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Drying of pulpwood in northern Finland

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TIIVISTELMÄ: KUITUPUUN KUIVUMINEN POHJOIS-SUOMESSA

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The drying of pulpwood logs of pine, birch and spruce was studied by measuring the drying of sample logs placed in experimental piles. The results revealed that the main factors affecting timber drying are debarked surface area, moisture content at the time of felling and the size of the log. Furthermore, pine and spruce logs located in the upper part of the pile dry better than logs near the ground.

The investigation of green weight changes of whole piles of pine and birch was based on data collected in 1987–1991. The green weight of piles was dependent mainly on storage time and on region; Effect of weather variables could not be distinguished. Specific calibrating coefficients for motor-manual and mechanical cutting were included in the green weight equations.

Comparison between green weight equations and detected weight losses of sample piles indicates that fitted models seem to produce at least approximate results for the green weights, the said results thus lending themselves to be utilized as part of a transportation cost model.

Yksittäisen mänty-, koivu- ja kuusipölkyn kuivumista tutkittiin koepinoihin sijoitettujen koepölkkyjen avulla. Pölkkyjen kevenemiseen vaikuttavat muuttujat olivat pölkyn kuorettoman vaipan määrä, kosteus kaatohetkellä sekä pölkyn koko. Lisäksi havaittiin, että ylempänä pinossa olevat pölkyt kuivuivat paremmin kuin maan pinnan läheisyydessä.

Koko pinon tilavuuspainon muutokset perustuivat 1987–1991 kerättyyn aineistoon. Tilavuuspaino oli riippuvainen vain varastointiajasta ja hankinta-alueesta. Säätilamuuttujien vaikutusta ei voitu osoittaa. Hakkuumenetelmää kuvaavat korjauskertoimet lisättiin tilavuuspainoyhtälöihin.

Tilavuuspainoa kuvaavien yhtälöiden vertaaminen koepinojen kevenemiseen osoittaa muodostettujen mallien tuottavan ainakin likimääräisiä tuloksia, joita voidaan käyttää kuljetuskustannusmallin osana.

Keywords: moisture, green weight, storage, weight losses.
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List of symbols

Significance of coefficients:
* : $p < 0.1$
** : $p < 0.05$
*** : $p < 0.01$

WL = % weight loss
m0 = initial moisture content (%)
D = mid-diameter (mm)
B% = debarked log surface area (%)
R = region (coefficients in Tables 1 and 3)
L = location in the pile (coefficients in Table 1)
V = log volume (dm^3)
GW = green weight (kg/m^3)
W = week number (W0–52)
W0 = cutting week number
Birch: 1–52
Pine: 12–52 (if 1–11, then W0 = 12)
M = cutting method (coefficients in Table 5)

1 Introduction

Timber in northern Finland is felled mainly in the wintertime. After felling water starts to evaporate from logs stored in piles at the landing. In spring the temperature rises and evaporation increases markedly. The green weight of timber changes during storage accordingly. Thus, timber transportation costs undergo changes during storage. This change is especially significant in northern Finland, where transportation distances are relatively long.

It is common knowledge that the evaporation of water from wood, and also from other materials, is similar to that from a water surface. In other words, evaporation is proportional to the absolute air temperature and the square root of wind speed, and inversely proportional to air pressure and relative humidity (Heiskanen 1953). Therefore, the influence of pile location and storage method can usually be explained by variation in macro- or microclimate. The surface temperature of logs, for example, varies greatly between logs in piles exposed to the sun and those in piles in the shade. Wind speed and air humidity vary considerably between piles and even within a pile. Only air pressure is almost the same in larger areas, but the effects of air pressure and wind speed on timber drying have not been investigated (Heiskanen 1953).

Because most of the water evaporates via crosscut surfaces, short logs dry faster than long ones (Heiskanen 1959). Nylinder (1950) noted in the case of incompletely barked logs that this zone of enhanced drying near the crosscut points is only 10–20 cm in width. In the case of unbarked logs, the effect of the crosscuts extends further, at least 30 cm (Hakkila 1962a).

Log diameter affects drying mainly if the logs are completely or partially debarked. Logs with bark dry primarily through branch-stumps and debarked surface areas. Because smaller logs usually have more branches and their moisture content is greater than that of larger logs, they also dry faster (Heiskanen 1959). Another factor connected to logs from mechanised logging operations is that the smaller logs tend to lose more bark than the larger ones. This is important, because on losing bark their effective evaporation area increases. Nylinder (1950) noted that the faster evaporation over debarked surface areas does not extend to areas still covered by bark.

Although the drying of firewood has been investigated extensively, drying and weight changes in pulpwood stored in present-day piles have not been studied throughly in northern Finland. It would be useful to know how great these weight changes are, what factors affect them, and how

the other wood properties change during storage. With this information, it would then be possible to optimize timber storage.

The present study focuses on the drying of wood and the resultant changes in weight. The aim of this study was to investigate weight changes in individual pulpwood logs and pulpwood piles in northern Finland, and to develop models for predicting changes in the green weight of timber. Models should be usable for logistics of timber transportation.

2 Material and method

2.1 Drying experiments

The first part of this investigation, the drying of individual logs, is based on drying experiments carried out in the summer of 1991. These experiments were designed to cover the geographical variation in northern Finland as well as possible. For this reason, experimental piles were located in the regions of Oulu, Rovaniemi and Sodankylä.

The following factors were chosen for further study:

1) The three main tree species, pine, spruce and birch, used for producing sulphate pulp in Finland.
2) The age of the stand. Timber from thinnings and final cuttings was studied separately in the Oulu region. In the other two regions only timber from final cuttings was studied.
3) The effect of cutting method was investigated by studying separately timber obtained from motor-manual and mechanised logging operations.
4) In addition, timber from mechanised logging operations harvested at the end of May. This is the period of sap flow, when the feeding rolls and delimbing knives of a single-grip harvester tend to cause considerable loss of bark from the timber.

The sample piles of the drying experiments are presented in Fig. 1 based on the above grouping.

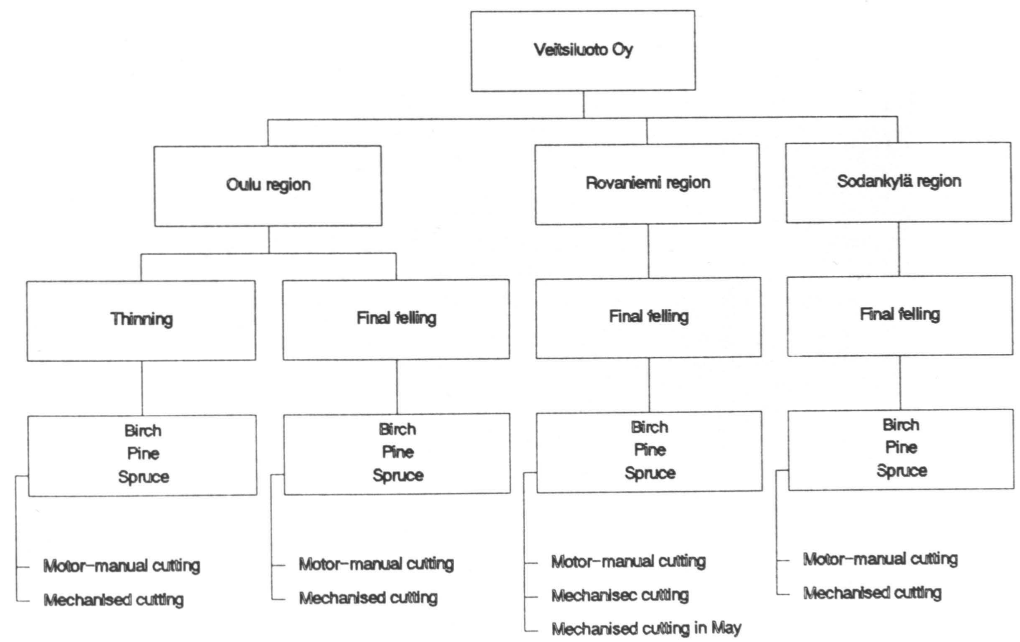

Fig. 1. Sample piles used in the drying experiments.

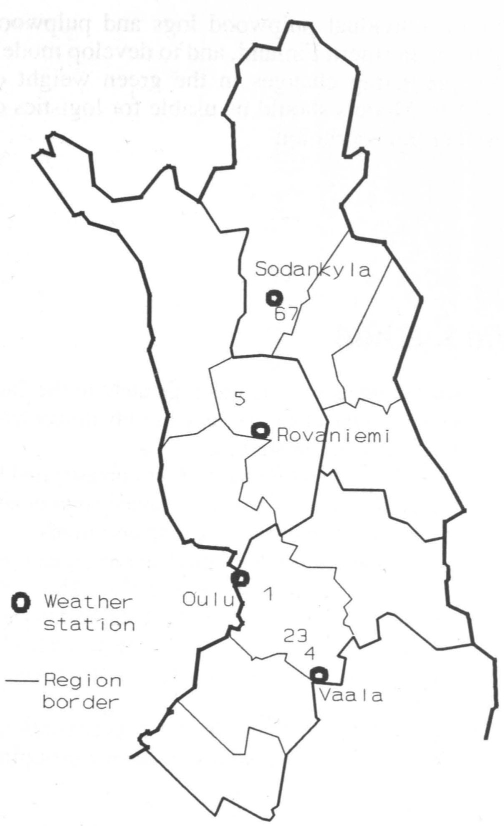

Fig. 2. The location and the number of the sample piles included in the drying experiments.

All sample stands had to meet the following requirements:

1. The stand had to represent a stand typical for the region, because the aim was to construct "normal" piles according to the tree species, cutting method and region in question.
2. No significant diseases or other defects were allowed to avoid their possible influence on the drying results.
3. To facilitate measurements, the stand had to be located near an all-season road.
4. The stand had to be located reasonably near a weather station.
5. The aim was to get a pile of timber of each tree species and region from the same stand, but this was not possible in all cases. The solution then was to select stands that were as similar as possible.

Based on these conditions, the selected stands are presented in Fig. 2.

The construction of sample piles was as follows:

Fig. 3. Triangular frame used in creating cavities in sample piles.

1. Each pile contained timber cut to 5 m of an approximate lengths.
2. The log diameters were typical for the tree species and region in question.
3. Each pile contained normal bed timber.
4. The minimum size of a pile was 60 m^3.
5. Each pile was about 2.5 m in height.
6. Two empty triangular cavities were created in each pile (Figs. 3–5). Later on, sample logs were placed in these cavities.

At the beginning of April, twenty logs were sampled from each pile so that their volume distribution was similar to distribution in the whole pile. Three of the logs were placed at the top of the pile, three others among the bed timber, and the rest within the two triangular cavities so that they were covered by the other logs (Fig. 5).

At the beginning and end of the experiment, about 15 m^3 of timber in each pile was weighed and had its volume measured in a xylometre at Veitsiluoto Oy's pulp mills (Fig. 5). The purpose was to calibrate the results obtained from log measurements so that they would be comparable to data collected previously in weight scaling at the mill.

The sample logs were weighed four times during the spring and summer of 1991. The weighing device was manufactured by Elektrovaaka Oy; its weighing capacity is 200 kg with an accuracy of 0.1 kg. The first measurements in the region of Oulu were made during weeks 16–17, in Rovaniemi during week 17 and in Sodankylä during week 18. The subsequent measurements were made three, six and twelve weeks later. Logs harvested during the period of sap flow in the Rovaniemi region were first weighed during week 23 and again three and nine weeks later.

The volume of the sample logs was measured with an electronic Pomot calliper in conjunction with the last weighing. The logs were measured in modules of 60 cm and the log volumes were calculated using the Huber equation. In this case the measurement errors should be less than 1% (Kärkkäinen 1984).

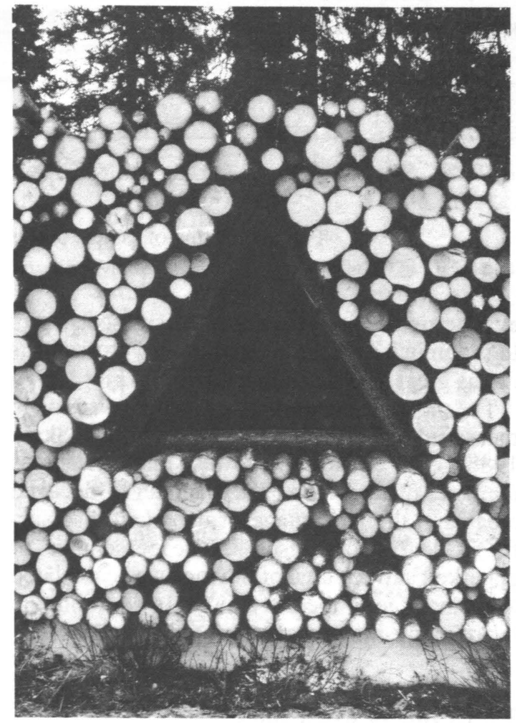

Fig. 4. Empty triangular cavity in a pile.

Three sample discs, each 2 cm in thickness, were removed from each sample log so that they represented an equal proportion (Fig. 6). In this way, it was possible to calculate the moisture content of the logs as an average of the three discs. Although this meant ignoring the enhanced

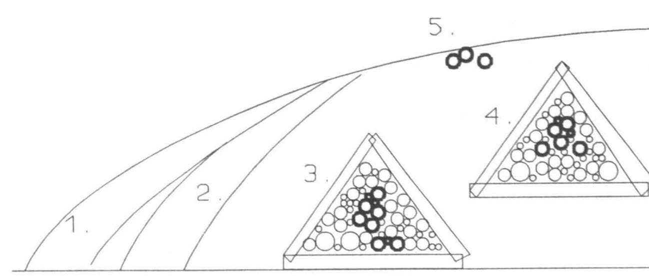

Fig. 5. Construction of a sample pile: 1. & 2. timber for xylometric measurements, 3. Lower triangular cavity with three sample logs among bed timber, 4. Upper triangular cavity, 5. Top sample logs.

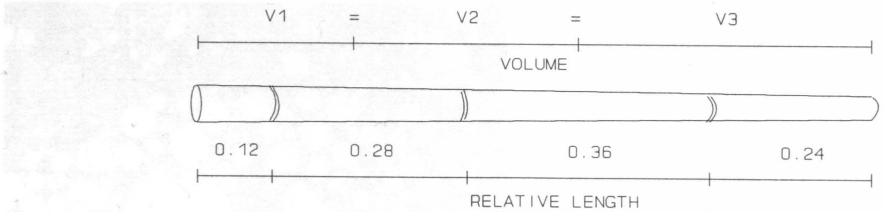

Fig. 6. Locating of sample pieces in a log (relative lengths).

evaporation taking place near the crosscuts, with logs 5 m in length the significance of crosscuts is not as great as with shorter logs (Hakkila 1964).

The moisture contents of the sample discs were measured using the oven-drying method (Skaar 1988). The age of the lowest disc, the cross diameter of every disc, the diameter of decayed areas and the percentage of debarked disc surfaces were also measured. The percentage of debarked surface area of the logs was calculated as an average of the three discs. In addition, the heartwood content was measured from pine.

2.2 Drying of whole piles

The second part of this investigation, the drying of and green weight changes in whole piles, is based on the weight and xylometric measurements of the timber delivered to Veitsiluoto Oy's pulp mills over the years 1987–1991. The timber included both 3- and 5-meter logs from the Oulu, Rovaniemi and Sodankylä regions.

2.3 Calculations

Relationships between the weight loss of logs and variables affecting it were analyzed using correlation matrixes and multiple regression analysis. The region and the location of the logs were used as dummy variables. The effect of location was also analyzed in a factor experiment.

Dependence of the green weight of the whole pile on weather conditions was analyzed using multiple regression analysis with the region as a dummy variable. Used weather variables were means of air temperature, air pressure, air humidity, rainfall, and their cumulative sums. Also other transformations and combinations of these variables were used. The variation of green weight as a function of time was also studied. The regression models and the weight losses of the sample piles were compared by calibrating the log-weighing results to correspond with the weight scaling at the mill.

3 Results

3.1 Drying experiments

The most important factor affecting drying was the debarked log surface area. Initial moisture content was also a significant factor. The third significant factor was log size; for pine the significant variable was volume, and for birch and spruce it was mid-diameter. Using these variables the 12-week weight loss for a birch log is expressed in equation 1, for a spruce log in equation 2, and for a pine log in equation 3.

$$WL = -7.49^{**} + 0.24^{***} \cdot m0 - 0.048^{***} \cdot D + 0.44^{***} \cdot B\% + R + L \quad (1)$$

$$WL = 16.76^{***} + 0.059^{***} \cdot m0 - 0.098^{***} \cdot D + 0.32^{***} \cdot B\% + R + L \quad (2)$$

$$WL = 4.50^{*} + 0.084^{***} \cdot m0 - 0.098^{***} \cdot V + 0.21^{***} \cdot B\% + R + L \quad (3)$$

where
WL = % weight loss
m0 = initial moisture content (%)
D = mid-diameter (mm)
B% = debarked log surface area (%)
R = region
L = location in the pile
V = log volume (dm^3)

Table 1. Values of the dummy variables for a single log weight loss.

		Birch	Spruce	Pine
R	Oulu	0	0	0
	Rovaniemi	–1.47*	–0.78	2.68**
	Sodankylä	2.35**	2.87**	5.36**
L	on the ground	0	0	0
	in lower cavity	1.11	1.75*	1.92*
	in upper cavity	1.19	–0.39	1.72*
	on top of the pile	0.12	1.51	1.99

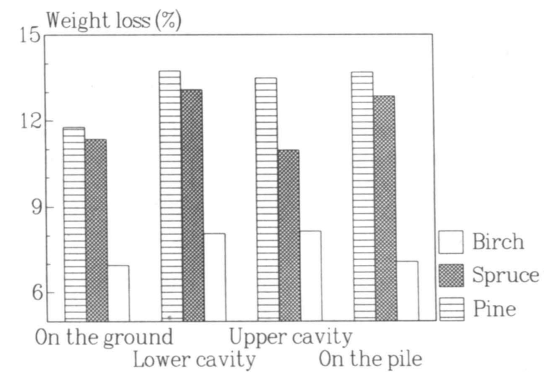

Fig. 7. Dependence of log weight loss on log location in pile. Covariates are debarked log surface area, initial moisture content and mid-diameter.

The values of the dummy variables are presented in Table 1 and the results on analysis of variance are presented in Table 2. The effect of log location is presented in Fig. 7.

3.2 Changes in green weight

Based on the weight scaling data from 1987–1991, the changes in the green weight of birch logs can be written as

$$GW = \frac{1}{\exp(0.00480^{***} \cdot W - 6.839^{***} + R)} \quad (4)$$

Table 2. Analysis of variance for a single log weight loss.

	Source	SS	DF	MS	F
Birch	Model	4152.50	8	519.062	44.8926
	Error	1745.91	151	11.562	
	$R^2 = 0.704$				
Spruce	Model	2736.22	8	342.028	25.3168
	Error	1999.47	148	13.509	
	$R^2 = 0.578$				
Pine	Model	4001.37	8	500.171	29.4821
	Error	2544.79	150	16.965	
	$R^2 = 0.611$				

and the changes in the green weight for pine as

$$GW = 896.4^{***} - 6.74^{***} \cdot (W - 12) + R \quad (5)$$

where
GW = green weight (kg/m^3)
W = week number (W0–52)
W0 = cutting week number
Birch: 1–52
Pine: 12–52 (if 1–11, then W0 = 12)

These relationships are presented in Figs. 8–9. It is striking that none of the variables describing the weather were significant. The values of the dummy variables are presented in Table 3 and the results on analysis of variance are presented in Table 4.

It was not possible to evaluate the equations for spruce logs because of the small amount and the wide deviation of the sampled data.

3.3 Effect of cutting method

The effect of cutting method was studied by comparing weight loss between piles of timber from motor-manual and mechanised logging operations. The proportion of timber from mechanised logging operations averaged 27.25 % during the years 1987–1991. The weight loss percentages and calibrating coefficients for cutting method are presented in Table 5.

When these coefficients are included, the green weight equation for birch can be written as

$$GW = \frac{M^{W-W0}}{\exp(0.00480 \cdot W - 6.84 + R)} \quad (6)$$

and for pine as

$$GW = M^{W-W_0} \cdot (896.4 - 6.74 \cdot (W - 12) + R) \quad (7)$$

where
M = cutting method

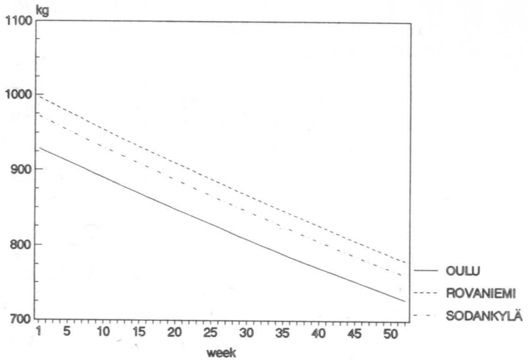

Fig. 8. Dependence of green weight of birch logs on time and region.

Table 3. Values of the dummy variables for changes in the green weight of whole pile.

		Birch	Pine
R	Oulu	0	0
	Rovaniemi	–0.0701***	–26.9***
	Sodankylä	–0.0450***	–90.4***

The comparisons between these equations and the detected weight losses of sample piles are presented in Figs. 10–15.

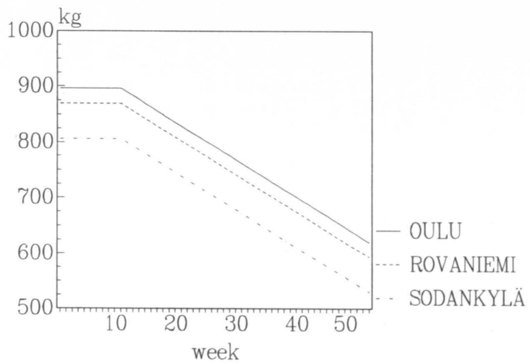

Fig. 9. Dependence of green weight of pine pulpwood on time and region.

Table 4. Analysis of variance for changes in the green weight of whole pile.

	Source	SS	DF	MS	F
Birch	Model	0.49115	3	0.16372	110.763
	Error	0.20545	139	0.00148	
	$R^2 = 0.705$				
Pine	Model	2161853	3	720618	228.715
	Error	768776	244	3150.7	
	$R^2 = 0.738$				

Table 5. Weight losses and calibrating coefficients for cutting method.

	Weight loss (%/week)	Calibrating coefficient
Birch, motor-manual	0.42	1.0011
Birch, mechanised	0.83	0.9970
Birch, average	0.53	
Pine, motor-manual	0.98	1.0008
Pine, mechanised	1.28	0.9978
Pine, average	1.06	

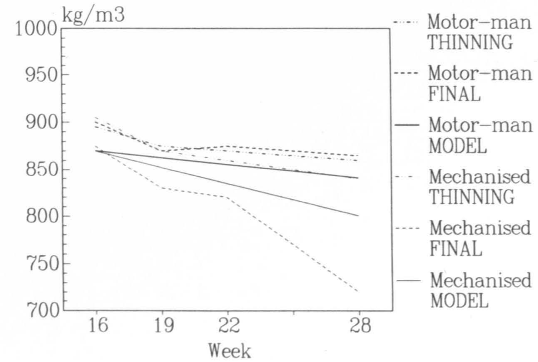

Fig. 10. Changes in the green weight of birch in the Oulu region.

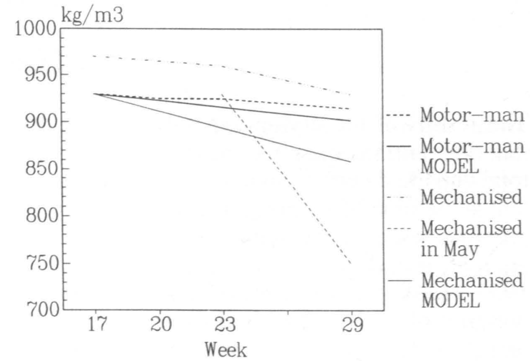

Fig. 11. Changes in the green weight of birch in the Rovaniemi region.

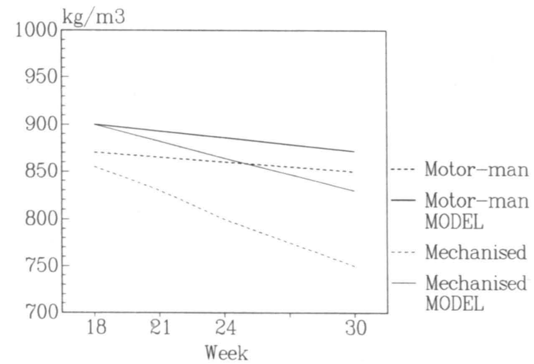

Fig. 12. Changes in the green weight of birch in the Sodankylä region.

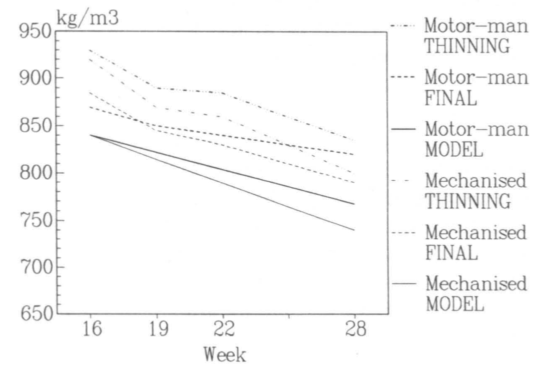

Fig. 13. Changes in the green weight of pine in the Oulu region.

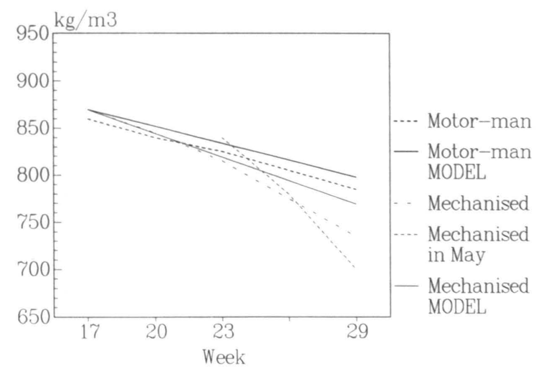

Fig. 14. Changes in the green weight of pine in the Rovaniemi region.

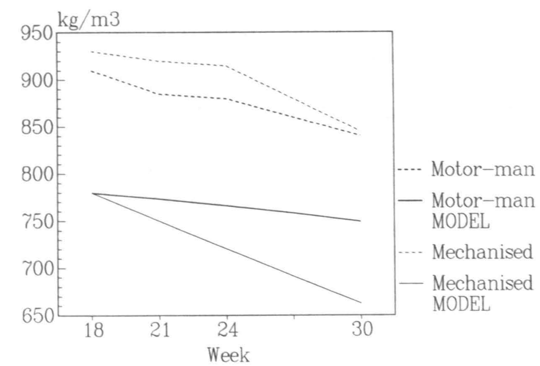

Fig. 15. Changes in the green weight of pine in the Sodankylä region.

4 Discussion

The results of the drying experiments revealed that the main factors affecting timber drying are total debarked surface area, initial moisture content at the time of felling, and log size. Based on previous research, the marked effect of the of the amount of bark was to be expected (Heiskanen 1953, Heiskanen 1959, Hakkila 1964). The importance of the bark loss is also indicated by the rapid drying of logs harvested in the period of sap flow. The effect of initial moisture content may be due to the fact that the proportion of fast capillary evaporation is the greater the higher the moisture content (Nisula 1974). The fact that the variable indicating the size of pine logs is log volume instead of diameter may be due to the fact that the variation in log length was quite small. In other respects, the effect of diameter was to be expected (Heiskanen 1959, Hakkila 1962b).

The effect of location of the log in the pile is logical; the longer the distance to the ground and the ground cover, the lower the air humidity. Another factor is the warming effect resulting from exposure to sunlight in the upper part of the pile. Also, snow in the spring affects the lower part of the pile more than the upper part. On the other hand, rain can wet logs in the upper part of the pile. This was observed while making the measurements; even two or three days after a rainy period, the logs in the top part of the piles were heavier than they had been three weeks earlier.

The validity of these models for the drying of individual logs was quite good. The sample size of 20 logs was sufficient and the confidence interval of weight loss was narrow enough. On the other hand, the number of sample piles was inadequate for determining random variation between the piles. Several factors that may affect drying were, however, not considered in this study; e.g. variation in timber properties, microclimate near the pile, pile size and density, influence of harvesting machinery. The fact that the intention was to construct "normal" piles would probably have excluded some of these factors.

In the Oulu region the difference between logs from clear fellings and those from thinnings was not clear. Therefore, separate models were not calculated. Because younger trees usually have greater initial moisture contents and are more heavily limbed than older trees, timber from thinnings probably dries slightly faster than timber from clear fellings.

The amount of data used to calculate green density was relatively small and variation within it was fairly large. This is probably why the weather variables were not statistically significant. Another reason may be that all the weather variables were somewhat correlated with time.

The calibrating coefficients for harvesting methods were based on the difference between two or four piles in each region. In this case it was not possible to consider random variation. This is why these coefficients are not very reliable and should be used only in the spring (the period when the measurements for this study were made).

In spite of these weaknesses, the models seem to produce at least approximate results for the green weights of birch and pine, and they can be included in transportation cost models. They could also be useful in constructing a storage-cost model including interest costs and costs due to losses in quality.

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