Site preparation	Temperature classes °C <0	0–5	5–10	10–15	15–20	20–25	25–30	>30	Temperatures °C x̄	min	max
+10 cm	No preparation	5	17	19	22	17	13	6	1	12.3	–4.0	31.6
	Patch	3	15	21	26	19	11	5	0	12.2	–3.9	30.4
	Between patches	5	17	19	23	16	12	7	1	12.3	–3.7	32.6
	Plough tilt	3	13	22	25	19	12	5	1	12.8	–3.2	33.2
	Plough shoulder	3	14	22	25	21	12	3	0	12.4	–3.0	30.5
	Between tilts	6	17	19	24	18	10	5	1	12.1	–4.0	33.1
	C-plough hump	2	10	23	27	20	12	5	1	13.1	–2.2	32.2
	C-plough hollow	2	12	24	26	21	12	3	0	12.7	–2.3	31.4
0 cm	No preparation	0	6	29	37	21	7	0	0	12.1	1.7	24.7
	Patch	0	2	24	51	21	2	0	0	12.3	3.9	22.6
	Between patches	0	5	27	42	21	5	0	0	12.4	2.7	25.4
	C-plough hollow	0	3	18	40	26	11	2	0	14.0	1.8	29.3
–5 cm	No preparation	0	2	30	61	7	0	0	0	11.0	4.4	18.0
	Patch	0	0	23	63	14	0	0	0	11.9	5.0	20.0
	Between patches	0	0	27	66	7	0	0	0	11.4	5.2	18.6
	Plough tilt	0	3	15	41	29	11	1	0	14.1	2.5	27.4
	Plough shoulder	0	3	19	49	24	5	0	0	13.0	2.9	24.0
	Between tilts	0	1	25	65	9	0	0	0	11.5	4.4	18.5
	C-plough hump	0	2	14	44	33	7	0	0	14.0	3.9	26.2
	C-plough hollow	0	3	18	48	26	5	0	0	13.3	3.3	25.3
–50 cm	No preparation	0	0	59	41	0	0	0	0	9.1	5.7	11.0
	Patch	0	0	48	52	0	0	0	0	9.3	5.7	12.1
	Between patches	0	0	54	46	0	0	0	0	9.2	5.7	11.9
	Plough tilt	0	0	31	69	0	0	0	0	10.4	5.6	13.4
	Plough shoulder	0	0	30	70	0	0	0	0	10.6	5.7	13.9
	Between tilts	0	0	37	63	0	0	0	0	9.7	5.7	12.0
	C-plough hump	0	0	24	71	5	0	0	0	11.9	6.1	16.3
	C-plough hollow	0	0	29	71	0	0	0	0	11.0	6.2	15.0
–100 cm	No preparation	0	0	100	0	0	0	0	0	8.4	4.0	10.0
	Patch	0	0	88	12	0	0	0	0	8.7	5.2	10.5
	Between tilts	0	1	62	37	0	0	0	0	8.7	3.7	12.2
	C-plough hollow	0	0	34	66	0	0	0	0	10.8	6.7	13.5

Year 1983

Level	Site preparation	Temperature classes °C <0	0–5	5–10	10–15	15–20	20–25	25–30	>30	Temperatures °C x̄	min	max
+10 cm	No preparation	5	9	19	25	23	13	5	1	13.3	–3.7	32.9
	Patch	3	9	20	31	22	11	4	0	13.0	–3.5	30.1
	Between patches	4	9	21	27	20	13	5	1	13.2	–4.5	32.4
	Plough tilt	1	9	20	31	21	12	5	1	13.5	–2.4	31.8
	Plough shoulder	1	10	21	31	24	10	3	0	13.0	–2.7	30.1
	Between tilts	4	10	22	26	22	11	5	0	12.8	–3.6	31.0
	C-plough hump	1	8	20	31	23	12	5	0	13.7	–2.0	30.9
	C-plough hollow	1	8	21	31	23	11	5	0	13.5	–2.4	29.3
0 cm	No preparation	0	3	22	42	27	6	0	0	13.0	3.0	24.6
	Patch	0	0	18	58	23	1	0	0	13.0	5.9	20.7
	Between patches	0	1	19	50	26	4	0	0	13.1	4.4	22.3
	C-plough hollow	0	0	15	44	32	9	0	0	14.4	4.6	25.1
–5 cm	No preparation	0	0	23	67	10	0	0	0	11.9	6.6	18.4
	Patch	0	0	16	71	13	0	0	0	12.5	7.4	18.1
	Between patches	0	0	16	71	13	0	0	0	12.4	7.4	17.8
	Plough tilt	0	0	10	47	37	6	0	0	14.5	6.3	23.7
	Plough shoulder	0	0	14	54	31	1	0	0	13.5	6.1	21.5
	Between tilts	0	0	17	70	13	0	0	0	12.5	7.0	18.5
	C-plough hump	0	0	9	48	38	5	0	0	14.6	6.6	23.2
	C-plough hollow	0	0	13	50	34	3	0	0	13.9	6.2	22.6
–50 cm	No preparation	0	0	37	63	0	0	0	0	10.4	6.9	12.4
	Patch	0	0	49	51	0	0	0	0	9.8	6.8	12.5
	Between patches	0	0	40	60	0	0	0	0	10.3	7.4	12.4
	Plough tilt	0	0	20	80	0	0	0	0	11.4	8.1	14.1
	Plough shoulder	0	0	17	83	0	0	0	0	11.5	8.1	13.8
	Between tilts	0	0	28	72	0	0	0	0	10.8	7.4	13.3
	C-plough hump	0	0	7	84	9	0	0	0	12.9	9.6	15.8
	C-plough hollow	0	0	13	87	0	0	0	0	11.9	8.6	14.3
–100 cm	No preparation	0	0	74	26	0	0	0	0	9.0	5.9	11.0
	Patch	0	0	74	26	0	0	0	0	9.1	6.0	10.7
	Between tilts	0	0	41	59	0	0	0	0	9.8	6.2	11.7
	C-plough hollow	0	0	15	85	0	0	0	0	11.9	8.6	13.7

Year 1984

Level	Site preparation	Temperature classes °C <0	0–5	5–10	10–15	15–20	20–25	25–30	>30	Temperatures °C x̄	min	max
+10 cm	No preparation	5	8	22	30	19	11	5	0	12.9	–5.0	31.0
	Patch	5	8	22	30	21	11	3	0	12.5	–3.6	27.4
	Between patches	5	9	21	28	20	11	6	0	12.8	–4.0	30.0
	Plough tilt	2	8	23	30	21	9	7	0	13.3	–2.8	33.2
	Plough shoulder	3	8	24	32	20	9	4	0	12.6	–2.7	29.8
	Between tilts	5	9	23	31	18	9	5	0	12.4	–4.4	31.9
	C-plough hump	2	6	23	32	22	11	4	0	13.3	–3.3	29.1
	C-plough hollow	2	7	24	32	21	11	3	0	12.9	–3.3	27.9
0 cm	No preparation	0	3	22	48	23	4	0	0	12.8	2.4	22.3
	Patch	0	0	20	63	17	0	0	0	12.4	5.3	18.6
	Between patches	0	1	22	52	24	1	0	0	12.8	4.6	22.1
	C-plough hollow	0	2	18	51	31	4	0	0	13.6	2.8	22.0
–5 cm	No preparation	0	0	24	68	8	0	0	0	11.8	6.0	17.3
	Patch	0	0	19	73	8	0	0	0	12.1	6.9	17.1
	Between patches	0	0	20	70	10	0	0	0	12.1	6.5	17.4
	Plough tilt	0	0	14	43	39	4	0	0	14.2	5.4	22.6
	Plough shoulder	0	0	17	52	30	1	0	0	13.2	5.5	20.6
	Between tilts	0	0	19	70	11	0	0	0	12.3	6.4	17.3
	C-plough hump	0	0	14	45	40	1	0	0	14.1	5.7	21.4
	C-plough hollow	0	0	15	55	30	0	0	0	13.3	5.7	20.0
–50 cm	No preparation	0	0	48	52	0	0	0	0	10.3	7.5	12.9
	Patch	0	0	51	49	0	0	0	0	10.0	7.4	12.4
	Between patches	0	0	51	49	0	0	0	0	10.1	7.5	14.0
	Plough tilt	0	0	22	78	0	0	0	0	11.3	8.0	14.3
	Plough shoulder	0	0	18	82	0	0	0	0	11.4	7.1	14.2
	Between tilts	0	0	32	68	0	0	0	0	10.8	8.0	13.3
	C-plough hump	0	0	10	83	7	0	0	0	12.8	9.5	15.8
	C-plough hollow	0	0	14	86	0	0	0	0	11.6	8.8	14.2
–100 cm	No preparation	0	0	67	33	0	0	0	0	9.1	6.3	11.2
	Patch	0	0	68	32	0	0	0	0	9.0	6.2	13.2
	Between tilts	0	0	48	52	0	0	0	0	9.8	6.9	12.0
	C-plough hollow	0	0	16	84	0	0	0	0	11.4	8.9	16.2

Year 1985

Level	Site preparation	Temperature classes °C								Temperatures °C		
		< 0	0–5	5–10	10–15	15–20	20–25	25–30	>30	x̄	min	max
+10 cm	No preparation	2	9	19	31	23	11	4	1	13.3	–1.7	31.7
	Patch	2	9	23	34	21	10	1	0	12.4	–1.8	26.4
	Between patches	2	12	20	31	18	10	7	0	13.0	–2.8	31.1
	Plough tilt	1	9	19	33	24	9	5	1	13.9	–0.2	33.2
	Plough shoulder	1	8	22	35	22	9	3	0	13.1	–0.3	29.9
	Between tilts	1	9	19	31	22	12	5	1	13.6	–1.7	33.7
	C-plough hump	0	7	20	33	21	13	6	1	14.0	–0.2	32.2
	C-plough hollow	0	8	21	35	22	13	3	0	13.4	–0.1	28.2
0 cm	No preparation	0	3	24	53	19	1	0	0	12.2	–0.3	21.6
	Patch	0	3	23	70	4	0	0	0	11.3	3.9	17.1
	Between patches	0	3	25	54	18	0	0	0	11.8	2.8	19.8
	C-plough hollow	0	6	19	45	26	4	0	0	12.7	1.9	22.7
–5 cm	No preparation	0	2	22	75	1	0	0	0	11.1	4.3	15.9
	Patch	0	2	23	74	1	0	0	0	10.9	4.3	15.6
	Between patches	0	3	24	72	1	0	0	0	11.0	4.1	16.2
	Plough tilt	0	0	10	56	33	1	0	0	13.9	4.0	22.3
	Plough shoulder	0	1	14	65	20	0	0	0	12.6	3.8	19.3
	Between tilts	0	1	19	78	2	0	0	0	11.6	4.4	16.2
	C-plough hump	0	0	12	51	36	1	0	0	13.9	4.7	22.3
	C-plough hollow	0	1	15	60	24	0	0	0	12.8	4.4	19.8
–50 cm	No preparation	0	10	57	33	0	0	0	0	8.8	4.0	12.4
	Patch	0	13	45	42	0	0	0	0	8.6	3.7	12.4
	Between patches	0	13	43	44	0	0	0	0	8.8	3.9	12.5
	Plough tilt	0	7	25	68	0	0	0	0	10.0	4.0	13.7
	Plough shoulder	0	4	24	72	0	0	0	0	10.1	4.7	14.4
	Between tilts	0	11	38	51	0	0	0	0	9.5	4.3	14.0
	C-plough hump	0	0	20	80	0	0	0	0	11.6	5.3	14.9
	C-plough hollow	0	3	23	74	0	0	0	0	10.5	4.7	13.5
–100 cm	No preparation	0	11	57	32	0	0	0	0	8.7	3.2	14.5
	Patch	0	20	80	0	0	0	0	0	7.2	1.9	10.3
	Between tilts	0	24	53	23	0	0	0	0	7.6	3.6	11.1
	C-plough hollow	0	1	26	73	0	0	0	0	10.4	4.7	13.0

Instructions to Authors

Acta Forestalia Fennica publishes monographs in forest science. These may be original research articles or comprehensive reviews aiming at a synthesis of knowledge in a particular topic. The series covers all aspects of forest science, both basic and applied subjects. Manuscripts are subject to peer review. Authors are anonymous to reviewers of manuscripts.

Acta Forestalia Fennica is published in English. The minimum length of the papers is 32 printed pages, and the maximum 80 printed pages.

Submission of a manuscript to Acta Forestalia Fennica is taken to imply that the manuscript has not been published nor is being considered for publication elsewhere.

Submission of Manuscripts

Please send three copies of the manuscript, including copies of all figures. Do not send original figures. The cover letter should carry the name(s) of the author(s), the title of the manuscript, the postal address, phone and fax numbers, and e-mail address of the corresponding author. Do not identify the author(s) in the manuscript itself nor on the figure copies. You may suggest reviewers.

Manuscripts are usually sent to two or three reviewers. Once you have received the reviewers' comments, you should send the revised manuscript to the editor in three weeks. The editor-in-chief will inform you about his decision by letter. Following acceptance, no major changes may be made to the manuscript without the permission of the editor.

Send your manuscript to

Acta Forestalia Fennica
Editorial Office
Unioninkatu 40 A
FIN-00170 Helsinki, Finland

Phone +358 0 857 051
Fax +358 0 625 308
e-mail silva.fennica@metla.fi

Sending Final Version for Printing

Please forward the final manuscript and original figures to the editorial office within one week from acceptance. In the cover letter, state that the manuscript is the final version ready for printing.

The manuscript should be arranged as follows: title, abstract complete with keywords and author's affiliation, table of contents, preface, list of symbols, body text, acknowledgements, references, tables, legends to figures and figures.

Text and tables are best submitted on a 3.5" PC or Mac diskette. The cover letter or the diskette label should give the name and the version of the software used. The diskette should be accompanied by a printout. On the printout, indicate the desired positions of the figures and tables. If the text contains any special characters that may be lost in software conversion (Greek letters, mathematical symbols, dots, squares, etc.), mark them clearly on the printout.

Form of Manuscript

Lay-out

Manuscripts should be printed on A4-sized paper, on one side only, leaving a 40 mm margin on the left. Sufficient space should be left between lines (maximum 40 lines per page). Pages should be numbered consecutively, starting with the title page.

Paragraphs should be separated by blank lines. Headings are preceded by two blank lines.

Equations and the like should be separated from the body text by two blank lines.

Information presented in tabular form in the text itself should be of single column width and no more than 10 printed lines in height. Anything more substantial than this should be presented in the form of a table with an appropriate title.

Headings

Words in the headings, except for prepositions and articles, should have an initial capital. Headings are numbered as follows: 1, 1.1, 1.1.1 etc. Of the first level headings, "References" is not numbered.

Italics

If italics have not been set in the text processing software, they should be indicated on the printout by underlining.

Equations

Equations will be printed over a single column width. Equations should be numbered consecutively in parenthesis on the right margin of the page. Symbols used should be explained in the List of Symbols.

Citing References in the Text

When citing references in the text, the "name and date system" should be used:

(Allen 1984)
Allen (1985a, b)
(Allen et al. 1986)
(Allen and Jones 1980)
(Allen 1978, Smith 1981, Jones 1984)*
(Smith 1977, 1980, Allen 1978, Jones 1979)*
(Handbook of forest... 1981)**
"Allen (1985, p. 12) on the other hand has shown that...".

* If in the same connection reference is made to the work of several authors, the references should be given in chronological order. If however, each author has several works referred to, the references should be given in chronological order of the oldest publications of each author.

** Where a publication has no known author or editor, the first 2–3 words of the title are quoted (followed by three dots), together with the year of publication. The term "Anonymous" must not be used in references.

References to Figures and Tables

References to all figures and tables should be made in the text. References are written with an initial capital letter: Fig. 3, Figs. 3–5, Table 2.

Footnotes

Footnotes should not be used in the body text. They can be used in tables.

Tables

The title of the table should be written above the table. A horizontal line should be drawn above and under the column headings, and at the bottom of the table. In tables neither upper case letters nor vertical lines are normally used. The tables are numbered consecutively.

Figures

Line drawings should be submitted on a A4 sheet. Most figures will be printed either one column (68 mm) or two columns (140 mm) wide. For letters and numerals appearing on graphs, transfers, stencils or high quality computer graphics systems should be employed. When preparing graphs, bear in mind the effect of reduction on text size and line weight. Characters should have a height of 1.5–2 mm when printed. Aim at clarity and simplicity, avoid unnecessary effects, like depth and shadows on column graphs. Where a figure is made up of several parts, the parts should be numbered (e.g. 5a, 5b, ...).

Monochrome prints should preferably be on glossy paper of size approx. 13 x 18 cm (5 x 7 in.). There should be a good range of tones: Colour prints or transparencies (slides) are less suitable as originals. Any desired cropping of the print should be clearly marked.

The costs of colour pictures are normally paid by the author. The best original in this case is a colour transparency with good colour saturation.

All figures should be marked with the number of the figure. The figures should be numbered consecutively irrespective of the type of figure.

Legends to figures should be printed on a separate sheet. The legends should be self-explanatory and independent, so that the reader need not refer to the text.

Where the copyright to a figure is held by someone other than the author, the copyright holder's name should be published with the figure. In matters of copyright, strict adherence to the law must be observed.

Title and Abstract

A good title is one that is brief and informative. Empty words and constructions like "A study of...", "Observations on..." and the like conveying very little to the reader are not used.

An abstract is a concise, independent résumé of the paper. Its purpose is to assist the reader in deciding whether it is worth reading the entire paper, to provide sufficient information for a reader who is not an expert on the topic involved, and to assist the communication of information. Its length should not exceed 20 type-written lines. Use of the first person singular and references or quotes must be avoided.

The abstract is preceded by bibliographic information necessary for identifying the paper, and followed by 3–7 keywords describing the topics dealt with as fully as possible.

FDC classification is supplied by the editors.

List of References

Reference should be made only to published, available material. For sources of low circulation or extreme rarity, the author should indicate where they are available from. Reference should not be made to second-hand sources.

Personal communications are not included in the list of references.

For the order, structure and form of the references, consult the examples below. In addition, note the following:

- Where the same author has more than one publication, the author's name should not be repeated, but replaced by a dash. Where there are several authors, only the name of the first author is replaced by a dash.
- Where a publication has no obvious author or editor, the publication should be listed in alphabetical order of its own title.
- The titles of journals should always be written in full, not abbreviated.
- The standard number, ISBN in books, or STRN in reports, should be given for sources of low circulation. The number is placed at the end of the reference.
- No italics are used in the reference list.

Examples:

Order of references

Smith, C. 1977. Aspen. Timber 77(4): 369–384.
— 1978. Silver birch. Timber 78(1): 17–23.
— & Harris, B. 1976a. Scots pine. Forest Management 15(1): 5–9.
— & Harris, B. 1976b. Norway spruce. Forest Management 15(2): 135–143.
— , Harris, B. & Allen, A. 1969. Sawn goods. Timber 69(2): 131–140.

Article in a journal

Repo, T. 1988. Physical and physiological aspects of impedance measurements in plants. Silva Fennica 22(3): 181–193.

Article in a book

Jarvis, P. G., Edwards, W.E. & Talbot, H. 1981. Models of plant and crop water use. In: Rose, D.A. & Charles-Edwards, D.A. (eds.). Mathematics and plant physiology. Academic Press, London. p. 151–194.

Monograph

Cochran, W. G. 1977. Sampling techniques. 3rd edition. John Wiley & Sons, New York. 428 p.

Congress proceedings

Cooper, R. W. 1971. Current use and place of prescribed burning. Proc. Prescribed Burning Symposium, Charleston, South Carolina, April 14–16, 1971. USDA Forest Service, Southeastern Forest Experiment Station, Asheville, N. C. p. 21–27.

Scientific Names

Scientific names should be according to authoritative contemporary sources. Scientific names should be in italics, except in the list of references. Authors of scientific names should be added only the first time a name is given.

Correcting the Proofs

Corrections should be clearly marked, preferably in red ink. The positions of figures and tables should be checked. Proof reading is an important task and at least two people should check each proof. Alterations to the original text may not normally be made. Corrected proofs should be returned to the editors within one week from receipt.

Offprints

Authors will usually receive 50 copies of the paper. They may request extra copies from the publishers at a cost based on the number of printed pages. Such extra copies must be ordered at the latest when the page proofs are sent in by the author.

Submission of Manuscripts Manuscripts should be submitted in triplicate to Acta Forestalia Fennica, Unioninkatu 40 A, FIN-00170 Helsinki, Finland. Detailed instructions to authors are printed in Acta Forestalia Fennica 244. Offprints of Instructions are available on request.

Publication Schedule Acta Forestalia Fennica is published intermittently about five numbers in a year.

Subscriptions and Exchange Subscriptions and orders for back issues should be addressed to Academic Bookstore, Subscription Services, P.O. Box 23, FIN-00371 Helsinki, Finland, Phone +358 0 121 4430, Fax +358 0 121 4450. Subscription price for 1995 is 70 FIM per issue. Exchange inquiries should be addressed to the Finnish Society of Forest Science, Unioninkatu 40 B, FIN-00170 Helsinki, Finland, Phone +358 0 658 707, Fax +358 0 191 7619.

Statement of Publishers Acta Forestalia Fennica has been published since 1913 by the Finnish Society of Forest Science. In 1989 Acta Forestalia Fennica was merged with Communicationes Instituti Forestalis Fenniae, started in 1919 by the Finnish Forest Research Institute. In the merger, the Society and Forest Research Institute became co-publishers of Acta Forestalia Fennica. The Finnish Society of Forest Science is a nonprofit organization founded in 1909 to promote forest research. The Finnish Forest Research Institute, founded in 1917, is a research organization financed by the Ministry of Agriculture and Forestry.

Abstracting Articles in Acta Forestalia Fennica are abstracted and indexed in Agrindex, Biological Abstracts, Current Advances in Ecological Sciences, Current Advances in Plant Sciences, Ecological Abstracts, Forest Products Journal, Forestry Abstracts, International Bibliography of Periodical Literature, Life Sciences Collection.

ACTA FORESTALIA FENNICA

The Finnish Society of Forest Science
The Finnish Forest Research Institute

ISBN 951-40-1409-X
ISSN 0001-5636

Cover: Jarmo Koivunen