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JULKAISUJA

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MEDDELANDEN FRÅN SKOGSFORSKNINGSINSTITUTET I FINLAND
MITTEILUNGEN DER FORSTLICHEN FORSCHUNGSANSTALT IN FINLAND
PUBLICATIONS OF THE FINNISH FOREST RESEARCH INSTITUTE
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77.1 Hakkila, Pentti. 1972. Mechanized harvesting of stumps and roots. A sub-project of the joint Nordic research programme for the utilization of logging residues. *Seloste:* Kanto- ja juuripuun koneellinen korjuu. Yhteispohjoismaisen hakkuutähdetutkimuksen alaprojekti ..... 1—71

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MECHANIZED HARVESTING OF STUMPS AND ROOTS

A SUB-PROJECT OF THE JOINT NORDIC RESEARCH PROGRAMME FOR THE UTILIZATION OF LOGGING RESIDUES

PENTTI HAKKILA

KANTO- JA JUURIPUUN KONEELLINEN KORJUU

YHTEISPOHJOISMAISEN HAKKUUTÄHDETUTKIMUKSEN ALAPROJEKTI

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CONTENTS

Page

1. Introduction 7
2. Research material 10
   21. Material for technical stump data 10
   22. Logging experiments 13
3. Stump data for development of logging equipment 16
   31. Stump diameter as tree size indicator 16
      311. Correlation between stump diameter and breast height diameter .. 16
      312. Correlation between stump diameter and bole volume 17
   32. The dimensions of stump-root system 18
      321. Stump height 18
      322. Depth of the stump-root system 19
      323. Horizontal diameter of the stump-root system 21
   33. The dry matter in stumps and roots 23
      331. Dry matter in kilogrammes per stump-root system 23
      332. Dry matter of the stump-root system in percentage of bole wood 26
      333. Distribution of dry matter in the stump-root system 28
4. Special characteristics of the harvesting of stumps and roots 30
5. Logging methods 33
   51. Extraction from the soil 33
      511. Extraction of complete trees 33
      512. Extraction of stump-root systems 38
         5121. Extraction by crawler tractor 39
         5122. Extraction by wheel loader 44
         5123. Extraction by excavator 47
   52. Splitting of stump-root systems 50
      521. Splitting as a separate operation 51
      522. Combined extraction and splitting 55
      523. Solid volume content of stump and root wood 58
   53. Forest transportation of stump and root wood 59
   54. Harvesting schedule alternatives 62
6. Summary 64

Literature 67

Lyhennelmä 70

PREFACE

A joint Nordic Research project for industrial utilization of logging residues was started in 1969 on the recommendation of the Nordic Council. The aim is to obtain additional raw material for the forest industry from unmerchantable tops, branches, stumps and roots.

The Finnish Forest Research Institute was chosen to direct the work. A project council subordinated to the Council for Nordic Forest Work Studies (Nordiska Skogsarbetsstudiernas Råd) was set up to supervise the work. Its members are Peter Moltesen and Aage-Marcus Pedersen, from Denmark; Carl Bredberg and Bertil Nilsson, from Sweden; Kjell Wibstad from Norway; and Veijo Heiskanen as chairman and Pentti Hakkila as the actual project leader, from Finland.

On the initiative of the Central Association of Finnish Woodworking Industries two working teams were set up in 1970 to study the utilization of stump and root wood, one at the mill end and the other at the forest end. The chairman of the forest-end team is Pentti Hakkila (Finnish Forest Research Institute) and vice-chairman Uolevi Sarapää (Kemi Oy). The other members are Matti Ahonen (Kemi Oy), Aulis E. Hakkarainen (Metsäteho), Erkki Huhanantti (Oulu Osakeyhtiö), Juhani Järvinen (Tehdaspuu Oy), Jorma Klami (VAPO), Raimo Koskinen (Oy W. Rosenlew Ab), Osmo Lehtonen (Enso-Gutzeit Osakeyhtiö), Lauri Lähteenmäki (National Board of Forestry), Markku Mäkelä (Finnish Forest Research Institute), Pentti Nisula (Finnish Forest Research Institute) in charge of the machine development, Ilpo Palenius (Finnish Pulp and Paper Research Institute), Osmo Räisänen (United Paper Mills Ltd), Mikko Rysä (Metsäteho) and Martti Siirilä (Oy Wilh. Schauman Ab).

The research programme was conducted partly as a joint Nordic project and partly in cooperation between Finnish researchers. The majority of the field experiments were carried out at the work sites of Kemi Oy and the company played a decisive part in the programme.

So many members of the staff of different companies and research establishments participated in 1970 and 1971 in the development of the

machinery and in research that only a small proportion of those who contributed to the work can be mentioned by name here. The greatest burden of the field work fell on Mr. Simo Jaaranen, Mr. Jaska Kosamo, Mr. Markku Mäkelä and Mr. Sauli Takalo who collected most of the investigation material and participated independently in the development work.

The data processing on the materials was performed by Mrs. Arja Panhelainen. Mr. Klaus Rantapuu translated Russian and Bulgarian studies on the subject. The laboratory and office work was done by Mrs. Taija Havanto, Mrs. Kaarina Koskinen, Mrs. Aune Rytkönen, Miss Pirjo Salonen and Miss Raija Siekkinen. The figures were drawn by Mrs. Pirkko Hakkila and Miss Leena Paumola.

The manuscript was checked by Professor Olli Makkonen and Professor Max. Hagman. The study was translated into English by Miss Päivikki Ojansuu and checked by Mr. L. A. Keyworth.

My sincere thanks go to all those who contributed to this research project.

Padasjoki, August 1972

Pentti Hakkila

1. INTRODUCTION

Stump and root wood was used in Finland earlier as fuel and for the production of charcoal and tar. As late as in 1938, over 200 000 solid cu.m. of firewood was made of stumps and roots (E r k k i l ä 1943). During World War II tar-burning attained significant dimensions for the last time; 825 000 piled cu.m. of mature stump wood was utilized for the purpose in 1943—1947 (M u r t o 1951).

Stumps were extrated from the earth by simple methods by hand tools or by blasting. Splitting was done by axe and, eventually, also by a tractor-driven device of guillotine type. When human labour costs increased the activity became unprofitable. Utilization of stump and root wood ended in Finland.

In some countries, however, stumpwood preserved its position, primarily as raw material of the chemical industry. The stumpwood is always mature pine stumps the thin side roots of which have already mostly rotted away. In Poland, for instance, 100 000 solid cu.m. of 5—15-year-old pine stumps is harvested yearly for four factories specialising in the extraction of stumpwood for the production of naval stores. Wood extracted by benzine is utilized in the fibre board and particle board industry (H a k k i l a 1971a).

The Soviet Union utilizes yearly 500 000 solid cu.m. of old *Pinus silvestris* and *Pinus cembra* stumps as raw material for the chemical industry (M e d n i k o v 1971 [1]). The bulk of the wood is still harvested by blasting, but purposeful work has been done since the middle of the 1960s to mechanise the logging methods. The raw material is treated by dry-distillation or extraction. The principal products are tar, colophony, turpentine and essential oils. The residual wood can be utilized for hydrolysis, board production, as charcoal or firewood. This is an expanding branch with a sharply increasing wood requirement. Five new mills will start up in a couple of years, each consuming 100 000 solid cu.m. of stump wood per annum (D e m i n, V a s j u k o v and K u z n e t s o v a 1970). The assumption in the planning of new mills is that a part of the raw material must be taken sooner or later from fresh stumps.

Crawler tractors are used in the United States to extract annually about 300 000 solid cubic metres of old *Pinus palustris* stumps for use as raw

[1]) Professor F. A. Mednikov, oral communication.

material for the chemical industry. Fresh stumps are not accepted. The first pulp mill has recently begun to utilise the fibre left after resin, turpentine and other chemicals have been extracted from the stumps. A linerboard mill in Georgia obtains over 100 000 tons of raw material yearly in this way, i.e., 30 per cent of the total fibre need (Davis 1971).

The forest industry's capacity was enlarged so much in the 1960s in Finland that there are now occasional and local shortages of raw material. The situation is especially critical in the sulphate pulp industry for which further expansion is no longer possible without new raw material sources. As the stump and root wood of Scots pine and Norway spruce has been found to meet the requirements of the sulphate process, interest in the underground parts of the tree has arisen in Finland. Attention is now directed to fresh instead of mature stumps.

The United Paper Mills Ltd. carried out extensive studies in the early 1960s on stump and root wood, but the plans for exploitation foundered because the harvesting costs were too high. Splitting and chipping in particular caused insurmountable difficulties. An interval of several years followed although the Finnish Forest Research Institute and Enso-Gutzeit Osakeyhtiö carried out limited studies on stump extraction in the middle of the decade (Koivulehto 1969).

At the end of the 1960s attitudes had finally matured enough to permit the beginning of really thorough studies. The joint Nordic programme for the utilization of logging residues was instituted, and independent experiments were conducted by the North-Finnish companies Kemi Oy and Oulu Osakeyhtiö. Forces were combined on the initiative of the Central Association of Finnish Woodworking Industries and all the sulphate pulp mills and several research institutes started to cooperate on developing the utilization of stump and root wood.

The work was divided in two parts. One team was assigned to perform the research and development work at the forest end and the other focused on the mill treatment of stump and root wood and pulping experiments. The meeting point of the two assignments was the delivery by the forest-end team of stump and root wood to the mill at the lowest cost possible. For further treatment at the mill, the pieces of stump and root were to be 50—60 cm long and at the most 20—30 cm in diameter. Additionally, roots should be harvested down to a minimum diameter of 5 cm.

It was found in an early stage that a lack of basic data on stump and root wood hampered planning. Modern machine development has no firm scientific foundation if the properties of the timber to be processed are not known. The acquisition of basic information on stump and root wood harvesting techniques was therefore regarded as indispensable and urgent.

The ultimate target is the development of harvesting methods suitable for different conditions, but the early phase has been study of individual work phases and machines. During the first two years, a great many independent studies were made. Preliminary results have been published from some of them (Ahonen 1970 a, b and c, 1971, Ruoste 1970, Sarapää 1970 a and b, Hakkila 1971 b, Mäkelä 1971 and 1972, Ahonen and Mäkelä 1972), but many have not yet been reported. The present study is a summary and a progress report of the work done in 1970 and 1971 for the development of the harvesting of stumps and roots.

2. RESEARCH MATERIAL

21. Material for technical stump data

Stump and root data needed to develop harvesting equipment were collected from 10 sample stands, seven in Ruotsinkylä and Padasjoki, South Finland, and three in Säynäjä, just above the Arctic Circle in Lapland. The sample stands represented partly pure Scots pine (*Pinus silvestris* (L.) or Norway spruce (*Picea abies* (L.) Karst.) stands, partly mixed softwood forests. Fifty stumps from each sample stand were studied.

Table 1 describes the material. The range of the stump diameter was

Table 1. The material for technical stump data
Taulukko 1. Korjuuteknisten kanto- ja juuritietojen aineisto

Stand *Metsikkö*	Number of trees *Koepuita, kpl*	Location *Paikkakunta*	Latitude *Leveysaste*	Site type [1] *Metsätyyppi* [1]	Age, years *Ikä, vuotta*	Stump diameter, cm *Kannon läpimitta, cm*	
						With bark *Kuorineen*	Without bark *Kuoretta*
			Pine — *Mänty*				
1	27	Ruotsinkylä	60°21′	MT	74	35.9	32.0
2	50	Ruotsinkylä	60°21′	VT	80	29.9	26.5
4	44	Säynäjä	66°55′	CT	142	29.9	26.3
5	42	Säynäjä	66°55′	EVT	186	28.1	24.3
6	5	Vesijako	61°24′	MT	92	25.4	22.5
3	50	Vesijako	61°24′	VT	77	20.9	18.1
9	6	Maakeski	61°24′	Swamp	99	31.7	27.7
Aver. *Kesk.*					112	28.2	24.8
			Spruce — *Kuusi*				
1	20	Ruotsinkylä	60°21′	MT	92	36.1	35.3
4	6	Säynäjä	66°55′	CT	143	21.0	19.1
10	50	Säynäjä	66°55′	EMT	150	23.4	21.4
5	8	Säynäjä	66°55′	EVT	153	21.7	20.3
6	45	Vesijako	61°24′	MT	119	29.8	28.1
7	50	Vesijako	61°24′	MT	106	20.1	18.9
8	50	Maakeski	61°24′	VT-MT	66	28.5	26.6
9	44	Maakeski	61°24′	Swamp	108	26.7	25.1
Aver. *Kesk.*					111	26.2	24.5

[1] CT = *Calluna* type, EMT = *Empetrum-Myrtillus* type, EVT = *Empetrum-Vaccinium* type, MT = *Myrtillus* type, VT = *Vaccinium* type and Swamp = spruce swamp = *korpi*.

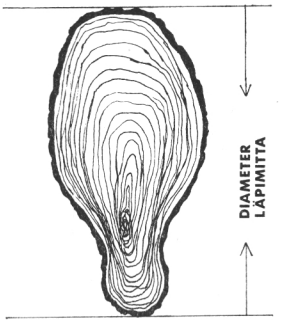


Figure 1. Measurement of the diameter of eccentric roots.
Kuva 1. Epäkeskisten juurten paksuuden mittaaminen.

15—70 cm, but only 15—50 cm can be accepted as the range of application of the results.

The majority of the sample stands were on mineral soils; only the southern sample stand No. 10 was on *Sphagnum* peat. Sample stands 5, 7 and 8 represented moraine soil and the rest were classifiable primarily as sandy soil. Sample stands No. 5 and especially No. 8 were stony.

Stumps were extracted with an Allis-Chalmers TL-645 wheel loader or RH-4 excavator. As far as possible, all root down to a minimum diameter of 5 cm was also extracted. It is obvious, however, that thicker root wood was sometimes left in the ground. Thinner parts of roots were disregarded as the prospect of their utilization appears to be very remote for economic, reasons, at least for the present. The 5-cm limit refers to the greatest, vertical diameter in unsymmetrical roots (Fig. 1).

Dry weight is the most practical indicator of the amount of stump and root wood. The precondition is, however, that the stump-root system can be completely cleaned of stones and loose earth before weighing. This work phase was the most difficult and slowest in the collection of the material, and it also determined the size of the total material. When the experiments were commenced the following methods of cleaning the stump-root system were tested.

— Manually by steel brush
— With a power-saw-mounted nylon brush
— Water jet
— Pneumatic pressure
— By dropping the stump-root system from a height of 4—5 m with the stump cross-section foremost onto a steel platform
— By vibrating the stump-root system in the cub of a wheel loader

The best method proved to be the preliminary cleaning of the stump-root systems by wheel loader by means of vibration and dropping and the finishing done manually with a steel brush. The stump-root system cleaned so

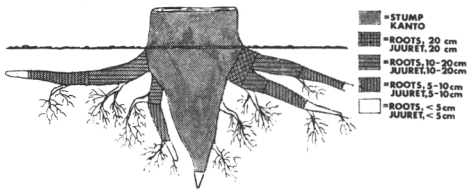


Figure 2. Division of stump and root wood into diameter classes.

Kuva 2. Kanto- ja juuripuun jakaminen läpimittaluokkiin.

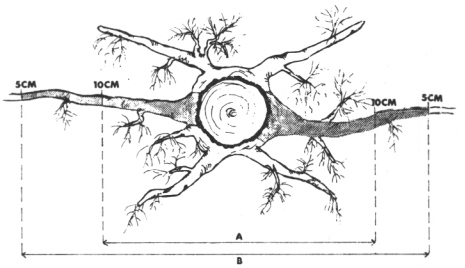


Figure 3. Measurement of »root span» from 10 to 10 (A) and from 5 to 5 cm (B).

Kuva 3. »Juurivälin» mittaaminen 10 (A) ja 5 (B) cm:n minimiläpimittaa käytettäessä.

completely that it was possible to perform the weight scaling with sufficient reliability.

The wood in every stump-root system was cut by chain saw into the following parts: Stump proper, root wood over 20 cm in diameter, root wood 10—20 cm in diameter and root wood 5—10 cm in diameter (Fig. 2). Each part was weighed green including bark, and a moisture sample was taken from each part for calculation of dry weight. The aim was to establish what proportion of the dry matter of the stump-root system can be harvested with different methods and minimum diameters for root wood. The bark percentage and basic density were also determined from sample discs to convert dry weights into volume.

The sample stands were in clear-cutting areas from which bole wood had already been harvested. Thus the above-ground portion of the bole could not be measured. For this reason materials of 50—100 trees were collected from the immediate vicinity of each sample stand and from corresponding soil and diameter classes. The correlation of stump diameter with breast height diameter and bole volume was determined from these materials. It was thus possible to calculate the per cent proportion of stump and root wood in bole wood on the dry weight basis.

From each stump were measured the height of the above-ground portion and the depth of the underground part down to a diameter of 5 cm. The longest horizontal diameter, i.e., the »root span» and the diameter perpendicular to it, were also measured in two sample stands. Again, only root wood with a minimum diameter of 5 or 10 cm was accepted (Fig. 3). These data are needed in the development of splitting machines.

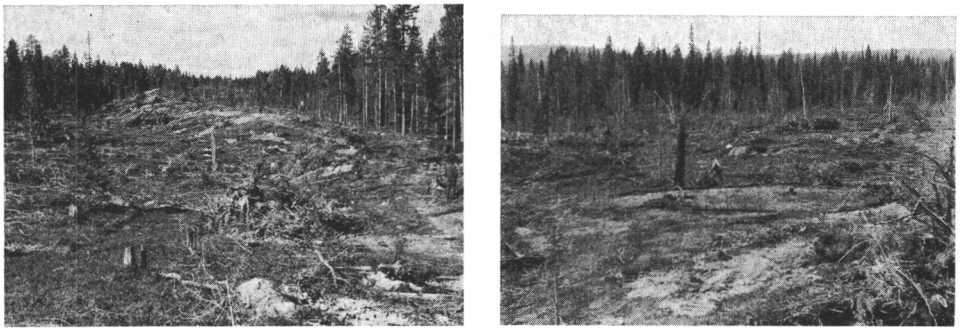


Figure 4. Parts of the Säynäjä work site in North Finland.
Kuva 4. Osia Säynäjän koetyömaasta Pohjois-Suomessa.

22. Logging experiments

The majority of the logging experiments were conducted at the Säynäjä work site of Kemi Oy in North Finland (Fig. 4). Studies on a smaller scale were made in the experimental forest at Ruotsinkylä of the Finnish Forest Research Institute and at the work site of United Paper Mills Ltd. in Maakeski. The main aim was the development of harvesting methods, but a simultaneous objective was to meet the raw material requirement of the Kemi pilot plant for stump chipping. All the studies were concerned with fresh stump and root wood of Scots pine and Norway spruce.

The first studies were carried out in autumn 1969 in Säynäjä, where 780 piled cu.m. of Scots pine stump and root wood was harvested, partly by blasting and partly by bulldozer. The following harvesting schedules were applied:

Blasting method:

— Preliminary extraction and splitting by blasting
— Final extraction from the soil with a Fiskars one-tooth ripper mounted on a Nuffield farm tractor
— Forest haulage by a Nuffield farm tractor equipped with a Joutsa boom loader
— Removal of thin roots by axe
— Final splitting by a tractor-driven splitting machine of guillotine type manufactured by Lypsyniemi engineering works
— Long-distance transport to the Kemi pilot plant by truck equipped with a grapple

Crawler tractor method:

— Extraction with a Caterpillar D 6 C crawler tractor with a rake fitting on its bulldozer plate
— Forest haulage as above
— Preliminary splitting by blasting

— Removal of thin roots by axe
— Final splitting as above
— Long-distance transport as above

The harvesting experiments in Säynäjä continued in summer 1970. A total of 2 500—3 000 piled cu.m. of stump and root wood was extracted. However, only 1 500 piled cu.m. was delivered split to Kemi and the remainder was left unsplit in intermediate storage over the winter. In addition to the machines and methods used in the previous year, the following were now used experimentally in the different stages of harvesting.

Extraction:

— Allis Chalmers Tl-645 wheel loader equipped with a stump cub of special construction
— Volvo LM-840 wheel loader equipped with a log grapple of standard construction
— Volvo LM-840 equipped with a prototype stump extraction machine manufactured by Tuomen Konepaja engineering works
— Tree Farmer skidder equipped with a prototype stump extraction machine manufactured by L. Marttiini Yhtymä engineering works

Forest haulage:

— Tree Farmer skidder equipped with a hydraulic loader
— Skidding by a 2-drum winch manufactured by Peltosalmen Konepaja engineering works and mounted on a Nuffield farm tractor

Splitting:

— Chain saw

In 1971, a further 1 880 piled cu.m. of Scots pine stump and root wood was delivered from Säynäjä to Kemi; most of it had been extracted from the soil during the previous summer. A new method tried in the harvesting of stumps was the use of a combined extraction and splitting device mounted on an RH-4 excavator. The apparatus was constructed by Mr Kyösti Pallari.

Limited experiments were made in Ruotsinkylä in summer 1970 with the above machines in the conditions of South Finland. A study was also made of the uprooting of complete pine and spruce trees with an Allis Chalmers wheel loader.

At the work site of the United Paper Mills Ltd. in Maakeski a total of 204 piled cu.m. of stump and root wood of South Finnish spruce was harvested in 1970 and 1971. A small amount of stumps was extracted with an RH-4 excavator with standard equipment. The principal harvesting schedule was as follows:

— Preliminary extraction by blasting
— Final extraction and skidding alongside the strip road by the winch of a Valmet skidder. Alternatively, final extraction by the grapple of a Valmet forwarder and short-distance transport by the same tractor

— Final splitting by chain saw
— Long-distance transport by truck equipped with a hydraulic grapple of special construction to Lahti and on by rail to Kemi

The work was largely of the nature of machine development. Time studies were performed in the different stages of the experiments following the customary working time distribution principle. On the basis of the time studies improvements were made in the construction of the machines in the course of the work. The cost calculations and future developmental work are also based on these time studies.

3. STUMP DATA FOR DEVELOPMENT OF LOGGING EQUIPMENT

31. Stump diameter as tree size indicator

311. Correlation between stump diameter and breast height diameter

Preliminary planning of logging operation often includes measuring the breast height diameter distribution of trees for estimation of the amount of timber. To obtain the same information on the size of stump-root systems it is necessary to know the correlation between breast height diameter and stump diameter. This correlation is presented by sample plots in Table 2.

The breast height diameter in the sample plots was 73—79 per cent of the stump diameter. The close correlation makes it possible by using a single general formula to estimate even for an individual tree the stump diameter from the breast height diameter with 95 per cent reliability to an accuracy of 3 cm. Although tapering at the top end of the bole is more pronounced in the north there are no significant differences in the butt end of

Table 2. Correlation between stump diameter (x, cm) and breast height diameter (y, cm), bark-on basis

Taulukko 2. Kannon kuorellisen läpimitan (x, cm) ja rinnankorkeusläpimitan (y, cm) välinen korrelaatio

Stand *Metsikkö*	Location *Sijainti*	Regression equation *Regressioyhtälö*	R	$s_{x \cdot y}$, cm	Mean dbh, cm $D_{1.3}$, *cm keskim.*
		Pine — *Mänty*			
1	South — Etelä	$y = 0.7506\,x$	.9668	1.4	35.9
2	South — Etelä	$y = 0.7434\,x$	.9846	1.2	29.9
3	South — Etelä	$y = 0.7561\,x$	.9694	0.9	20.9
4	North — Pohjoinen .	$y = 0.7729\,x$	.9845	1.4	29.9
5	North — Pohjoinen .	$y = 0.7746\,x$	.9697	1.6	28.1
Average	All — Kaikki	$y = 0.7604\,x$	.9807	1.4	28.2
		Spruce — *Kuusi*			
6	South — Etelä	$y = 0.7328\,x$	.9452	1.6	29.8
7	South — Etelä	$y = 0.7888\,x$	.9322	1.3	20.1
8	South — Etelä	$y = 0.7523\,x$	.9624	1.3	28.5
9	South — Etelä	$y = 0.7590\,x$	.9190	2.0	26.7
10	North — Pohjoinen .	$y = 0.7544\,x$	.9647	1.5	23.4
Average	All — Kaikki	$y = 0.7411\,x$	.9567	1.6	26.2

the bole between south and north. The same observation has been made in Sweden (A g e r, N i l s s o n and von S e g e b a d e n 1964).

The differences between pine and spruce are so small that the same equation, $y = 0.75x$, is applicable to both (cf. N y y s s ö n e n 1954). The following average values may be used.

	Diameter above bark, cm					
At breast height	15	20	25	30	35	40
At stump height	20	26	33	40	46	53

Stump diameter, average of two right-angled measurements above bark, was 1.32 times the breast height diameter in the present material. In Sweden the minimum stump diameter is 1.25 and the maximum 1.40 times the breast height diameter (A g e r, N i l s s o n and von S e g e b a d e n 1964).

312. Correlation between stump diameter and bole volume

The volume of standing trees is generally estimated on the basis of breast height diameter, height and tapering. Clearly, then, stump diameter alone cannot be an accurate indicator of bole volume. Table 3 shows that the variation between sample plots is great.

Trees generally taper more sharply in the north than in the south. A stump of the same diameter thus represents a smaller tree in the north. The

Table 3. Correlation between tree volume (y, litres) and stump diameter (x, cm), bark-on basis

Taulukko 3. Rungon kuorellisen tilavuuden (y, litraa) ja kannon kuorellisen läpimitan (x, cm) välinen korrelaatio

Stand *Metsikkö*	Location *Sijainti*	Regression equation *Regressioyhtälö*	R	$s_{x \cdot y}$	Mean volume, l *Keski-kuutio, l*
		Pine — *Mänty*			
1	South — Etelä	$y = 0.4237\ x^2$	.9147	105	566
2	South — Etelä	$y = 0.3751\ x^2$	.9501	77	352
3	South — Etelä	$y = 0.3283\ x^2$	.9464	31	151
4	North — Pohjoinen .	$y = 0.3599\ x^2$	.9535	86	337
5	North — Pohjoinen .	$y = 0.4163\ x^2$	.9437	79	382
Average	All — Kaikki	$y = 0.3858\ x^2$	.9466	82	336
		Spruce — *Kuusi*			
6	South — Etelä	$y = 0.4472\ x^2$	.9434	77	432
7	South — Etelä	$y = 0.4317\ x^2$	.9384	34	182
8	South — Etelä	$y = 0.4719\ x^2$	.9521	67	416
9	South — Etelä	$y = 0.4238\ x^2$	.8952	94	330
10	North — Pohjoinen .	$y = 0.3401\ x^2$	.9255	68	201
Average	All — Kaikki	$y = 0.4170\ x^2$	.9241	86	317

stem form may be sharply tapering also in the south. Sample plot 3 which was very stony *Vaccinium*-type terrain is an example of this.

Stump diameter is thus a rather inaccurate indicator of tree volume. The accuracy given by the mean equation for the tree species is only ± 165 litres with 95 per cent reliability. Better results are achieved by formulating separate equations for different growth sites. The following figures may, however, be regarded as indicative examples.

Stump diameter, cm	Pine Bole volume, litres	Spruce
20	150	170
30	350	380
40	620	670
50	970	1 040

32. The dimensions of stump-root system

321. Stump height

Information on stump height is needed for different technical solutions. For instance, the dimensions of the stump-root system must be known in planning the size of splitting equipment. There are many plans for tree fellers which lower the stump cross-section to ground level or even below it. The present height of the stump must be known to calculate the quantity of timber accumulating in this way.

Stump height refers here to the distance of the stump cross-section from ground level (Fig. 5). The theoretical stump height is the height at which a tree can be cut without serious disturbance to the work and the butt log form by the uppermost top of the root (cf. Ilvessalo 1948). In practice, however, and especially in winter conditions, the stump tends to be higher. On the other hand, the power saw often makes it possible to cut a tree even below the theoretical stump cross-section.

When stump diameter increases by 1 cm the theoretical height of stump grows by 2—3 mm. The correlation is weak, however, for the butt swell

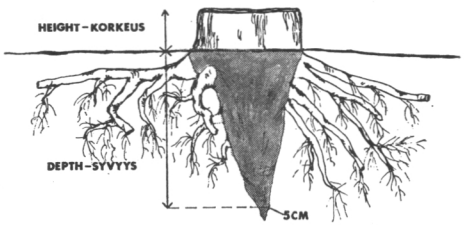


Figure 5. Measurement of stump height and depth of the stump-root system.
Kuva 5. Kannon korkeuden ja juurakon syvyyden mittaaminen.

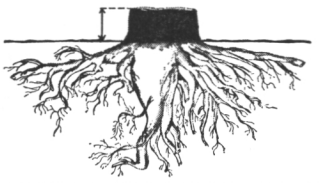


Table 4. The theoretical stump height (y, cm) as a function of stump diameter above bark (x, cm)

Taulukko 4. Kannon teoreettinen korkeus (y, cm) kannon kuorellisen läpimitan (x, cm) funktiona

Stand *Metsikkö*	Location *Sijainti*	Regression equation *Regressioyhtälö*	R	$s_{x.y}$, cm	Mean height, cm *Keskikorkeus, cm*
		Pine — *Mänty*			
1	South — Etelä	$y = 0.29\,x$	.7187	2.0	7.8
2	South — Etelä	$y = 5.8 + 0.10\,x$	.4139	1.9	8.4
3	South — Etelä	$y = 5.6 + 0.17\,x$	.3404	2.2	12.7
4	North — Pohjoinen .	$y = 2.5 + 0.31\,x$	.7843	2.3	14.2
5	North — Pohjoinen .	$y = 5.1 + 0.20\,x$	.6696	1.8	16.1
Average	All — Kaikki	$y = 4.7 + 0.19\,x$	.5630	2.5	12.1
		Spruce — *Kuusi*			
6	South — Etelä	$y = 5.7 + 0.21\,x$	.4373	3.1	10.7
7	South — Etelä	$y = 5.4 + 0.21\,x$	.2357	3.3	6.6
8	South — Etelä	$y = 2.7 + 0.35\,x$	.4809	4.3	10.8
9	South — Etelä	$y = 4.0 + 0.22\,x$	.4203	3.0	13.0
10	North — Pohjoinen .	$y = 5.8 + 0.23\,x$	.4660	1.9	11.7
Average	All — Kaikki	$y = 2.6 + 0.26\,x$	.6013	3.8	10.6

and topography also influence height. The following figures show the difference between the theoretical and real height of the stump in the total investigation material.

Species	Stump height, cm	
	Theoretical	Real
Pine	10.1	12.0
Spruce	12.0	10.6

Even a small change in the height of the stump cross-section affects the stump diameter, for the stem tapers sharply near the ground. For instance, a 5 cm increase in stump height reduces the stump diameter of saw timber trees by an average of 1 cm. In sample plots 1 and 5 the real stump diameters were therefore corrected by 1 cm before computer treatment of the material. The stump diameters in the regression equations thus correspond to the theoretical stump height. An endeavour was made in this way to eliminate from the final results the inter-stand variation caused by the external conditions.

322. Depth of the stump-root system

The depth of the stump-root system affects the force and technique applied in the extraction process. On it depends also the size of the holes, and

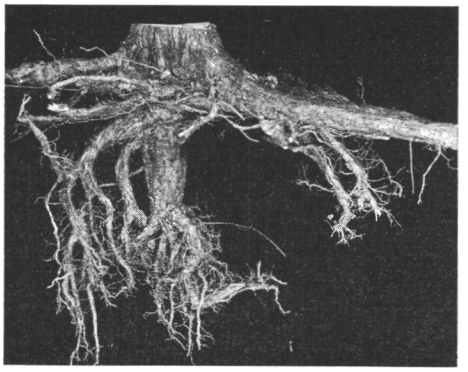


Figure 6. Stump-root system of pine in South Finland (Photo Lalli Laine).
Kuva 6. Männyn juurakko Etelä-Suomessa (Kuvannut Lalli Laine).

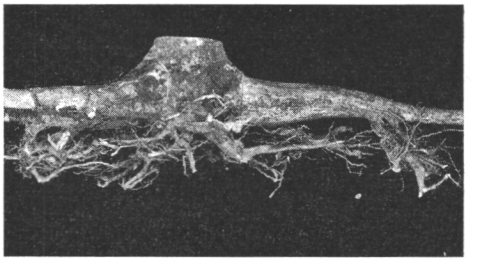


Figure 7. Stump-root system of spruce in South Finland (Photo Lalli Laine).
Kuva 7. Kuusen juurakko Etelä-Suomessa (Kuvannut Lalli Laine).

it affects the dimensioning of the splitting equipment. The depth of the stump-root system refers here to the vertical length of the projection of the stem underground, disregarding the part thinner than 5 cm of the tip of the tap root (Fig. 5).

A strong tap root is characteristic of the pine (Fig. 6). However, the tap root is poorly developed or missing altogether in the cold conditions of the north; in waterlogged peat lands the pine never grows a tap root even in the south (cf. Laitakari 1929). The root system of the spruce is superficial everywhere compared with the pine (Fig. 7) and the stump-root system extraction technique consequently varies with the tree species. For instance, extraction of the stump-root system by pushing the whole tree over requires 40 per cent less force for spruce than for pine (Kišenko, Unt, Komšilov, Gerasimov and Abol 1962).

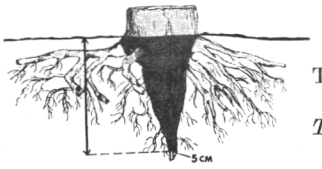


Table 5. The depth of the stump-root system (y, cm) as a function of stump diameter above bark (x, cm)
Taulukko 5. Juurakon syvyys (y, cm) kannon kuorellisen läpimitan (x, cm) funktiona

Species *Puulaji*	Location *Sijainti*	Regression equation *Regressioyhtälö*	R	$s_{x \cdot y}$, cm	Mean depth cm *Keski-syvyys cm*
Pine	South — Etelä	$y = 18 + 2.8\,x - 0.028\,x^2$	.441	20	73
»	North — Pohjoinen .	$y = 2 + 2.3\,x - 0.020\,x^2$	.491	16	50
»	All — Kaikki	$y = 16 + 2.4\,x - 0.023\,x^2$	.370	22	64
Spruce	South — Etelä	$y = 15 + 0.9\,x$	.485	13	39
»	North — Pohjoinen .	$y = 5 + 1.1\,x$	.660	8	31
»	All — Kaikki	$y = 12 + 0.9\,x$	.533	13	37

The average depth of the pine stump-root system was 73 cm in south and 50 cm in north Finland. The depth increased by 0.9 cm when the stump diameter grew by 1 cm. The correlation was weak, however, and diameter consequently explained only 10—40 per cent of the within-stand variation.

The stump-root system of spruce is lower. Its depth was 39 cm in south and only 31 cm in north Finland. For spruce, too, the depth grew by 0.9 cm when diameter increased by 1 cm but the correlation was somewhat closer. Diameter explained 15—45 per cent of the variation.

The size of the hole formed after stump extraction depends on the depth of the stump-root system. No measurements were made, but it was noted that the pine leaves a definitely deeper hole than the spruce. On an average more than 90 per cent of the volume of lateral roots in Scots and Norway spruce is in the surface layer of 20 cm in thickness (K a l e l a 1949). It has been observed that in Hungarian conditions the depth of the hole left by Austrian pine is the same as the stump diameter (H o r v a t h - L a i k o, K a r d a s and M a u r e r 1971).

323. Horizontal diameter of the stump-root system

It is important to know the horizontal dimensions of the stump-root system when designing the splitting equipment, vehicles and other apparatus. These dimensions decide also the size of the spots of mineral soil that are exposed by stump extraction.

The lateral roots of spruce are significantly longer than those of pine. On average, for a stump of 30 cm, the longest root from the butt of the root down to 5 cm diameter in the investigation material was 100 cm for pine



Table 6. The longest root (y, cm down to 5 cm diameter) of a stump-root system as a function of stump diameter above bark (x, cm)

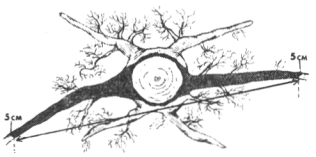
Taulukko 6. Juurakon pisimmän juuren pituus (y, cm 5 cm:n läpimittaan saakka) kannon kuorellisen läpimitan (x, cm) funktiona

Species *Puulaji*	Location *Sijainti*	Regression equation *Regressioyhtälö*	R	$s_{x \cdot y}$, cm	Longest root, cm *Pisin juuri cm*
Pine	South — Etelä	$y = 20 + 2.6\,x$	.548	33	91
»	North — Pohjoinen .	$y = -18 + 4.2\,x$	.723	38	104
»	All — Kaikki	$y = 7 + 3.1\,x$	.571	38	94
Spruce	South — Etelä	$y = -83 + 11.5\,x - 0.125x^2$	.714	39	126
»	North — Pohjoinen .	$y = 39 + 0.141x^2$	.796	36	120
»	All — Kaikki	$y = -84 + 11.5\,x - 0.124x^2$	.717	39	125

and 150 cm for spruce. The length of the spruce root is related to the stump diameter. The roots of spruces growing in peat land are particularly long.

For the measurement of the root span, the stump-root systems of 44 spruces growing on peat land in south Finland and of 167 pines in mineral soil in north Finland were examined. The longest root span of each of the trees was measured accepting alternatively at first only root wood of 10 cm and later also root wood of 5 cm in diameter. The corresponding characteristics were determined also in the perpendicular direction against the longest diameter.

In the north the longest average root span of the 30 cm pine stump-root system was 1.1 m for a minimum root diameter of 10 cm and 1.3 m for a minimum diameter of 5 cm. Stump diameter explained less than a half of the variation.



Species	Soil	Equation	R	$S_{x \cdot y}$, cm
Pine	Mineral	$y_1 = 3.63\,x$	.6694	38
»	»	$y_2 = 4.20\,x$	.5733	47
Spruce	Peat	$y_1 = 8.06\,x$	.8709	44
»	»	$y_2 = 10.43\,x$	.8473	55

y_1 = The longest root span from 10 to 10 cm, in centimetres
y_2 = The longest root span from 5 to 5 cm, in centimetres
x = Stump diameter above bark, in centimetres

The longest horizontal diameter of the stump-root system of a peatland spruce is over twice that of a pine of the same size in mineral soil (Fig. 8). The root span of a 30 cm stump in the spruce sample plot was 2.4 m for a

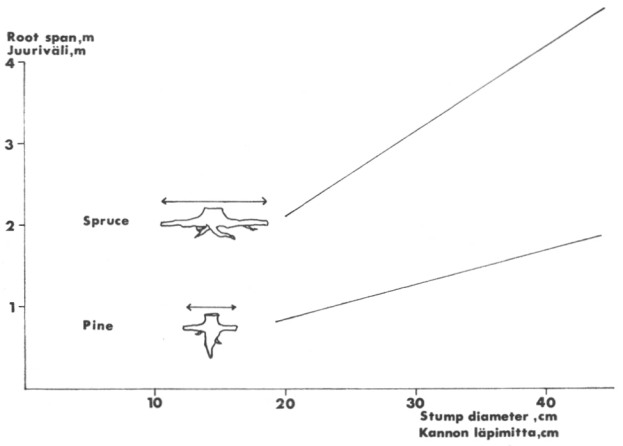


Figure 8. The 5 to 5 cm root span in northern pine on mineral soil and in southern spruce on swamp.
Kuva 8. Pohjoisen mineraalimaan männyn ja etelän suomaan kuusen juuriväli 5 cm:n minimiläpimittaa noudatettaessa.

minimum diameter of 10 cm and 3.1 m for a minimum diameter of 5 cm. Stump diameter explained three-fourths of the variation.

The diameter of the stump-root system perpendicular to the maximum diameter was 20—25 per cent shorter for pine and 10—15 per cent shorter for spruce. It is possible with the help of these data to calculate the area covered by the network of thick roots. They give an idea of the possible maximum size of the spot that will be exposed when the stump-root system is extracted. For instance, the network of parts of roots thicker than 5 cm of a 20 cm stump covers about 0.4 sq.m. for pine in mineral soil and 3.0 sq.m. for peatland spruce. When the stump diameter doubles, the areas are quadrupled, i.e. 1.6 and 12.0 sq.m.

33. The dry matter in stumps and roots

331. Dry matter in kilogrammes per stump-root system

The aim of the development work is to lower harvesting costs. However, cost calculations cannot be made without knowing the available timber quantities. Calculations may be based initially on per-stump data of which the most important is the dry matter content of the stump-root system. Only when this factor is known can the costs of the alternative harvesting methods in different conditions be compared (Fig. 9).

Table 7 shows the within-stand correlation between stump diameter and dry weight of the stump-root system when root wood under 5 cm thickness is disregarded. The other variables such as stump height improve the reliability of the equation so little that they are not of great practical significance. In some cases the first power diameter variable is also significant, but to simplify the comparison the equations for all sample plots are given in the same form.

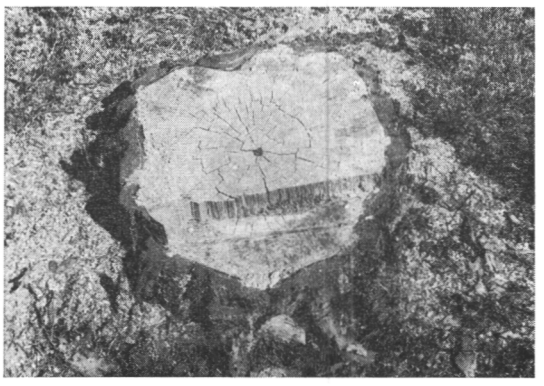


Figure 9. An example of the dry matter content of a stump root system of pine. Stump diameter 30 cm, dry weight 35 kg, bark-on basis. Proportion of bark 14 per cent.

Kuva 9. Esimerkki männyn juurakon kuiva-ainesisällöstä. Kannon kuorellinen läpimitta 30 cm ja juurakon kuivapaino 35 kg, josta 14 % kuorta.

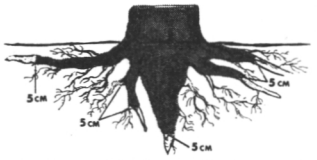


Table 7. Correlation between the dry weight of the stump-root system (y, kg) and stump diameter (x, cm), bark-on basis

Taulukko 7. Juurakon kuorellisen kuivapainon (y, kg) ja kannon kuorellisen läpimitan (x, cm) välinen korrelaatio

Stand *Metsikkö*	Location *Sijainti*	Diameter range, cm *Läpimitan vaihteluväli, cm*	Regression equation *Regressioyhtälö*	R	$s_{x \cdot y}$, kg	Mean weight, kg *Keskipaino, kg*
			Pine — *Mänty*			
1	South — Etelä ...	25—50	$y = 8.3 + 0.031\ x^2$	.7892	12.1	49.3
2	South — Etelä ...	20—40	$y = -11.1 + 0.047\ x^2$	.9410	6.6	33.2
3	South — Etelä ...	15—30	$y = -2.9 + 0.044\ x^2$	.9228	4.3	17.4
4	North — Pohjoinen	20—40	$y = -7.5 + 0.048\ x^2$	.8429	12.4	37.2
5	North — Pohjoinen	20—40	$y = -6.8 + 0.046\ x^2$	.9647	11.8	35.9
Aver.	South[1]) — Etelä[1]).	15—45	$y = -2.0 + 0.039\ x^2$	.9231	8.2	30.1
»	North — Pohjoinen	20—40	$y = -6.7 + 0.047\ x^2$	.9395	12.0	36.5
»	All — Kaikki	15—45	$y = -4.9 + 0.044\ x^2$	.9186	11.3	33.7
			Spruce — *Kuusi*			
6	South — Etelä ...	20—40	$y = -6.3 + 0.054\ x^2$	.9332	11.6	45.6
7	South — Etelä ...	15—30	$y = -4.0 + 0.043\ x^2$	.9125	3.5	14.2
8	South — Etelä ...	20—40	$y = -8.4 + 0.048\ x^2$	.9605	7.4	34.1
9	South — Etelä ...	20—25	$y = -1.8 + 0.109\ x^2$	.9325	16.8	67.7
10	North — Pohjoinen	15—30	$y = -20.0 + 0.083\ x^2$	.8925	13.1	29.0
Aver.	South[1]) — Etelä[1]).	15—40	$y = -7.0 + 0.051\ x^2$	.9480	9.1	34.7
»	North — Pohjoinen	15—30	$y = -18.3 + 0.079\ x^2$	.8862	13.7	26.4
»	All — Kaikki	15—40	$y = -7.1 + 0.060\ x^2$	.8279	19.4	38.1

[1]) Does not include swamp stand No. 9. — *Ei sisällä suokoealaa n:o 9.*

The equations for different sample plots and tree species are very similar. The obvious exceptions are northern spruces and sample plot No. 9, the only swamp stand in the material. A single sample plot does not warrant far-reaching conclusions, but again it substantiates the general view that the stump-root system of peatland conifers contains an exceptional amount of wood.

It is thus possible to estimate the dry weight of the stump-root system from stump diameter (Fig. 10). However, the confidence limits for a single stump-root system are broad, for the situation is influenced also by the soil structure, stoniness and moisture, terrain, stand density, wind conditions, carefulness of logging, and other factors.

The spruce stump-root system contains more wood on an average than that of pine. The differences between south and north Finland are relatively small for pine (Table 8). The spruce stump-root system appears to be greater in the north of the country. The northern data are based, however, on a single sample plot.

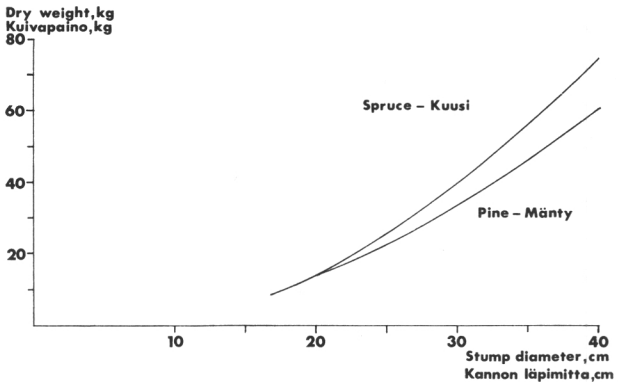


Figure 10. Dry weight of the stump-root system of pine and spruce in mineral soil in South Finland, bark-on basis.
Kuva 10. Männyn ja kuusen juurakon kuorellinen kuivapaino Etelä-Suomessa kivennäismaalla.

The dry weight of the stump-root system in peatland sample plot 9 was over double that in mineral soil. The data must be treated with reserve, but Table 8 evidently gives too small values for peatland trees.

Root wood under 5 cm in thickness was not taken into consideration in the present work as its harvesting does not seem feasible. However, 1—5 cm thick roots would add one-third to the figures reported for pine (M ä l k ö n e n 1972). The significance of thin roots is essentially more important for small-sized trees (I l v e s s a l o 1965).

Profitability calculations require information on the raw material value of the stump-root system. The value is obtained by comparing the dry matter content of a piled cubic metre of pulpwood proper and that of a stump-root system. Pine pulpwood, the principal raw material of sulphate pulp, which has a wood density of 405 kg/solid cu.m. in south and 380 kg/solid cu.m. in north Finland, makes a suitable object of comparison (cf.

Table 8. Dry weight of the stump-root system [1]) as a function of stump diameter on mineral soil, bark-on basis
Taulukko 8. Juurakon [1]) kuorellinen kuivapaino kannon kuorellisen läpimitan funktiona kangasmaalla

Species *Puulaji*	Location *Sijainti*	Stump diameter, cm — Kannon läpimitta, cm					
		20	25	30	35	40	45
Pine	South — Etelä ...	13.7	22.9	34.2	47.5	62.9	80.3
»	North — Pohjoinen	12.1	22.7	35.6	50.8	68.5	..
Spruce	South — Etelä ...	13.4	24.9	38.9	55.4	74.6	..
»	North — Pohjoinen	13.4	27.9	52.4	..	..	..

[1]) Exclusing root wood under 5 cm in diameter — *Ei sisällä alle 5 cm:n paksuista juuripuuta.*

Hakkila 1968). The slightly greater bark percentage of stump-root systems compared with bole is disregarded here.

	Stump diameter, cm					
	20	30	40	20	30	40
	Number of stump-root systems corresponding to					
	Solid cubic metre of pine pulpwood			Piled cubic metre of pine pulpwood		
Pine in south	29.6	11.8	6.4	19.3	7.7	4.2
Pine in north	31.4	10.7	5.6	20.5	7.0	3.7
Spruce in south	28.4	9.8	5.1	18.5	6.4	3.3
Spruce in north	28.4	(7.3)	..	18.5	..	..

332. Dry matter of the stump-root system in percentage of bole wood

In practice, information is often needed on the dry matter content of the stump-root system in per cent of bole wood. These data are especially useful in calculations for large areas and the whole country when it is desired to know the amount of stump and root wood available to a certain industrial plant or to estimate the possibilities of employment for machines and contractors.

The relative amount of stump and root wood varies between stands. However, the variation appears to be small for pine and it cannot be explained by the stump diameter. The average proportion of unbarked stump and root wood was 23.6 per cent in south and 23.0 per cent in north Finland when unbarked bole wood was denoted by 100. It must be remembered that root wood under 5 cm in diameter was disregarded and that the material consists of saw timber-sized trees. When thin roots are included, the percentage of root wood is considerably higher in small trees (Laitakari 1929).

Swamps, however, are an obvious exception. The investigation material included only six swamp pines, in sample plot 9. The proportion of stump and root wood in them was an average of 36.6 per cent.

The variation between sample plots is greater for spruce. The butt swell of spruce boles is quite notable in some sites, and thick lateral roots are associated with pronounced butt swell. The average amount of stump and root wood in spruce was 22.4 per cent in the mineral soils of south Finland, whereas it was significantly greater, 29.7 per cent, in north Finland.

The proportion of stump and root wood of spruce was very great in the southern swamp sample plot, 46.7 per cent. As the result is derived from a single sample plot of 44 trees, no general conclusions can be drawn. Nevertheless, equally high percentages have been recorded in earlier foreign investigations (Ovington 1957, Ovington and Madgwivk 1959, Bray and Gorham 1963, Baskerville 1965, Young,

Table 9. The dry weight of stump and root wood as a percentage of the dry weight of full tree bole, bark-on basis

Taulukko 9. Kuorellisen kanto- ja juuripuun kuivapaino prosentteina kuorellisen runkopuun kuivapainosta

Stand *Metsikkö*	Location *Sijainti*	Bole volume, l *Rungon tilavuus, l*	Stump and root wood, % [1] *Kanto- ja juuripuuta* % [1]		% of variance explained by bole volume *Rungon tilavuuden selittämä vaihtelu,* %
			x	s	
		Pine — *Mänty*			
1	South — Etelä	566	20.7	5.4	6
2	South — Etelä	352	21.2	5.0	14
3	South — Etelä	151	26.1	6.5	5
4	North — Pohjoinen	337	25.8	8.3	11
5	North — Pohjoinen	382	20.0	8.0	14
Average	South [2] — Etelä [2]	322	23.6	7.0	1
»	North — Pohjoinen	359	23.0	8.6	8
»	All — Kaikki	336	23.3	7.6	1
		Spruce — *Kuusi*			
6	South — Etelä	432	23.5	6.7	24
7	South — Etelä	182	19.0	4.8	27
8	South — Etelä	416	19.2	5.3	35
9	South — Etelä	330	46.7	15.6	57
10	North — Pohjoinen	201	31.5	14.2	47
Average	South [2] — Etelä [2]	361	22.4	7.2	33
»	North — Pohjoinen	193	29.7	13.5	47
»	All — Kaikki	317	28.0	13.7	10

[1]) Excludes root wood under 5 cm in diameter. — *Ei sisällä alle 5 cm:n paksuista juuripuuta.*
[2]) Excludes swamp stand No. 9. — *Ei sisällä suokoealaa n:o 9.*

Gammon and Hoar 1963, Young. Strand and Altenberger 1964, Keays 1971). It seems evident that because of their marked butt swell spruces growing in swamps contain an exceptionally large amount of stump wood and particularly root wood.

On the whole, the combined proportion of stump wood and over 5 cm root wood in southern and northern pine and southern spruce growing in mineral soils may be taken as 23 per cent. The figure seems to be higher for northern spruce, 30 per cent. The share of the stump-root system in swamps is even greater.

The proportion of stump and root wood in pine is not greatly dependent on the tree size within a certain stand. For the spruce, in contrast, the share of stump wood and over 5 cm thick roots grows with tree size.

The relative weight of the stump-root system varies greatly by tree species. In general, the percentage stump-root system is between 20 and 30 for northern forests, but is appreciably lower for equatorial forests with the exception of mangrove (Bray and Gorham 1963). The results

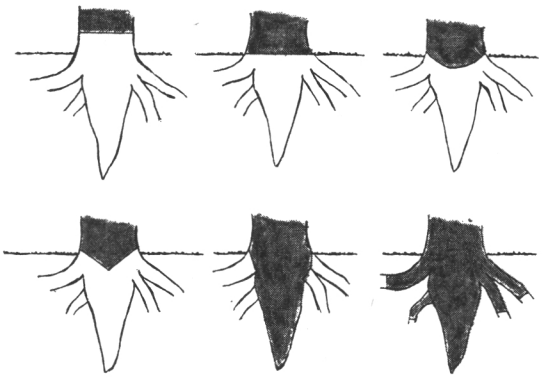


Figure 11. Alternatives for different degrees of stump and root wood harvesting.
Kuva 11. Vaihtoehtoja kanto- ja juuripuun eriasteiseksi talteenotoksi.

obtained in the present study agree closely with earlier results for the same tree species in the same conditions. The measured proportion of the pine stump-root system in e.g. the Soviet Union is 22—23 per cent (Kišenko, Unt, Komšilov, Gerasimov and Abol 1962, Komšilov, Kišenko and Kyalina 1963). Exactly the same result was obtained for *Abies balsamea* in North America (Baskerville 1966). In their comparison of the volumes rather than dry weights of the pine stump-root system, excluding under 5 cm roots, and bole Kamiński (1961) in Poland and Mäkinen (1965) and Mälkönen (1972) in south Finland arrived at 15—22 per cent.

333. Distribution of dry matter in the stump-root system

The solution models for the development of logging methods depend on the proportion of the stump-root system it is intended to harvest. The ultimate aim is utilisation of all wood below ground, but as acceptable intermediate targets, are, say, only the above-ground part of the stump, stump wood in its entirety or stump and root wood down to a certain minimum diameter (Fig. 11). The amount of wood to be obtained in each case must be known for comparison of the alternatives. For this, the distribution of dry matter in the different parts of the stump-root system was measured.

Well over a half of the dry matter of the pine stump-root system in the south is contained in the stump. However, in swamps the proportion of stump wood is only one-third, even in the pine. The tap root is shallow in the north and the proportion of lateral roots greater than in the south.

Table 10. Distribution of the dry matter of the stump-root system into stump proper and roots of different diameter, bark-on basis

Taulukko 10. Juurakon kuorellisen kuiva-aineen jakaantuminen varsinaisen kantopuun ja eri läpimittaisen juuripuun kesken

Stand *Metsikkö*	Location *Sijainti*	Roots — *Juuret* 5—10 cm	10—20 cm	20 + cm	Total [1] *Yht.*[1]	Stump *Kanto*	Grand total *Kaikki yhteensä*
		Proportion, % — *Osuus*, %					
		Pine — *Mänty*					
1	South—Etelä ...	13	19	12	44	56	100
2	South—Etelä ...	15	20	8	43	57	100
3	South—Etelä ...	19	16	3	38	62	100
4	North—Pohjoinen	15	26	14	55	45	100
5	North—Pohjoinen	15	18	14	47	53	100
Average	South[2]—Etelä[2]	15	19	8	42	58	100
»	North—Pohjoinen	15	22	14	51	49	100
»	All—Kaikki ...	15	20	12	47	53	100
		Spruce — *Kuusi*					
6	South—Etelä ...	14	25	27	66	34	100
7	South—Etelä ...	23	33	10	66	34	100
8	South—Etelä ...	15	27	24	66	34	100
9	South—Etelä ...	17	30	27	74	26	100
10	North—Pohjoinen	14	28	25	67	33	100
Average	South[2]—Etelä[2]	15	25	25	65	35	100
»	North—Pohjoinen	15	28	23	66	34	100
»	All—Kaikki ...	16	27	25	68	32	100

[1] Excludes root wood under 5 cm in diameter. — *Ei sisällä alle 5 cm:n paksuista juuripuuta.*
[2] Excludes swamp stand No. 9. — *Ei sisällä suokoealaa n:o 9.*

In the spruce only one-third of the dry matter of the stump-root system is in the stump proper and even less in swamps. In contrast, thick lateral roots contain a particularly large amount of wood.

Table 10 indicates the proportion of stump and root wood that can be recovered with the different harvesting alternatives. Again taking only over 5 cm thick root wood, the following figures are arrived at in an average saw timber stand in south Finland.

Portion harvested	Pine	Spruce
	Percentage of total dry matter in stump-root system utilized	
Stump + roots down to 5 cm	100	100
Stump + roots down to 10 cm	85	85
Stump + roots down to 20 cm	66	60
Stump including taproot	58	35
Above-ground portion of stump	15	15

4. SPECIAL CHARACTERISTICS OF THE HARVESTING OF STUMPS AND ROOTS

Stump and root wood differs from the traditional timber assortments in harvesting technique. New machines and working methods are needed. The harvesting schedule is re-arranged.

1) A salient special feature is small unit size. For instance, pine of 30 cm DBH yields in south Finnish conditions an average of 300 kg of dry bole wood, but only 63 kg of stump and root wood. Modern, highly mechanised logging methods appear to advantage only when large pieces are handled. Mechanised harvesting of stump-root systems therefore tends unavoidably to be expensive. Only the utilisation of the stump-root systems of large trees is within the scope of economic feasibility.

2) Another characteristic feature of harvesting stump and root wood is the small amount of wood obtained per stand. The average yield of bole wood from clear cutting areas by a stand in Finland is 318 solid cu.m. (cf. Savolainen 1967). As the dry matter of stump-root systems is roughly 23 per cent of that of bole wood, the corresponding amount of stump and root wood per stand is only 73 solid cu.m. It is not worth moving heavy equipment to small work sites, so some of the stands must be excluded.

3) The average bole wood yield from clear cutting areas in Finnish conditions is 86 solid cu.m./hectare (Savolainen 1970), and the corresponding quantity of stump and root wood is 20 solid cu.m./hectare. A small amount of wood per unit of area reduces the productivity of both extraction and forest transport work. This alone makes for high logging costs.

4) Great force is required in harvesting stump-root systems. The extraction of a pine stump of 20—35 cm by vertical lifting requires a force of 70 000—80 000 kg (Fiolek 1961). Because of decay of the sap wood of thin roots and the stump, mature stump-root systems can be extracted by vertical lifting with a force of 1 500—15 000 kg (Fiolek 1962). However, the work can be facilitated by leverage, and then a fresh 26—30 cm pine stump can be worked loose with a

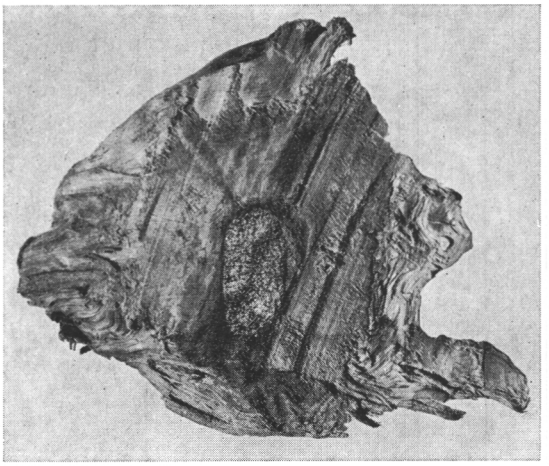


Figure 12. A stone inside stump wood
Kuva 12. Kantopuun sisään kasvanut kivi.

force of 7 000 kg (K i š e n k o, U n t, K o m š i l o v, G e r a s i m o v and A b o l 1962) or 10 000 kg (C z e r e y s k i 1965 a and b). Even then, heavy machines are necessary. When stump-root systems are split several thick roots may have to be split at the same time, again requiring the application of great force. On the other hand, the use of heavy equipment increases the costs when the units handled are small in size.

5) There are always impurities in the stump-root systems. Stones and loose earth are additional weight and they also preclude the use of sharp edges in the splitting machines. Chipping in particular meets with extremely great difficulties. Stones are generally found also inside the stump (Fig. 12). The utilisation of stump and root wood has been largely halted so far just because of the difficulties caused by stones and sand.

6) The extraction work at any rate is restricted to the season of the year when the soil is unfrozen and free from snow. As the heavy equipment thus stands idle for a great part of the year, capital costs per production unit increase. In addition, the advantages of freezing weather and snow are forfeited in terrain where the going is difficult.

7) The solid volume content of whole stump-root systems is so low that their long-distance transport is out of the question. The solid volume content can be raised considerably by splitting the stump-root systems into smaller parts, but even at its best it is only 60 per cent of the solid volume of round coniferous pulpwood. The load space of

the transport equipment can be dimensioned correspondingly, but this again will raise costs. The economic radius around the mill is shortened.

8) The stump and root wood is suitable technically mainly for the sulphate pulp, fibre board and particle board industries. The last two, however, are users of cheap raw material, and therefore stump and root wood will probably go in the future solely to sulphate pulp mills, of which there were 16 in Finland at the beginning of the 1970s. Because of the need at the mill end, too, for special equipment for handling, debarking, cleaning and chipping or crushing, the most practical solution would be to concentrate the use of stump and root wood in a couple of mills only. When utilisation points are far apart, the average transport distances become longer.

All the factors enumerated raise stump and root wood harvesting costs compared with the traditional raw materials. It it therefore not probable that it will ever be a cheap source of raw material for industry. In addition, as the wood quality is slightly poorer than in bole wood stumps and roots must be regarded merely as a necessary additional raw material for industry suffering from a shortage of raw material. In economic terms, it is marginal wood.

The stumpage price of stump and root wood will at most be only a fraction of that of bole wood. Scarifying of the soil alone may be sufficient compensation to the forest owner. No stumpage price could perhaps make up for the higher costs of harvesting. The pulpwood cost structure at the mill in 1971 shows the size of the different cost factors. It should be noted that the share of stumpage price is considerably smaller in north Finland.

Cost factor	Softwood %	Hardwood %
Stumpage	40	20
Logging	34	44
Long-distance transport	20	30
General costs	6	6
Total cost at pulp mill	100	100

The sum of money corresponding to the stumpage of coniferous pulpwood can probably be offset for the most part against the extraordinary harvesting and transport costs of stump and root wood. There might be real possibilities of utilisation in Finland if the harvesting costs including long-distance transport are not more than 50—60 per cent higher than the costs of harvesting bole wood.

5. LOGGING METHODS

51. Extraction from the soil

511. Extraction of complete trees

If the stump-root system is harvested simultaneously with the bole certain advantages are gained. The bole can be used as a lever, which will reduce the force required for extraction. When pine trees were overthrown in Karelian conditions by pulling them down with a winch fixed at a height of 1 ½—3 m, the power requirement decreased to one-fourth of that needed to extract the stump by pushing. It was possible to overthrow a tree of 20 cm DBH with a force of 700 kg and one of 40 cm DBH with a force of 4 800 kg (Kišenko, Unt, Komšilov, Gerasimov and Abol 1962). The average force needed in Polish experiments to overthrow a pine tree of 30—40 DBH was 5 300 kg (Czereyski 1965 a and b).

When the stump-root system is part of the bole some of the stump proper can be used as saw timber instead of utilising it in the pulp industry. It has been shown in Sweden that there is still an average of 20 cm wood below the stump cross section that is suitable for lumber. The value of the extra lumber thus obtained is at least 40 U.S. cents per sawlog with a top diameter of 20 cm and one dollar per sawlog with a top diameter of 30 cm (Wiklund 1970, 1971 a and b).

New alternative solutions will be found also for short-distance transport. Even truck transport of complete trees is technically feasible (cf. Kišenko, Unt, Komšilov, Gerasimov and Abol 1962).

Complete trees in Central ans East Europe are sometimes overthrown by pulling to prepare the area for reforestation and cultivation or other uses. The overthrowing can be performed manually, by hand winch or tractor winch. Manual work calls for the cutting of lateral roots and the digging of ditches around the tree. With a tractor winch the roots are loosened completely from the ground provided that the tree is overthrown onto a support like a sulky, a wooden stand or a short log (Loycke 1962, Czereyski, Galinska and Robel 1965, Anonymous 1968).

However, the productivity of these methods is much too small for economic harvesting of stump and root wood for industrial uses. An essentially smaller labour input is needed for heavier tractors which can overthrow



Figure 13. Pushing over a tree with an Allis Chalmers TL-645 wheel loader.

Kuva 13. Allis Chalmers TL-645 pyörä-kuormaaja työntämässä puuta nurin.



Figure 14. Much loose earth and humus remains in the stump-root system after felling the tree by pushing.

Kuva 14. Työntämällä kaadetun puun juurakkoon jää runsaasti maata ja humusta.

a tree by direct pulling without auxiliary apparatus. The Timberjack skidder and Caterpillar D 4 crawler tractor overthrew a saw timber pine in an average of 170 cmin.[1]) in the experiments conducted by the Finnish Forest Research Institute (K o i v u l e h t o 1969). This corresponds to 250 trees within an 8-hour working day.

Overthrowing by pulling requires a helper to rig and disengage the cable. Cable breaks cause interruptions and additional expense, and are a safety hazard. The productive time in the Caterpillar D 4-test was broken down in the following way:

	cmin./tree	% of total
Cable transfer	62	37
Cable rigging	42	25
Pulling the tree down	37	22
Disengaging the chocker	28	16
Total productive time	169	100

The distribution shows that transfer, rigging and disengaging of the cable takes most of the working time. Pushing must thus be a more effective felling method than pulling. In a Soviet study the bulldozer blade on a

[1]) cmin. = centiminute = one-hundredth of a minute.

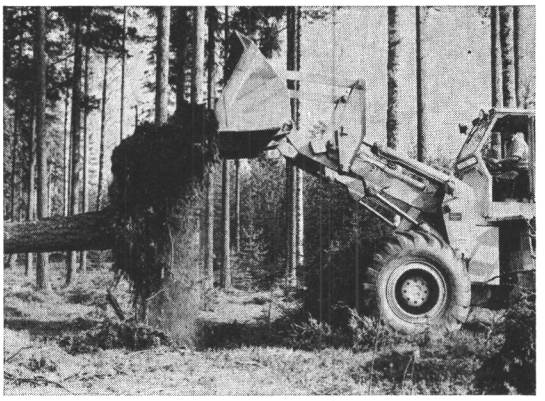


Figure 15. Preliminary cleaning of the stump-root system by shaking the butt of the tree with an Allis Chalmers TL-645 wheel loader.

Kuva 15. Juurakon alustava puhdistus ravistelemalla puun tyveä Allis Chalmers TL-645 pyöräkurmaajalla.

crawler tractor turned out to be far more effective than different methods with cable winch in uprooting complete trees (K i š e n k o, U n t, K o m š i l o v, G e r a s i m o v and A b o l 1962). For pushing, however, heavy machines are absolutely essential.

In the experiments of the Finnish Forest Research Institute, excluding tree-to-tree moving time, pushing the pine down with an Allis Chalmers HDG crawler tractor took 24 cmin. for trees under 35 cm DBH and 31 cmin. for heavier timber (K o i v u l e h t o 1969). The time expended by the Allis Chalmers TL-645 wheel loader on pushing down in another experiment (Fig. 13) was an average of 43 cmin. for a 35 cm pine (A h o n e n 1971).

When the stump-root system comes out with the falling tree, much loose earth and humus remains in the roots (Fig. 14). However, when the pushing is over the working machine can do the preliminary cleaning by raising the butt of the tree, shaking it and letting it fall to the ground from a height of 2—4 m (Fig. 15). This phase of work can be fitted in more easily with pushing than pulling. The total expenditure of time by the Allis Chalmers TL-645 wheel loader was thus as follows:

	cmin./tree	% of total
Felling by pushing	38	29
Final extraction by pushing	16	12
Preliminary cleaning by shaking	26	20
Moving from tree to tree	52	39
Total productive time	132	100

The daily achievement of the method during an 8-hour working day is 300 trees. Pushing is thus clearly superior to pulling. The work output is greater, the procedure includes preliminary cleaning, no helper is necessary and, in addition, the danger and additional costs of using a cable are avoided.

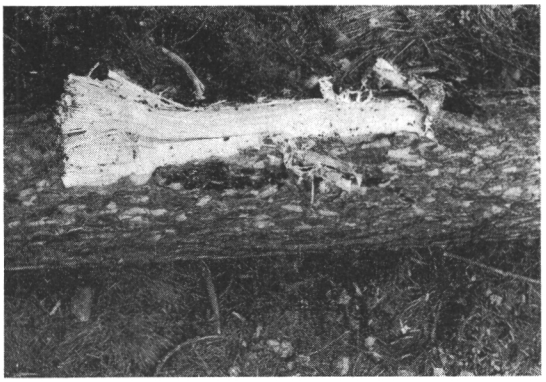


Figure 16. Damage to bole wood caused by the bulldozer blade when pushing the tree over.

Kuva 16. Puskulevyn runkoa nurin työnnettäessä aiheuttama vaurio.



Figure 17. Tree broken in two when pushed over.

Kuva 17. Nurin työnnettäessä kahtia haljennut puu.



Figure 18. The Swedish »Rotryckare» prototype machine lifts the tree complete with roots from the ground (Photo Pentti Nisula).

Kuva 18. Ruotsalainen »Rotryckare»-prototyyppikone nostaa puun maasta juurineen (Kuvannut Pentti Nisula).

A drawback of pushing is the damage it causes to bole wood. With ordinary equipment the bulldozer blade sometimes cuts several centimetres into the tree (Fig. 16). If the wheels or tracks of the pushing machine come to rest partly on the lateral roots of the tree, the tree may break in two (Fig. 17). The value of the stump and root wood will not then offset the loss caused by the damage. Damage can be largely avoided, however, by developing the equipment and applying the correct working technique.

A tree feller-stump extractor called DK-1 »Vepr» has been developed in the Soviet Union for the T-100 GP crawler tractor. It is used to push a tree down at a height of 2—3.5 m, extract the root finally from the soil, do the preliminary cleaning of the stump-root system and skid the tree together with its stump-root system. The average expenditure of time for pine of 48 cm DBH in an experiment was as shown in the table (Z i m a and K u r i l o 1968).

	cmin./tree	% of total
Felling by pushing	17	6
Final extraction by pushing	25	9
Preparing and moving from tree to tree	100	34
Total productive time without skidding	142	49
Skidding	150	51
Grand total	292	100

The Elektro-Diesel Company in Sweden has constructed a »Rotryckare»-prototype machine on a forest tractor chassis. The machine first lifts the tree with roots from the ground (Fig. 18) and then cuts the stump-root system off the bole with a hydraulic chain saw. The grapple mounted on the cab skids 8—10 trees simultaneously. The machine is being developed further.

Harvesting of stump and root wood concomitantly with bole wood offers certain advantages and the principle appears to be promising in the long-term view. However, it is more realistic in the present stage of development to be content with harvesting stump-root systems as a separate work phase, for forest transport and handling of complete trees at the working platform is difficult with the available machines and methods. The bunch size in skidding decreases, the sand and stones hamper the cross-cutting of the butt by chain saw, bole wood suffers damage and the need for working platforms grows. In addition to everything else, the splitting of the stump-root system is unsolved and, as will become clear later, it is splitting rather than extraction that is the true bottleneck in harvesting of stumps and roots in Scandinavian conditions.

512. Extraction of stump-root systems

Stump extraction is carried out everywhere to some extent. Only in a few cases is industrial utilisation of stump and root wood the aim, but mature pine stumps are harvested in Poland, the USSR and the USA as raw material for the chemical industry. Mostly, however, stumps are extracted to clear the soil for field, for building or other purposes, or stump-root systems are removed in order to facilitate mechanical reforestation.

Extraction was previously performed by simple methods in which the human labour input was extremely great. Devices of many kinds were evolved for different conditions and they are described in detail in the literature (Moltesen 1940, Stentzel 1946 and 1958, Czereyski, Galinska and Robel 1965, Anonymous 1968). The utilisation of stump and root wood in pulp production presupposes, however, lower costs and such high productivity of work that mechanised methods only can have a future.

This study is concerned only with mechanised harvesting. Methods based on the farm tractor (Fig. 19) have also been omitted as no significant development has occurred in them since the middle of the 1960s (cf. Czereyski, Galinska and Robel 1965).

Mechanised extraction is possible either by standard machines or equipment of special construction. As it is possible to do the work for only a part of the year at least in northern conditions, continuous employment of special apparatus is difficult. On the other hand, higher productivity and possibly better quality work may tilt the balance in favour of special equip-

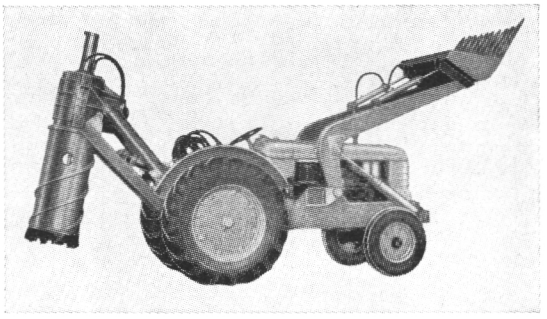


Figure 19. Hydraulic stump excavator of the Ellettari Mechanical Works mounted on a farm tractor. The device is designed for extraction of the stump proper without lateral roots from stone-free soil.

Kuva 19. Ellettarin hydraulinen kannonnostolaite maataloustraktoriin asennettuna. Kone nostaa vain varsinaisen kanto-osan ilman sivujuuria ja edellyttää kivetöntä maaperää.

ment if harvesting of stump and root wood is broadened into a regular form of forest work. For the present, it is chiefly crawler tractors fitted with simple auxiliary equipment of special construction that are used.

5121. Extraction by crawler tractor

The most important mechanised stump-harvesting methods are based on the use of the crawler tractor. This is mostly the case in clearing work and, in the USA, also for harvesting mature stumps.

Stump-root systems are generally extracted intact by crawler tractor, but the power requirements can be reduced by first splitting the stump into two or several parts. Splitting done in this way is usually not enough in itself with green stumps for the achievement of adequate solid volume content and it is necessary later to shear off the lateral roots as a separate work phase.

Splitting can be done prior to extraction by e.g. a knife blade fitted to the rear of the tractor. In Poland the height of the blade is adjusted mechanically by a winch (Figs. 20 and 21). The tractor splits the stump in two by driving over it with the knife lowered. Large stumps are split in four by driving over them lengthwise and crosswise.

A more common method is to substitute a longer splitting blade for one or sometimes two of the teeth of the uprooting device. This modification has been made in e.g. the Soviet D 210 G uprooting equipment. The same principle is commonly used in the southern states of the USA (Anonymous 1964 c) (Fig. 22), while a wedge-shaped stump splitter, mounted like a



Figure 20. A Polish crawler tractor-mounted splitting knife in the raised position.

Kuva 20. Telaketjutraktorin taakse kiinnitetty puolalainen kannonhalkaisuveitsi ylös nostettuna.



Figure 21. A Polish crawler tractor-mounted splitting knife lowered in the working position.

Kuva 21. Telaketjutraktorin taakse kiinnitetty puolalainen kannonhalkaisuveitsi työasennossa alas laskettuna.



Figure 22. A splitting blade (on the right edge of the picture) fitted to the stump extraction device of a crawler tractor in the southern states of the USA.

Kuva 22. Telaketjutraktorin kannonnostolaitteeseen kiinnitetty halkaisuterä (kuvan oikeassa laidassa) Yhdysvaltain etelävaltioissa.

stinger on the rear or the front ripper bar of the tractor has been developed on the west coast (Anonymous 1964 a and b).

When a crawler tractor is used, a whole or split stump root system is generally hoisted with a device consisting of one or several strong teeth mounted on a mechanically or hydraulically controlled framework in the front of the tractor in place of the dozerblade (Figs. 23—26). Smaller stumps



Figure 23. A crawler tractor equipped with a mechanically controlled four-tooth extraction device. Poland.

Kuva 23. Mekaanisesti hallittavalla nelikyntisellä kannonnostolaitteella varustettu telaketjutraktori Puolassa.



Figure 24. A crawler tractor equipped with a mechanically controlled seven-tooth extraction device. Poland.

Kuva 24. Mekaanisesti hallittavalla seitsenkyntisellä kannonnostolaitteella varustettu telaketjutraktori Puolassa.

can be extracted with one push, while for larger stumps several moves may be needed depending on the power of the tractor. Simultaneous pushing and lifting may be used (Czereyski, Galinska and Robel 1965).

The KT-50 crawler tractor with a strong hydraulic, exchangeable tooth in the front has a capacity of 200—250 stumps of 20—40 cm in diameter per day. When extracting thicker stumps the side roots must first be undercut.



Figure 25. A hydraulically controlled one-tooth extraction device in a crawler tractor (Photo Pentti Savilampi).
Kuva 25. Hydraulisesti hallittava yksikyntinen kannonnostolaite telaketjutraktorissa (Kuvannut Pentti Savilampi).

The Luckenwalde uprooting device consists of five strong teeth placed in a frame in the rear of the Soviet S-80 or S-100 tractor. The tractor first runs over the stump, drops the winch-driven uprooting device down and then runs forward. The daily production is 300—400 stumps of 35 cm in diameter (Czereyski, Galinska and Robel 1965) or about 100 stumps of 50 cm in diameter (Lentzner 1964). The Soviet-made S-100 tractor equipped with a mechanical K-1-A (Fig. 27) or hydraulic K-2-A device in the rear can extract stumps of up to 70 cm in diameter. In Hungary, the capacity is higher than that of other corresponding machines (Horvath-Laiko, Kardas and Maurer 1971). In East Germany, S-80 and S-100 tractors equipped with a front device of 2—4 teeth have extracted 300—350 stumps per day (Müller and Laubner 1961). In Finnish experiments, a Caterpillar D6 C tractor with one-tooth uprooting device in front extracted 240—260 stumps per day (Fig. 25). In the south-eastern conditions of the United States a caterpillar D6 C has an uprooting capacity of 300 mature pine stumps per day. Due to the very small number of acceptable stumps per hectare, however, the actual result is 100 stumps only.

Perhaps the most highly specialised stump extraction device for crawler tractors is the Soviet AKP-1 prototype (Fig. 28). It is mounted in place of the hydraulic grapple loader of the TDT-55 crawler tractor. The basic machine can be balanced with the help of hydraulic supporting legs. The turning circle of the loader is 270 deg., radius 2—10 m and extracting capacity



Figure 26. A caterpillar D-5 crawler tractor extracting stumps in Florida.

Kuva 26. Caterpillar D-5 telaketjutraktori kannonnostotyössä Floridassa.

with the longest boom 1 500 kg. The maximum extraction capacity is 27 tons. The extraction device itself consists of a four-finger grapple, a hydraulic cylinder for the grapple, a vibrator and two hydraulic stump-extraction cylinders.

Work begins with the machine lowering its supporting legs and positioning the extraction device above the stump. The fingers of the grapple are pushed

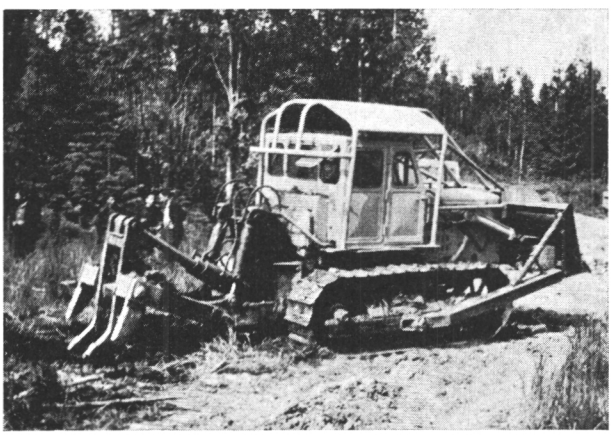


Figure 27. A S-100 crawler tractor equipped with a K-1-A stump extraction device. Soviet Union. (Photo Aaro Karjalainen.)

Kuva 27. S-100 telaketjutraktori varustettuna K-1-A kannonnostolaitteella (Kuvannut Aaro Karjalainen).

under the stump which is vibrated to cut the small roots. The stump is then uprooted by extraction cylinders combined with vibration. Loose soil falls into the hole left by the stump-root system. The stumps are bunched alongside the strip road. The machine is used for harvesting mature pine stumps and has an actual output of 250 stumps in 8 hours (Demin, Vasjukov and Kuznetsova 1968, Vasiljev, Demin and Mankovskij 1970).

This machine offers certain advantages that are lacking in other methods based on the crawler tractor. It enables harvesting of mature stumps also in a young seedling stand, for only approx. 10 per cent of the tree plants are destroyed in the course of extraction and transport (Demin, Vasjukov and Kuznetsova 1970). From 85 to 90 per cent of the loose soil drops off, which is important for transport and splitting. The capacity of the equipment at present, however, is sufficient only for the extraction of mature stumps.

The per-hour costs are high for heavy crawler tractors. Movement from one work site to another is expensive, which sets certain minima for the quantity of wood to be harvested. Unsatisfactory driving vision slows the work with many tractors. Cleaning presents additional difficulties, for the method leaves a great deal of loose soil in the stump-root systems. For these reasons, the use of crawler tractors for extraction is relatively expensive in Finnish conditions. On the other hand, stumping is extremely taxing work for the machines and crawler tractors are more durable in this respect than most other machines.

5122. Extraction by wheel loader

The possibilities of utilising stump and root wood increase if the stump-root systems found in comparatively small work sites can also be recovered. The cost of moving heavy machines restricts, however, the minimum size of the work site and it has therefore been sought in Finland to perform the harvesting work with machines that do not require a separate transporter for movement. Attention has been paid specifically to wheel loaders.

Wheel loaders move faster than crawler tractors within the work site and their average per-hour costs are lower. They are capable of versatile work and can be used not only for extraction but also for preliminary cleaning and bunching of the stump-root systems. Further advantages are good vision and a centre of gravity that enables the machine to be used as a lever in the extraction process.

Wheel loaders require, however, a bearing and relatively even terrain. Their manoeuvrability and strength are inadequate in difficult conditions.

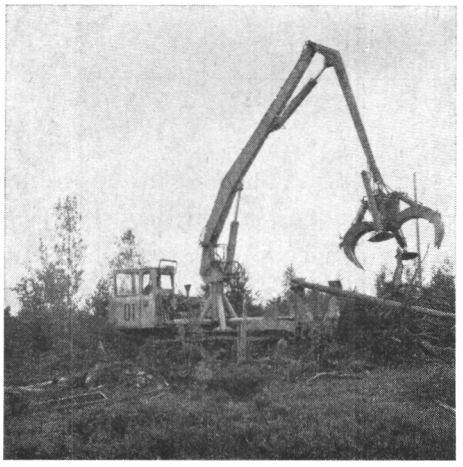


Figure 28. A TDT-55 crawler tractor equipped with an AKP-1 prototype machine for stump extraction. Soviet Union. (Photo Pentti Nisula).

Kuva 28. TDT-55 telaketjutraktori varustettuna AKP-1 kannonnostolaitteen prototyyppikoneella (Kuvannut Pentti Nisula).



Figure 29. The log grapple of a Volvo LM 840 wheel loader cleaning a stump-root system.

Kuva 29. Volvo LM 840 pyöräkuormaajan tukkikoura juurakon puhdistuksessa.

They are not equal to the crawler tractor in durability and for continuous use in stump extraction probably require some structural reinforcement.

Two main wheel loader alternatives have been experimented with in Finland within the framework of the joint Nordic programme for the utilisation of logging residue: the Volvo LM 840 equipped with a log grapple and the heavier Allis Chalmers TL 645 equipped with a stump cup of special construction (cf. A h o n e n and M ä k e l ä 1972). The overall weight of the former is 9.6 tons, motor effect 95 HP/2 400 RPM and the extraction and lifting strength of the log grapple 5.5 tons. The weight of the latter is 12.1 tons, effect 164 HP/2 200 RPM, extracting strength at the tip of the cub 15.5 tons and lifting capacity 10.9 tons.

The working technique of the Volvo LM 840 wheel loader is based on a 0.95 sq.m. log grapple (Fig. 29) with which the machine grips the stump from above and simply lifts it up. The stump-root systems are collected in small piles. As it moves the wheel loader cleans the stump-root system by vibrating the teeth of the log grapple (Fig. 30). The expenditure of time on a 35 cm pine stump is as follows:

	Sandy soil		Stony soil	
	cmin./tree	% of total	cmin./tree	% of total
Slash removal	4	3	4	2
Extraction from soil	45	37	80	45
Simultaneous cleaning and collecting into piles	58	38	54	31
Moving from stump to stump	34	22	39	22
Total productive time	152	100	177	100

The working technique of the Allis Chalmers TL 645 is based on the stump cub (Fig. 31). It has been developed from the standard construction gravel cub by adding two lifting teeth in front of the cub. The space between the teeth is sharpened for the shearing of roots, and gaps have been made on the side and bottom of the cub for cleaning the stump-root system.

Before uprooting, the slash and soil on both sides of the stump are pushed aside. This reduces the amount of loose soil left in the stump-root system and the breaking of lateral roots reduces the power requirement for extraction. Roots can be shorn by the blade between the lifting teeth also from behind the stump. The actual uprooting is done by the teeth of the stump cub, partly by pushing with the machine and partly by lifting with the hydraulic cylinders. Preliminary cleaning is done by shaking the stump-root system hydraulically in the stump cub (Fig. 32). The expenditure of time on a 35 cm pine stump is shown in the following:



Figure 30. A Volvo LM 840 wheel loader in extraction work.

Kuva 30. Volvo 840 pyöräkuormaaja kannonnostotyössä.



Figure 31. An Allis Chalmers TL 645 wheel loader equipped with a stump cub.

Kuva 31. Allis Chalmers TL 645 pyöräkuormaaja kantokauhalla varusteltuna.

	cmin./tree	% of total
Slash and soil removal	1	1
Extraction from soil	39	36
Cleaning by shaking	10	9
Collecting into piles	31	28
Moving from stump to stump	29	26
Total productive time	110	100

The Allis Chalmers TL-645 has a capacity of 400 pine stump-root systems during an 8-hour working day in favourable sandy soil conditions. The corresponding capacity of the smaller Volvo LM 800 wheel loader is 290 stump-root systems. However, the latter is cheaper in cost and therefore competitive especially when the stump-root systems are of small size. Stones slow down the work; for instance, the output of a Volvo LM 840 wheel loader is reduced to 250 stump-root systems in stony terrain.

Extraction devices of special construction can also be designed for wheel loaders. A Finnish hydraulic prototype machine is seen in Fig. 33. The lowest costs are achieved, however, by using the above-mentioned log grapple or a simple stump cub. Thus the use of expensive special apparatuses on wheel loaders does not seem to be justified at present.

5123. Extraction by excavator

Excavators offer certain advantages in stump extraction which make them when properly equipped competitive with the crawler tractor and



Figure 32. An Allis Chalmers TL 645 wheel loader cleaning a stump-root system.
Kuva 32. Allis Chalmers TL 645 pyöräkuormaaja juurakon puhdistuksessa.



Figure 33. A Volvo LM 840 wheel loader equipped with a hydraulically controlled prototype device for stump extraction.
Kuva 33. Volvo LM 840 pyöräkuormaaja varustettuna hydraulisesti hallittavalla kannonnostokone-prototyypillä.

wheel loader. Their movements are generally relatively slow, but their great reach makes them capable of extracting several stumps from one place and simultaneously pre-stacking the stump-root systems. Shearing off the lateral roots and removing the soil from around the stump-root system are simple to perform when necessary, and the excavator can thus extract even large stump-root systems. The machines are constructed for just this kind of work and are obviously more durable than at any rate the wheel loaders for harvesting tougher stumps. The relatively high working pressures of the basic machine make it possible to use hydraulic auxiliary apparatus requiring power, and when equipped with wide swamp tracks excavators can work also in marshy terrain.

The main negative feature is slow movement. Moving from one work site to another usually requires the use of a transporter and the driving speed imposes certain limitations also on the working methods.

A considerably cheaper solution than the excavator proper is a hydraulic tractor digger mounted on a farm tractor. The Finnish Forest Research Institute experimented with a Nuffield farm tractor on which was mounted a Hymas 4 Super digger. The cub of the digger was replaced by a two-toothed stump hook (cf. K o i v u l e h t o 1969). The radius of the excavator is 5.1 m, turning circle 170 deg., digging strength 2.4 tons, pulling strength 3.9 tons and extraction strength 0.7 tons.

The most advantageous uprooting technique with small stumps is pulling from behind the stump. This is not enough for stumps over 20 cm in diameter; some of the lateral roots must be sheared and it is necessary to heave

the stump-root system upwards with a stump hook. The capacity of the digger is totally inadequate for the stubbornest stump-root systems; loose soil must first be removed from around them, which considerably retards the work. For spruce, it is possible to use a technique by which the stump-root system is split in the extraction phase by pulling from the lateral root. Even then the digger power is adequate only for small stump-root systems.

The work performance of the tractor digger depends decisively on the size of the stump-root system. Small stumps 15 cm in diameter are uprooted in 30 cmin., but their recovery is hardly justified economically because of the small wood yield. A 25 cm stump requires an extraction time of 150 and a 35 cm stump 450 cmin. The following figures are for stump-root systems 35 cm in diameter.

	Pine, Easy terrain		Spruce, Difficult terrain	
	cmin./stump	% of total	cmin./stump	% of total
Extraction	459	90	454	81
Moving from stump to stump	50	10	109	19
Total productive time	509	100	563	100

The power of the tractor digger is inadequate for harvesting of stumps over 20 cm. Its 8-hour output for stump-root systems 35 cm in diameter is only 80 stumps, and even then the machine only does the uprooting but not the preliminary cleaning and bunching. It is consequently clear that extraction can be done more effectively by excavators proper than by tractor diggers.

The Finnish studies were conducted with a West German RH-4 excavator (cf. Ahonen 1970 c) equipped with 60 cm tracks. The machine weighs 10.5 tons, the motor effect is 51 HP, turning circle 360 de., turning speed 18 RPM and boom radius 7.95 m. The excavation force in the teeth of the cub is 6.0 tons.

The RH-4 LC equipped with a standard cub first removes the soil from above the lateral roots and then undercuts a part of them. After this the cub is placed behind the stump and the stump-root system is uprooted by pulling the boom towards the machine. Cleaning is done by shaking the stump-root system in the cub. The expenditure of time on uprooting depends largely on the size of the stump-root system, and is as follows for a 35 cm stump in favourable conditions in moraine terrain.

	Pine		Spruce	
	cmin./stump	% of total	cmin./stump	% of total
Extraction	204	68	106	54
Cleaning	46	15	41	21
Collecting into piles	17	6	17	9
Moving from stump to stump	32	11	32	16
Total productive time	299	100	196	100



Figure 34. The Pallari extraction-splitting device prototype mounted on an RH-4 LC excavator.
Kuva 34. RH-4 LC-kaivukoneeseen asennettu kannonnostoon ja pilkkomiseen tarkoitettu Pallarin prototyyppilaite.

In this example the 8-hour work performance is 140 stump-root systems for pine and 210 for spruce. This cannot be regarded as enough in relation to costs and the excavator must be equipped with a supplementary device constructed specifically for uprooting the stump-root system. The extraction-splitting device shown in Fig. 34 is suitable for this and increases the uprooting performance greatly. As the device is designed not only for extraction but also for splitting, it is described in more detail in chapter 522.

52. Splitting of stump-root systems

After extraction from the ground, the next work phase in the harvesting schedule of stump and root wood is splitting, often together with rough cleaning. Sand and stones restrict the choice of equipment and prevent the use of sharp blades. Splitting has therefore proved to be the most difficult harvesting phase to mechanise.

The purpose of splitting may be only splitting the actual stump into pieces of desired size, removing lateral roots from the stump or also cutting them into shorter pieces. The working technique and the output depend decisively on the size and other properties of the stump-root system and on the target set. The following advantages are gained through splitting.

— Improvement of the solid volume content of stump and root wood in order to lower transport costs;
— Cleaning of stump and root wood;
— Easier handling in the transport and mill phase;

— The goods achieve a form in which they can be fed through the chipper infeed without additional procedures at the mill.

As the primary aim of splitting is to lower transport costs, it must be done at the forest end. It is theoretically best to split the stump-root systems before forest haulage, bus as splitting at intermediate storage also has certain advantages it is often practical to move the splitting procedure completely or at least partly to the intermediate storage.

The smaller the size of the wood piece and the more thoroughly it is cleaned, the higher the splitting costs rise. The most economical solution for the industrial enterprise as a whole is affected not only by transport costs but also by the capacity of the equipment at the mill end. A maximum piece size has been recommended in Finland for the research programme as the joint effect of these factors. The recommendation is a maximum diameter of about 30 cm and maximum length of about 60 cm. On the other hand, roots less than 5 cm in thickness should be left in the forest if possible.

Splitting may be performed separately or combined directly with extraction. The former alternative is possibly the simplest to implement technically, but in the long term the most interesting possibilities of mechanisation of the whole harvesting schedule lie in combined extraction and splitting.

521. *Splitting as a separate operation*

The simplest method of splitting stump-root systems is blasting. It can be applied either to stumps still in the ground or extracted stump-root systems. In the former case the aim of blasting is uprooting the stump and root wood in addition to splitting.

Blasting is done most practically by a team of 3—4 workers, with one man drilling the holes and the other doing the actual blasting. The expenditure of time in Finnish experiments was as follows for pine stumps.

	Extracted stump-root systems	Unextracted stump-root systems
	cmin./stump	
Hole driller:		
Hole drilling	..	126
Moving from stump to stump	..	23
Delay time	..	36
Total operating time	152	185
Blaster:		
Fetching of blasting material	16	45
Preparation of fuse	51	44
Insertion of charge into hole	185	130
Ignition of fuse	29	35
Taking cover	34	39
Checking the result	32	15
Moving from stump to stump	39	36
Delay time	78	36
Total operating time	464	380



Figure 35. Blasted stump-root systems.
Kuva 35. Räjäytettyjä juurakoita.

The productivity of blasting work is fairly low, in Finnish experiments 70—80 stump-root systems per man-day of work. Considerably higher achievements have, however, been reported earlier (Czereyski, Galinska and Robel 1965).

Blasting material costs are high. The most suitable charge for the extraction and splitting of a medium-sized stump-root system is 200—300 g of ammonium nitrate, trotyl and aluminium. The work is dangerous and only specially trained personnel are permitted to transport, store and use the explosives. The wood loss is also relatively great. Furthermore, blasting alone is not enough and the splitting must be finished by some other means (Fig. 35).

It is therefore obvious that the feasibility of the blasting method in the large-scale harvesting of stump and root wood is poor in the long term. This is true especially of splitting as a separate operation in which the expenditure of time is at least as great as in combined extraction and splitting.

The further treatment of pieces split by blasting can be done by a splitting device of guillotine type manufactured by Lypsyniemen Konepaja engineering works (Fig. 36) in which the power source is a farm tractor. The handling of the pieces is heavy and dangerous work, however. A 3-man team handles 20—60 piled cu.m. of blasted pieces of stump in an 8-hour work day (Sarapää 1970, Saarinen 1970), which cannot be regarded as satisfactory.

A power saw can also be used for splitting, but the difficulty is that sand and stones soon blunt the chain. The useful life of the chain is only some dozens of hours. It has therefore been endeavoured in Finnish experiments to devise a special chain with cutting parts of hard metal. This lengthened the intervals between sharpening, but did not prolong the useful life of the chain as sand continued to wear the other parts fast (Takalo 1972).

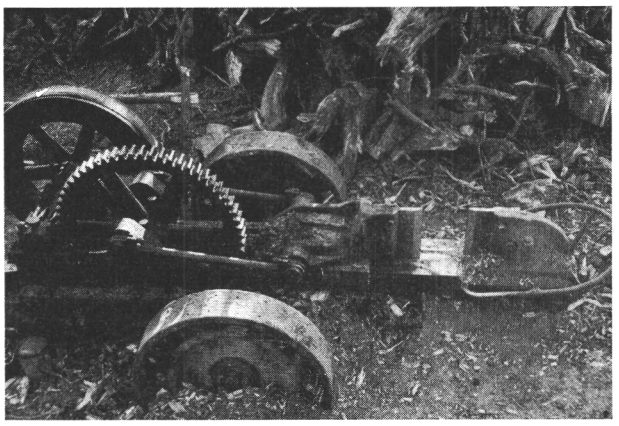


Figure 36. The tractor-driven Lypsyniemi guillotine for stump splitting (Photo Pentti Savilampi).
Kuva 36. Lypsyniemen traktorikäyttöinen giljotiinityyppinen kannonpilkkomislaite (Kuvannut Pentti Savilampi).

An advantage of splitting by power saw is that the costs do not greatly depend on the amount of wood involved. The method is consequently suitable mainly for small work sites. When a power saw is used the stump-root system can be split in the most feasible way for the benefit of the solid volume content of the load and thus a saving in transport costs arises.

The work output is small, however. The time expended on the further splitting of blasted pieces of spruce stump in Finnish experiments was 21 min./piled cu.m. Splitting whole stump-root systems by cutting off the lateral roots and splitting them into lengths of desired size, but leaving the stump proper intact required inclusive of cleaning 132 min./piled cu.m. The low output, high chain expenditure and the dangerousness of the work will in a long run exclude powersaw splitting of green stump-root systems. However, the work achievement is essentially higher when the lateral roots of mature stumps are removed — 13.4 piled cu.m. during an 8-hour working day has been reported in the Soviet Union (Vasiljev, Demin and Mankovskij 1970).

An LO-21 prototype machine mounted on a 1-axle trailer of the Belarus wheel tractor has been constructed in the Soviet Union for the splitting of mature stumps. The body of the device consists of the fixed shear blades of the outermost end of the steel frame and an anvil that moves against them. A conical ring blade which widens outwards and eight radial straight blades serve as shearing blades (Fig. 37). The pushing power of the hydraulic cylinder of the anvil is 27 tons.



Figure 37. The Soviet LO-21 hydraulic splitter prototype for mature stumps seen at the back (Photo Pentti Nisula).
Kuva 37. Tervaskannoille tarkoitettu venäläinen LO-21 hydraulinen halkaisulaiteprototyyppi takaa nähtynä (Kuvannut Pentti Nisula).

The machine splits only the stump proper after the roots have been removed by power saw. The stumps are placed singly into the splitting device by a Djatel-1 grapple loader for splitting along the grain (Fig. 38). The LO-21 prototype is suitable only for mature stumps from which the lateral roots have been removed. It is capable of treating 250 such stumps during an 8-hour work shift (S a l m i n e n 1971).

In Finland, a hydraulic cutter has been mounted in place of the cub of the RH-4 LC excavator (Fig. 39). It can be used to split the stump-root system in the desired way. In the first experiment at an intermediate storage, when the stump was split into four and the roots left intact, an output of 220 stump-root systems was achieved during an 8-hour working day with 35 cm pine stumps. When the roots were also cut off in accordance with the mill-end requirements, the output was 110—120 stump-root systems. However, as the apparatus was developed further a solution was arrived at in which uprooting and splitting were combined. The outcome was the Pallari Stumparvester which is described in the next chapter.



Figure 38. A mature pine stump being placed between the blade and anvil of an LO-21 splitter prototype (Photo Pentti Nisula).

Kuva 38. Tervaskantoa asetetaan LO-21 halkaisulaiteprototyypin terän ja vastaterän väliin (Kuvannut Pentti Nisula).

522. Combined extraction and splitting

When the harvesting schedule requires the use of several successive machines the work becomes difficult to organise. The cost of moving the machines from one work site to another is higher the greater the number of machines needed. The units often differ in capacity and the weakest link in the chain decides the output of the other links. The breakdown of one



Figure 39. An RH-4 LC excavator equipped with a hydraulic shear blade for stump splitting.

Kuva 39. RH-4 LC-kaivukone varustettuna hydraulisella kantoleikkurilla.

machine may halt the other machines too. Hence, there are certain benefits in having the same machine perform several work phases.

Extraction and splitting have been combined traditionally in the blasting method which was discussed in brief in Chapter 521. As the method has been described in other contexts (e.g. Zcereyski, Galinska and Robel 1965) and as this work is confined to the mechanised harvesting of stump and root wood, blasting will not be considered in the following.

A stump and root wood harvester, the Pallari Stumparvestor (Fig. 40), which is built onto the chassis of an RH-4 LC excavator, is under development in Finland. The basic machine is equipped with tracks, 60 cm in width for work on mineral soil and 95 cm for swampy terrain with poor bearing capacity. The turning circle of the boom is 360 deg., as the working technique requires.

The excavator cub is replaced in the Pallari Stumparvester by a hydraulically controlled extraction-splitting device. Uprooting is by pulling from behind the stump with one tooth or two teeth of the lower edge of the device. Depending on the technique, the stump-root system can be uprooted complete or it can be split into two already in this phase. Splitting proper is done by the hydraulic splitter of the same apparatus. Its principal components are a curved shear blade and two anvils placed 5 cm apart. The diameter of the biggest aperture of the shearing space is 65 cm.

There is a loading space of 4,6 cu.m. at the rear of the Stumparvester. Its walls are of 25 mm plate and the bottom is of 15 mm steel bar to improve the shedding of loose soil. The lower edge of the rear box rises in unloading to a height of 1.8 m so that the load can be dropped directly into a tractor.

The splitting of the stump-root system and collecting the wood into the rear box are done simultaneously. In the last phase splitting takes place above the rear box so that the particles fall direct into the load space. Preliminary cleaning is done in conjunction with splitting. Splitting may be done above the rear box when required so that only every other particel falls into the load while the other one falls to the ground. The particle size can be varied as desired, but productivity of work decreases when the particle size diminishes.

Thanks to its great radius the Stumparvester is capable in good conditions of harvesting several stump-root systems from the same position. Depending on the size, one load comprises 2—15 split Scots pine or Norway spruce stump-root systems. The load is tipped onto the ground or into a tractor trailer. The Stumparvester can haul timber directly to alongside the long-distance transport route in favourable conditions.

The Pallari Stumparvester proved to be highly reliable in operation in the first experiments of 1972 and the quality of the goods prepared meet the mill-end requirements. Equipped with the right tracks it can operate



Figure 40. The Pallari Stumparvester.
Kuva 40. Pallarin kantoharvesteri.

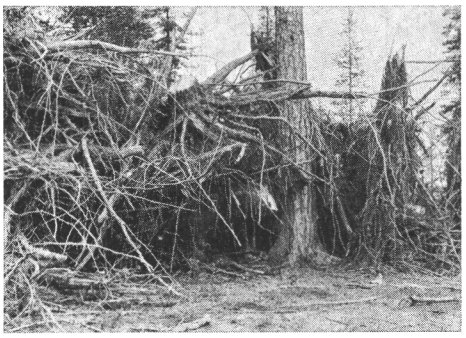


Figure 41. Stump-root systems of Scots pine in North Finland. Solid volume content 0.1.
Kuva 41. Männyn juurakoita Pohjois-Suomessa. Pinotiheys 0.1.

on either mineral soil or swampy ground. The shear blade is not particularly sensitive to stones and it can be sharpened easily with a power saw-mounted grinding device. A detailed description of the Pallari Stumparvester will be published at the beginning of 1973 by the Finnish Forest Research Institute. At the time of writing, preliminary information for spruce of wet peatland soil must suffice.

	cmin./solid cu.m.	% of total
Extraction	216	8
Splitting, cleaning and loading	1 972	76
Moving from stump to stump	134	5
Moving to unloading site	155	6
Unloading proper	135	5
Total productive time	2 612	100
Interruptions	261	10
Total operating time	2 873	110

When the Pallari Stumparvester performs the uprooting, cleaning, splitting and dragging of the timber over a short distance to alongside the road, its output is about 2 solid cu.m. per hour, that is, 16 cu.m. in an 8-hour working shift. Most of the time is expended on simultaneous splitting, cleaning and loading.

The Pallari Stumparvester has advantages in the harvesting of stump and root wood which will make it competitive with other methods in the future. The auxiliary equipment of the basic machine is relatively cheap and quick to install. It is of simple construction and reliable in operation. The basic machine can move over poorly bearing terrain. The whole harvesting schedule requires only 1 or 2 men, depending on the haulage distance;



Figure 42. Stump and root wood of Norway spruce in South Finland. Splitting by blasting, solid volume content less than 0.2.

Kuva 42. Räjäyttämällä paloiteltua kuusen kanto- ja juuripuuta Etelä-Suomessa. Pinotiheys alle 0.2.



Figure 43. Stump and root wood of Scots pine in North Finland. Splitting and cleaning by blasting and chain saw. Solid volume content 0.4.

Kuva 43. Männyn kanto- ja juuripuuta Pohjois-Suomessa. Paloittelu ja puhdistaminen räjäyttämällä ja moottorisahalla. Pinotiheys 0.4.

the latter alternative presupposes haulage alongside the road by a separate vehicle. However, owing to many unfavourable specific characteristics of stump and root wood, harvesting costs are relatively high with this method as well.

523. Solid volume content of stump and root wood

The solid volume content of complete stump-root systems is very low (Fig. 41), according to Finnish studies only 0.1. The most important aim of splitting at the forest end is improvement of the solid volume content to lower the cost of transport.

The solid volume content of split stump and root wood is influenced by the stump-root system size and properties, the splitting method, particle size distribution, carefulness of cleaning, quantity of thin roots, etc. Some examples are presented in the following (cf. Hakkila 1969, Mäkelä 1972).

Species	Timber assortment	Splitting method	Solid volume content of truck load
Pine	Stump proper	Chain saw	0.39
Pine	Roots	Chain saw	0.30
Pine	Stump and roots	Blasting + chain saw	0.51 [1]
Pine	Stump and roots	Blasting + guillotine	0.32
Pine	Stump and roots	Pallari Stumparvester	0.28
Pine	Stump and roots	Pallari Stumparvester + chain saw	0.32
Pine	Stump and roots	Pallari Stumparvester + chain saw	0.35 [1]
Spruce	Stump and roots	Blasting + chain saw	0.40

[1]) During the loading of the truck the wood pieces were packed tightly by hand.



Figure 44. Stump and root wood of Norway spruce in South Finland. Extraction and splitting by the Pallari Stumparvester. Solid volume content less than 0.3.

Kuva 44. Kuusen kanto- ja juuripuuta Etelä-Suomessa. Irroittaminen ja paloittelu Pallarin kantoharvesterilla. Pinotiheys alle 0.3.



Figure 45. Stump and root wood after drum barking at the mill.

Kuva 45. Kanto- ja juuripuuta tehtaalla suoritetun rumpukuorinnan jälkeen.

Splitting increases the solid volume content 3—4-fold (Figs. 42—45). However, it does not rise on average to as high a level as that of sawmill chips which in Finland is before haulage 0.37—0.38 and after haulage, depending on the transport distance and season 0.39—0.40 (Uusvaara 1972). Nevertheless, experience gained in the transport of chips may be used as a guide for dimensioning the haulage equipment.

53. Forest transportation of stump and root wood

The solid volume content of stump and root wood is always low, whatever splitting method is used, compared with the conventional raw material of the pulp industry. Moreover, as the uncertain form of the particles hampers mechanised loading, haulage costs rise and represent a considerable proportion of the mill price of the timber.

Standard equipment with certain modifications can be used for the transportation. Owing to the low solid volume content it is advantageous both over short and long hauls to furnish the vehicle with a relatively great load space and the grapple of the loader must be re-shaped for stump and root wood. Otherwise machines designed for round wood may be used.

The forest transport achievement increases and costs decrease when the green stump-root systems are split before transportation. This is apparent from the following numerical series for a Tree Farmer forest tractor equipped with a grapple loader and an 18 cu.m. trailer, haulage distance of 400—500 m in good topographical conditions (cf. Mäkelä 1972).

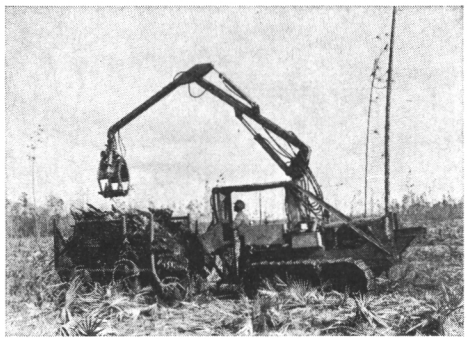


Figure 46. Forest transportation of mature long-leaf pine stumps in the southern United States.

Kuva 46. Pitkäneulasmännyn tervaskantojen metsäkuljetusta Yhdysvaltain eteläosissa.

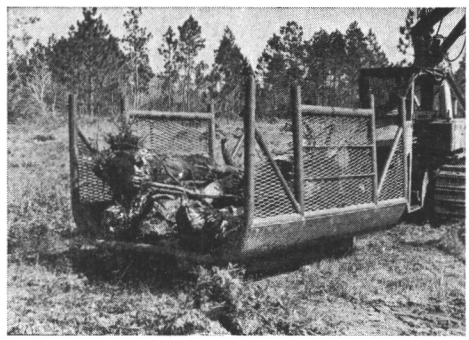


Figure 47. A 12 cu.m. pallet pulled on runners for short- and long-distance haulage of mature long-leaf pine stumps in the southern United States.

Kuva 47. Jalaksilla vedettävä, pitkäneulasmännyn tervaskantojen lähi- ja kaukokuljetukseen tarkoitettu 12 m³:n vaihtolava Yhdysvaltain eteläosissa.

	Complete stump-root systems			Split stump and root wood		
	cmin./load	cmin./solid cu.m.	% of total	cmin./load	cmin./solid cu.m.	% of total
Driving unloaded	588	346	19	588	131	14
Loading	968	570	30	1 673	372	39
Collecting driving	280	165	9	280	62	7
Hauling loaded	708	417	22	708	157	17
Unloading	647	380	20	994	221	23
Total productive time	3 191	1 878	100	4 243	933	100
Interruptions (10 %) ...	319	188	10	424	93	10
Total operating time	3 510	2 066	110	4 667	1 026	110

For transportation alone it is thus worth while splitting in the forest. This is particularly true for long forest hauls. However, a solution in which splitting is centralised alongside the road may be better in many cases for the overall harvesting schedule. For instance, mature pine stumps are forest hauled unsplit in the United States (Figs. 46—47). The stump-root system of long-leaf pine is almost free of lateral roots and no splitting is necessary. In the Soviet Union, the majority of mature pine stumps are extracted by blasting, but mechanically extracted stump-root systems are also transported complete from the forest to the central landing where they are split (Figs. 48—49).

The Pallari Stumparvester can also be used to transport stump and root wood (Fig. 50). The rear box with a volume of 4.6 cu.m. in practice accommodates not more than one solid cu.m. of split wood. As the maximum

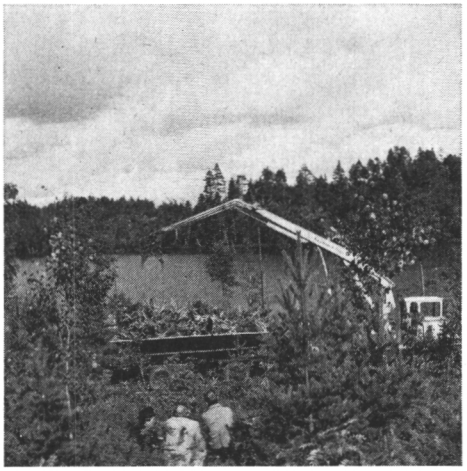


Figure 48. A 2-axle stump trailer connected to a Russian AKP-1 stump extractor (Photo Pentti Nisula).

Kuva 48. Venäläiseen AKP-1 kannonnostokoneeseen liitetty kaksiakselinen kantoperävaunu (Kuvannut Pentti Nisula).



Figure 49. The grapple loader of an AKP-1 stump extractor. (Photo Pentti Nisula).

Kuva 49. AKP-1 kannonnostokoneen kuormaajan koura. (Kuvannut Pentti Nisula).

travelling speed of the machine is only 2.2 km/hour, the transport distance is very short in practice, at the most 100 m. In spite of this it is possible to collect stump and root wood in such large piles that further transport by truck is feasible when the terrain permits it. When short-distance transport is continued by tractor the rear box of the Stumparvester can be emptied directly onto the tractor trailer (Fig. 51).

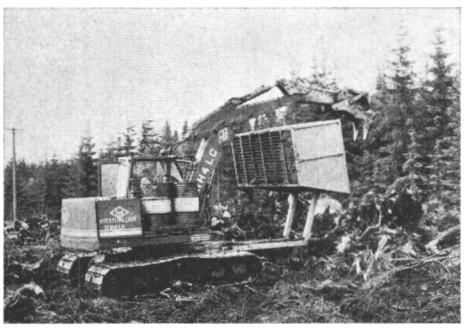


Figure 50. The Pallari Stumparvester unloading on the roadside.

Kuva 50. Pallarin kantoharvesteri purkamassa kuormaa tien varteen.

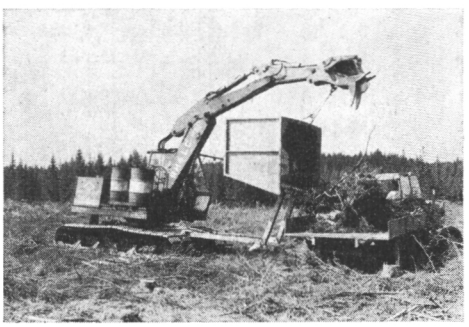


Figure 51. The Pallari Stumparvester unloading onto a farm tractor.

Kuva 51. Pallarin kantoharvesteri purkamassa kuormaansa maataloustraktoriin.

54. Harvesting schedule alternatives

Complete-tree logging offers interesting prospects for harvesting stump and root wood in the long term. However, it seems to be more realistic both technically and economically for the next few years to develop methods in which stumps and roots are harvested separately from bole wood. Only mechanised methods will be feasible in the future.

Several serviceable methods are available for the uprooting of stump-root systems and the differences from traditional timber are relatively small as regards transportation. Splitting to a transportable form has in fact become the real bottleneck of harvesting. The splitting of green stump-root systems is a difficult technical problem and it is in this phase that a considerable proportion of the harvesting costs arise. The placing of the splitting operation in the harvesting schedule is therefore very important.

The best solution as regards organisation is a harvester which itself performs all the work phases up to the intermediate storage. As the stump and root wood lots are often fairly small, a heavy and expensive machine is excluded. The only machine that meets these requirements so far is the Pallari Stumparvester. In favourable topographical conditions it collects the split stump and root wood within the reach of the truck. However, forest transportation must be continued in most cases by tractor which is loaded either by tipping direct from the Stumparvester or by the tractor's own grapple.

The harvesting schedule is more complicated when each work phase is performed by a different machine. Coordinating the capacity of the machines and the time table may present problems, and the productivity of human labour cannot rise as high as with harvesters.

Uprooting from the soil is done most effectively by crawler tractor or wheel loader. The latter may do the preliminary cleaning as well, but is suitable for use only on good terrain. Both machines are also capable of bunching stump-root systems to a limited extent.

Uprooted stump-root systems may be split before or after forest transportation. If the distance is not very short it is better for transportation costs alone to split the stump-root systems before transportation. The equipment constructed for splitting proper is all of the type for use at intermediate storage, however. Consequently, only the power saw comes into question if the splitting is done in the forest. This splitting method is, again, labour intensive and will be more and more uneconomic in the future. Splitting done separately from uprooting must therefore be centralised as far as possible at the intermediate storage.

Heavier machines which need not necessarily be highly manoeuvrable across country can be used for centralised splitting. Mention may be made

of the Russian LO-21, though it is suitable only for mature stumps and presupposes in addition shearing of the lateral roots by power saw. Even heavier equipment is necessary for green stump-root systems, but none is available at present. An exception is the Pallari Stumparvester which is suitable for use at intermediate storages as well. A shear device working on the same principle can be installed in other basic machines provided that the turning circle of the boom is sufficient to permit flexible operation.

6. SUMMARY

The study forms part of the joint Nordic project of NSR (Nordiska Skogsarbetsstudiernas Råd) the aim of which is to promote the utilisation of logging residues as industrial raw material. The present work on stump and root wood harvesting is based partly on earlier studies and partly on the material collected for the project. Other sections of the project deal with the quantity, technical properties and industrial processing of stumps, roots and branches and the by-effects of their harvesting from the forest.

The studies were conducted in cooperation with a project group appointed by the Central Association of Finnish Woodworking Industries. The materials were collected from the industry's experimental work sites, mostly in 1969—1971. Preliminary results of experiments performed in 1972 with the Pallari Stumparvester were obtained to supplement the work.

If additional raw material is to be obtained for industry from stumps and roots, the mill price of the wood cannot be permitted to rise appreciably above that of bolewood. Labour-intensive methods therefore have no future and the aim of development work must be mechanised harvesting.

The first task is to chart the harvesting-technical properties of stump-root systems. For this purpose, a total of 497 Scots pine and Norway spruce stump-root systems were collected from 10 stands. The stump-root systems were cleaned carefully and the following properties were measured: stump height above ground, depth and horizontal diameter of the stump-root system, weight fresh and oven-dry and the distributions of dry matter between the actual stump and root wood of different diameter (Figs. 1—7). The correlation of stump diameter with breast height diameter and bole volume was calculated from a separate material (Tables 2 and 3). The most important results are given as a function of stump diameter in Chapter 3 (Figs. 8—12 and Tables 4—10).

The exceptional properties of the stump-root systems characterise the harvesting process. Typical features are the small size of the units handled, small amount of wood obtained per acre and stand, great force required for extraction and splitting, difficulties caused by stones and other impurities, restriction of extraction to the season when the soil is unfrozen and snow-free, low solid volume content of the load and finally, few utilisation points and correspondingly long transport distances. All these factors raise harvest-

ing costs compared with traditional raw materials. However, the stumpage price, if any, will at most be only a fraction of that of bole wood. The difference could perhaps make up for the higher costs of harvesting and allow the utilisation of fresh stump and root wood as marginal raw material for the pulp and paper industry.

Serious attention should be paid in the long-term view to complete-tree logging in which the stump-root system is harvested simultaneously with bole wood. Uprooting work is simple to perform, but the most difficult problem of the process, that is splitting, still awaits solution (Figs. 13—18). It seems to be more realistic for the present to try to harvest the bole and the stump-root systems separately.

Stump-root systems can be uprooted, in addition to the traditional blasting method, also by wheel and crawler tractor, wheel loader and excavator. Many countries use the crawler tractor most. The additional equipment needed can be mounted at the front or rear of the basic machine. Finnish experiments have shown that wheel loaders are competitive for uprooting work in good topographical conditions, especially as they can also perform some degree of cleaning and bunching in conjunction with uprooting (Figs. 19—33).

Long-distance transport of stump and root wood requires splitting the stump-root system at the forest end. In fact, only mature stumps of American long-leaf pine are brought unsplit to the mill. Splitting is still most commonly done by blasting or power saw, but these methods have no future for cost reasons. An endeavour must therefore be made to develop a hydraulic or mechanical splitting device for use at the intermediate storage. An adequate performance and economicalness are required of the machine and it must also meet quality demands at the mill-end (Figs. 34—39).

It is beneficial for the organisation of the work, moving costs and minimising of the human labour input if the uprooting and splitting processes can be combined. The only machine that has achieved this is the Finnish Pallari Stumparvester (Fig. 40) which is based on the West-German RH-4 LC excavator and performs uprooting, rough cleaning, splitting to the desired particle size and short-distance haulage. Fitted with swamp tracks it is capable of operating also on soft soil. The output of the machine is 2 solid cu.m./hour. The driver is the only crew needed.

Whatever the splitting method used, the solid volume content of stump and root wood is always low compared with conventional pulp wood (Figs. 41—45). The solid volume content of complete stump-root systems is only 0.1, of split wood 0.2—0.4. The power saw gives the best result. The quality of the work tends to decline as the degree of mechanisation increases.

Forest transportation costs are lower if the splitting is done before haulage. However, it is generally more practical for the harvesting schedule

as a whole to centralise splitting at the intermediate storage if it is not combined with uprooting.

The use of normal forest haulage equipment for transporting stump and root wood presupposes in general enlargement of the load space and reshaping of the grapple. With the Pallari Stumparvester it is possible in some cases to collect stump and root wood without separate tractor haulage and place it within reach of a truck (Figs. 46—51).

The harvesting schedule of stump and root wood is simplest when harvester-type machines are employed. In methods in which uprooting and splitting are performed separately the absence of a splitting device at the intermediate storage constitutes a weak link in the chain. The future machine development programme must concentrate on the mechanisation of this phase of work and on the further development of stump harvesters.

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KANTO- JA JUURIPUUN KONEELLINEN KORJUU

Lyhennelmä

Tutkimus kuuluu NSR:n (Nordiska Skogsarbetsstudiernas Råd) alaiseen yhteispohjoismaiseen projektiin, jonka tavoitteena on edistää hakkuutähteitten käyttömahdollisuuksia teollisuuden raaka-aineena. Käsillä olevassa työssä keskitytään kanto- ja juuripuun korjuumenetelmiin osaksi aikaisempien tutkimuksien ja osaksi projektin puitteissa kerätyn oman aineiston perusteella. Muissa osatehtävissä selvitellään kantojen, juurien ja oksien määrää, teknisiä ominaisuuksia, teollista käyttöä ja talteenottoon liittyviä seurannaisvaikutuksia.

Kun tavoitteena on saada kannoista ja juurista teollisuudelle lisäraaka-ainetta, ei puun hinnan voida sallia kohota ainakaan huomattavasti runkopuun tehdashinnan yläpuolelle. Tästä syystä käsityövaltaisilla menetelmillä ei ole tulevaisuutta. Kehitystyössä onkin tähdätty koneellistettuun korjuuseen.

Tutkimukset on tehty yhteistyössä Suomen Puujalostusteollisuuden Keskusliiton asettaman metsäpään kantotoimikunnan kanssa. Aineistot on kerätty teollisuuden koetyömailta pääasiassa vuosina 1969—1971. Lisäksi on mukaan saatu ennakkotuloksia Pallarin kantoharvesterilla vuonna 1972 tehdyistä kokeista.

Ensimmäisenä tehtävänä on ollut juurakoitten korjuuteknisten ominaisuuksien kartoittaminen. Tätä varten kerättiin 10 koealalta yhteensä 497 männyn ja kuusen juurakkoa. Juurakot puhdistettiin huolellisesti ja niistä mitattiin seuraavat ominaisuudet: kannon maanpäällisen osan korkeus, juurakon syvyys ja vaakasuora läpimitta, paino tuoreena ja uunikuivana sekä kuiva-aineen jakaantuminen varsinaisen kannon ja paksuudeltaan erikokoisen juuripuun kesken (kuva 1—7). Erillisellä aineistolla selvitettiin lisäksi kannon läpimitan korrelaatio rinnankorkeusläpimitan ja rungon tilavuuden kanssa (taulukot 2 ja 3). Tärkeimmät tulokset on esitetty kannon läpimitan funktiona luvussa 3 (kuvat 8—12 ja taulukot 4—10).

Juurakoitten poikkeukselliset ominaisuudet luovat leimansa korjuuprosessiin. Tyypillisiä piirteitä ovat käsiteltävien yksiköitten pieni koko, hehtaaria ja leimikkoa kohti kertyvän puumäärän vähäisyys, irrottamisessa ja pilkkomisessa tarvittavat suuret voimat, kivien ja muitten epäpuhtauksien aiheuttamat vaikeudet, irrottamistyön rajoittuminen lumettomaan vuodenaikaan, kuorman alhainen pinotiheys sekä lisäksi käyttöpisteitten vähäisyys ja sen seurauksena pitkät kaukokuljetusmatkat. Kaikki nämä tekijät kohottavat korjuukustannuksia periinteellisiin raaka-ainelähteisiin verrattuina. Toisaalta kuitenkin kantohinta tullee parhaimmillaankin olemaan vain murto-osa runkopuun hinnasta, ja tästä aiheutuva ero saattaisi ehkä kompensoida kanto- ja juuripuun korkeammat korjuukustannukset ja mahdollistaa sen käytön massa- ja paperiteollisuuden marginaaliraaka-aineena.

Pitkällä tähtäyksellä on syytä kiinnittää vakavaa huomiota korjuumenetelmiin, joissa juurakko korjataan samanaikaisesti runkopuun kanssa. Irrottamistyö voidaan näin suorittaa yksinkertaisesti, mutta vaikein ongelma, paloittelu, jää silloinkin edel-

leen ratkaisematta. Toistaiseksi näyttää olevan realistisempaa pyrkiä korjaamaan runko ja juurakot toisistaan erillään (kuvat 13—18).

Juurakoitten irrottaminen voidaan suorittaa räjäyttämisen ohella pyörä- tai telaketjutraktorilla, pyöräkuormaajalla tai kaivinkoneella. Eniten käytetään eri maissa telaketjutraktoria, jonka lisälaitteet voidaan kiinnittää peruskoneen eteen tai taakse. Suomelaiset kokeet ovat puolestaan osoittaneet, että pyöräkuormaajat ovat hyvissä maasto-oloissa irrottamistyössä muitten koneitten kanssa kilpailukykyisiä, varsinkin kun niillä voidaan suorittaa jossain määrin myös puhdistamista ja kasausta (kuvat 19—33).

Kanto- ja juuripuun kaukokuljetus edellyttää juurakoitten paloittelua metsäpäässä. Ainoastaan amerikkalaisen pitkäneulasmännyn tervaskantoja tuodaan tehtaalle paloittelemattomina. Yleisimmin paloittelu tapahtuu esimerkiksi Neuvostoliitossa edelleen räjäyttämällä tai moottorisahalla, mutta kustannussyistä eivät ihmistyövaltaiset menetelmät voi säilyttää kilpailukykyään. Siksi on pyrittävä kehittämään välivarastolla toimiva hydraulinen tai mekaaninen paloittelulaite. Koneelta edellytetään riittävää tuotosta ja taloudellisuutta, ja sen on myös laadullisesti täytettävä tehdaspään vaatimukset (kuvat 34—39).

Työn organisoinnin, siirtokustannusten ja ihmistyöpanoksen minimoinnin kannalta on eduksi, jos irrottamis- ja paloittelutyö voidaan yhdistää. Ainoa tähän tavoitteeseen päässyt kone on RH-4 LC kaivukoneeseen pohjautuva Pallarin kantoharvesteri (kuva 40), joka suorittaa irrottamisen, karkean puhdistamisen, pilkkomisen haluttuun palakokoon ja kuljetuksen lyhyellä matkalla. Suoteloilla varustettuna se pystyy toimimaan myös pehmeällä maaperällä. Koneen tuotos on 2 k-m³/t. Kuljettajan lisäksi ei tarvita muuta miehistöä.

Paloittelumenetelmästä riippumatta kanto- ja juuripuun pinotiheys jää tavanomaiseen paperipuuhun verrattuna aina alhaiseksi (kuvat 41—45). Kokonaisten juurakoitten pinotiheys on vain 0.1, paloitellun puun vastaavasti 0.2—0.4. Paras tulos saavutetaan moottorisahalla. Koneellistamisasteen kasvaessa paloittelutyön laatu pyrkii laskemaan, jolloin kuljetuskustannukset kiintokuutiometriä kohden nousevat.

Metsäkuljetuksessa päästään alhaisempiin kustannuksiin, jos paloittelu tapahtuu jo ennen kuljetusta. Koko korjuuketjun kannalta on kuitenkin yleensä tarkoituksenmukaisempaa keskittää paloittelu välivarastolle, mikäli sitä ei yhdistetä irrottamiseen.

Vakiovalmisteisen metsäkuljetuskaluston käyttö kanto- ja juuripuuta korjattaessa edellyttää yleensä kuormatilan suurentamista ja kouran uudelleen muotoilua. Pallarin kantoharvesterilla voidaan kanto- ja juuripuu edullisissa maasto-oloissa kerätä ilman erillistä traktorikuljetusta suoraan kuorma-auton ulottuville (kuvat 46—51).

Kanto- ja juuripuun korjuuketju on yksinkertaisin silloin, kun käytetään kantoharvesteria. Menetelmissä, joissa irrottaminen ja pilkkominen suoritetaan toisistaan erillään, on ketjun heikkona lenkkinä välivarastolla toimivan paloittelulaitteen puuttuminen. Tulevassa konekehittelyohjelmassa on toisaalta keskityttävä tämän työvaiheen koneellistamiseen sekä toisaalta kantoharvestereitten edelleen kehittämiseen.

Juhani Nousiainen - Väinö Rantanen - Paavo Tiihonen

KIINTOKUUTIOMETRIN KÄYTTÖÖN PERUSTUVA KUITU- JA TUKKIPUIDEN KUUTIOIMISMENETELMÄ

MÄNTY, KUUSI JA KOIVU

DEUTSCHES REFERAT

EIN MASSENERMITTLUNGSVERFAHREN FÜR FASER- UND BLOCHHOLZ MIT DEM FESTMETER ALS MASSEINHEIT

KIEFER, FICHTE UND BIRKE

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ALKUSANAT

Puutavaran mittauksen uutta mittausjärjestelmää valmisteltaessa kiinnitettiin huomiota myös siihen, että mahdollinen yksikön muutos edellytti mittausperusteiden ja -menetelmien tarkistamista tai uusimista. Pystypuiden kuutioinnissa oli uusittava kaikkien puutavaralajien mittausperusteet. V. 1970 perustettu, tukkipuiden kuutioimisperusteiden yhdenmukaistamista käsitellyt työryhmä katsoi, että leimikoiden pystymittauksissa sovellettavien menetelmien uusiminen oli, toiminnan yleistymisestä johtuen, erittäin kiireellinen tehtävä.

Aikaisemman päätöksen (N o u s i a i n e n . . . 1970, s. 17) mukaisesti edellä mainittu työryhmä päätti jatkaa toimintaansa keväällä 1971. Oli suoritettava uusi, varsin laajamittainen kuutioimisperusteita käsittelevä selvitys. Tehtävän merkitystä käytännössä osoittanee se, että työryhmä laajeni entisestään ja siihen tulivat herrat B. F i n n e (Metsähallituksen kehittämisjaosto), M. I l v e s s a l o (MTK:n metsävaltuuskunta), T. J ä m s é n (Oy Wilh. Schauman Ab), J. K a h i l u o t o (Rauma-Repola Oy), R. K i v i v a s a r a (Yhtyneet Paperitehtaat Oy), R. K o s k i n e n (W. Rosenlew & Co Oy), A. K u r o n e n ja P. R ä s ä n e n (Kml. Tapio), J. N o u s i a i n e n (VTKK, Oulun aluekeskus), M. P o n s i (Oy Nokia Ab), K. P u l l i n e n (Riihimäen Saha Oy), J. P u r a n e n ja P. T i i h o n e n (Metsäntutkimuslaitos), V. R a n t a n e n ja Y. S c h i l d t (Enso-Gutzeit Osakeyhtiö), H. V a i n i o (G. A. Serlachius Oy) ja M. Y l i n e n (Tehdaspuu Oy). Työryhmään kuului ostajien ja myyjien edustajina lyhyen aikaa useita muitakin metsäammattimiehiä. Kml. Tapiossa laaditun suunnitelman mukaisesti maastomittauksiin osallistui huomattava määrä maan eteläpuoliskon piirimetsälautakuntien sekä metsänhoitoyhdistysten ja niiden liittojen metsäammattimiehiä. I t ä - S a v o n pml. keräsi myös oman tarkistusaineiston. Työryhmän toiminnalle oli siten jälleen ominaista eri osapuolten avoin ja luottamuksellinen yhteistyö.

Mainituilla tahoilla kerättiin kesä—syyskautena 1971 laaja ja monipuolinen ns. tarkistusaineisto. Metsäntutkimuslaitoksen metsänarvioimisen tutkimusosasto keräsi samanaikaisesti rinnakkaisaineiston. Tehtävässä saatiin arvokasta apua metsäntutkimuslaitoksen maan eteläpuoliskon kokeilualuei-

den metsäammattimiehiltä. Molempien aineistojen pohjalta voitiin valmistaa uusi leimikoiden pystymittauksissa ja yleensä pystypuiden mittauksissa käytettävä kuutioimismenetelmä.

Tutkimuksen aineiston käsittelyyn on osallistunut useita eri puunjalostusteollisuuslaitosten metsäosastojen, piirimetsälautakuntien ja metsäntutkimuslaitoksen palveluksessa olevia henkilöitä. Tutkimuksen käsikirjoituksen ovat lukeneet professorit Olli Makkonen ja Yrjö Vuokila. Julkaisuun liittyvän saksankielisen selostuksen ovat laatineet rouva Marianne Kahanpää ja fil. maisteri Yrjö Sihvo.

Tutkimusselostuksen kirjoittaminen jäi allekirjoittaneiden tehtäväksi. Esitämme kunnioittavat kiitokset saamastamme luottamuksesta ja tuesta.

Helsingissä syyskuussa 1972

Juhani Nousiainen *Väinö Rantanen* *Paavo Tiihonen*

SISÄLLYSLUETTELO

	Sivu
Johdanto	6
Tutkimusaineisto	8
Kuutioimismenetelmän yleisperusteet	13
Puutavaralajitaulukot	16
Taulukoiden laadintaperusteet	16
Taulukoiden rakenne	21
Taulukoiden käyttö	22
Puutavaralajien ATK-laskenta	23
Yleistä	23
Lähtötiedot	23
Tietokonekäsittelyn logiikka	24
Tulostus	30
Kuutioimismenetelmän luotettavuudesta	31
Kirjallisuusluettelo	40
Deutsches Referat	42

JOHDANTO

MTK:n metsävaltuuskunnan ja puunjalostusteollisuuden järjestöjen tekemän sopimuksen mukaisesti sovellettiin hankintakautena 1971—72 koemielessä uutta, kiintokuutiometrin käyttöön perustuvaa mittausjärjestelmää. Myönteisten kokemusten pohjalta edellä mainitut järjestöt päättivät suosittaa todellisen kuorellisen kiintokuutiometrin ottamista 01. 07. 1972 lukien kuitu- ja tukkipuiden mittayksiköksi. Tähän mennessä saadut tosin lyhyen ajan kokemukset viittaavat varsin suopeaan asennoitumiseen sekä puun myyjien että ostajien taholla. Työpalkkojen laskennassa on kiintokuutiometriä käytetty yksikkönä ns. työvaihetaksojen yhteydessä tunnetusti jo muutaman vuoden ajan.

Uuden mittayksikön valinta merkitsi olennaista muutosta sekä kuitupuun että erityisesti tukkien mittauksessa. Perusteiden selvittelyä ja uusien mittausmenetelmien kehittämistä tarvittiin sekä erilaiseksi puutavaraksi valmistettujen puuerien että pystypuiden kuutioinnissa. Jälkimmäisestä toiminnasta mainittakoon erityisesti leimikoiden pystymittaus. Uutta mittayksikköä koskevien neuvottelujen edistyessä kiinnitettiin pian useilla tahoilla huomiota leimikon pystymittauksessa sovellettavien perusteiden ja menetelmien tarkistamisen ja uusimisen tarpeeseen. PMP (pystymittaus- ja palkanlaskenta) -systeemin hoitokunta teki muutoksia koskevan esityksen metsäntutkimuslaitoksen metsänarvioimisen tutkimusosastolle keväällä 1971. V. 1970 muodostetun, tukkipuiden kuutioimisperusteiden yhdenmukaistamista käsitelleen työryhmän (ks. N o u s i a i n e n . . . 1970, s. 17) piirissä katsottiin samoin, kuten alkusanoissa on todettu, keväällä 1971, että odotettavissa oleva mittayksikön muutos antoi aiheen perusteiden selvittelyyn. Maaliskuun 7 päivänä 1969 annettu p u u t a v a r a n m i t t a u s s ä ä n t ö (163/69) edellytti, että metsäntutkimuslaitoksessa valmistetaan uuden mittayksikön käyttöön perustuvat puutavaralajitaulukot.

Sekä käytännön että tutkimuksen alalla kaivattiin siis perusteita selvitteleviä tutkimuksia. Uusien puutavaralajitaulukoiden laadintaa koskeva päätös tehtiin metsäntutkimuslaitoksessa v. 1971 alussa. Kevään kuluessa todettiin, että tukkipuiden kuutioimismenetelmän valmistaminen on syytä suorittaa edellä mainitun, perusteiden yhdenmukaistamista käsitelleen työ-

ryhmän puitteissa. Työryhmä olikin korostanut syksyllä 1970 toiminnan jatkamisen tarpeellisuutta vastaisissa tarkistustehtävissä (N o u s i a i n e n . . . mt., s. 17). Keväällä 1972 sisällytettiin tutkimustehtävään myös paperieli kuitupuiden kuutioimisperusteiden selvittäminen. Jäljempänä käytetään yksinomaan kuitupuu nimitystä. Työ hahmottui kokonaisuudessaan seuraavanlaiseksi. Valmistetaan kuitu- ja tukkipuiden kuutioimismenetelmä, jossa mittayksikkönä on (todellinen) kuorellinen kiintokuutiometri (k-m^3). Puulajit ovat mänty, kuusi ja koivu. Menetelmään sisällytetään, kuten aikaisemminkin (N o u s i a i n e n . . . mt., s. 4), kaksi laskentatapaa: ATK-laskenta ja numeeriset taulukot (puutavaralajitaulukot). Molemmilla vaihtoehdoilla oli päästävä käytännöllisesti katsoen samoihin, mieluummin täysin samoihin tuloksiin. Aikaisempien myönteisten kokemusten (N o u s i a i n e n . . . mt., s. 17) mukaisesti perustetaan molempien vaihtoehtojen laadinta mittaustuloksiin, joita ostajan ja myyjän edustajat yhteisesti keräävät käytännön hakkuutyömailta. Tätä avointa toimintaa noudatetaan kuutioimismenetelmän valmistamisen kaikissa vaiheissa.

Alkusanoissa mainittujen henkilöiden muodostama työryhmä aloitti toimintansa kesäkuussa 1971. Työ laajeni kesän aikana myös Pohjois-Suomeen. Tältä osin jatkuvat tutkimukset edelleenkin, joten tässä julkaisussa rajoitutaan vain maan eteläpuoliskon työryhmän selvityksiin. Maan eteläpuoliskon pohjoisrajaksi on tässä katsottu Oulun läänin eteläraja. Kuutioimismenetelmän keskeisimmät perusteet saatiin selvitetyiksi v. 1972 juhannukseen mennessä. Kesäkuun 29 päivänä 1972 pitämässään kokouksessa työryhmä katsoi, että uutta kuutioimismenetelmää voidaan suosittaa sovellettavaksi myös käytännön mittaustoiminnassa, erityisesti leimikoiden pystymittauksissa.

Tässä julkaisussa esitetään uuden kuutioimismenetelmän keskeisimmät perusteet sekä selostetaan sen käyttöä ja luotettavuutta.

TUTKIMUSAINEISTO

Tutkimuksen aineisto koostuu seuraavista viidestä osa-aineistosta:

— tukkipuiden kuutioimismenetelmän ja erityisesti männyn ja kuusen tukkipuutaulukoiden laadinnassa käytetty aineisto, jäljempänä taulukkoaineisto, joka käsittää kaadetuista rungoista koottuja mittaustietoja,

— lyhyiden (10—13 m), yksitukkisten puiden tukkiosuutta koskevat pystymittaustiedot, joita on käytetty lähinnä vertailumielessä tutkittaessa edellisen aineiston perusteella ko. pituusluokkien kohdalla suoritettua extrapolointia,

— aikaisempien tutkimusten (T i i h o n e n 1966 a, 1969 a, 1969 b; K u r o n e n . . . 1970) yhteydessä kertyneet, käytön ulkopuolelle jäävän latvan kokoa valaisevat mittaustulokset,

— lähinnä tukkipuiden kuutioimismenetelmää varten koottu tarkistusaineisto, joka käsittää kaikkiaan 3 koivu-, 17 mänty- ja 17 kuusikoepuuerää, sekä

— poikkeuksellisten mänty- ja kuusitukkipuiden aineisto.

Kuitupuiksi luettiin sellaiset rungot, joiden läpimitta rinnankorkeudelta kuoren päältä on vähintään 6 cm (7 cm:n $d_{1.3}$-luokka, jäljempänä merkintä d-luokka), ja joista saadaan ainakin yksi ao. laatuvaatimukset täyttävä, 2 m:n pituinen ja latvaläpimitaltaan 6 cm (kuoren alta) oleva pölkky. Kaikilla puulajeilla (mänty, kuusi ja koivu) on siis samat minimimitat.

Tukkipuiden pienin d-luokka on 19 (18.1—20.0) cm. Erotettiin minimirunko ja minimitukki: M i n i m i r u n k o määritettiin puulajeittain seuraavasti:

— männyllä rungosta saadaan 490 × 15 cm:n (läpimitan latvasta kuoren alta, täytettävä 15 cm) kokoinen, II laatuluokan tukki,

— kuusella vastaavat vaatimukset ovat 490 × 17 cm (täytettävä 17 cm), oksaisuus II—III, muutoin II laatuluokka, ja

— koivulla 340 × 17 cm, läpimitta latvasta kuoren päältä ohuimmalta puolen, laatuluokka 1.5 m:n matkalla II, muilta osin III.

Minimitukin koko oli männyllä 430 × 15 (täytettävä 14 cm), kuusella 430 × 17 (täytettävä 16 cm) ja koivulla 310 × 17 cm, läpimitta kuten edelläkin havupuilla tukin latvasta kuoren alta, koivulla sensijaan keskeltä kuoren päältä.

Edellä esitettyjen vähimmäisvaatimusten rinnalla voitiin soveltaa myös eräitä muita tukin pituuden ja läpimitan yhdistelmiä. Näiden samoin kuin muiden tukkien apteerauksen ja laatuluokituksen yksityiskohtien suhteen rajoitutaan tässä vain viittaamaan eri osapuolten sopimiin ohjeisiin (MTK:n Metsävaltuuskunnan ja... 1971; Sahatukkien laatuvaatimukset 1971; Uudistuva... 1972; Vanerikoivujen... 1972).

Taulukkoaineiston, sitä täydentävät pystyapteerauskoepuut ja neljä tarkistusaineiston koepuuerää (koeleimikkoa) on kerännyt metsäntutkimuslaitoksen metsänarvioimisen tutkimusosaston mittausryhmä maan eteläpuoliskon eri osista. Havupuiden mittaukset on tehty kesä—syyskautena 1971, muut mittaustiedot ovat pääosiltaan peräisin Ilvessalon »Pystypuiden kuutioimistaulukoiden» ja kapenemistaulukoiden (Tiihonen 1961) aineistosta. Lisäksi oli käytettävissä kolme tarkistusaineistoon sisältyvää, v. 1967, 1968 ja 1972 kerättyä koivutukkipuuerää.

Tarkistusaineiston pääosan sekä poikkeuksellisten mänty- ja kuusitukkipuiden aineiston keruusta ovat huolehtineet yhdeksän puunjalostusteollisuusyhtiön metsäosastoa, metsähallituksen kehittämisjaosto sekä lisäksi yhden koeleimikon osalta Itä-Savon piirimetsälautakunta. Kml. Tapiossa laaditun suunnitelman mukaisesti useiden piirimetsälautakuntien ja metsänhoitoyhdistysten metsäammattimiehet valvoivat ja avustivat tarkistusaineiston keruussa. Metsähallituksen ja Itä-Savon pml:n koeleimikoiden keruuta seurasi vuorostaan ostajan edustaja. Muodostui siis paikallisia, ostajaa ja myyjää edustavia kenttätyöryhmiä. Yhteistyötä valaisee seuraava luettelo, johon on otettu myös edellä mainittu metsäntutkimuslaitoksen mittausryhmän keräämä koeleimikko.

1. Enso-Gutzeit Osakeyhtiö, leimikko n:o 1
   Etelä-Karjalan pml.
2. Enso-Gutzeit Osakeyhtiö, leimikko n:o 2
   Etelä-Karjalan pml.
3. Enso-Gutzeit Osakeyhtiö, leimikko n:o 3
   Keski-Suomen mhy:n liitto
4. Enso-Gutzeit Osakeyhtiö, leimikko n:o 4
   Pohjois-Karjalan mhy:n liitto
5. Itä-Savon pml.
   Tehdaspuu Oy

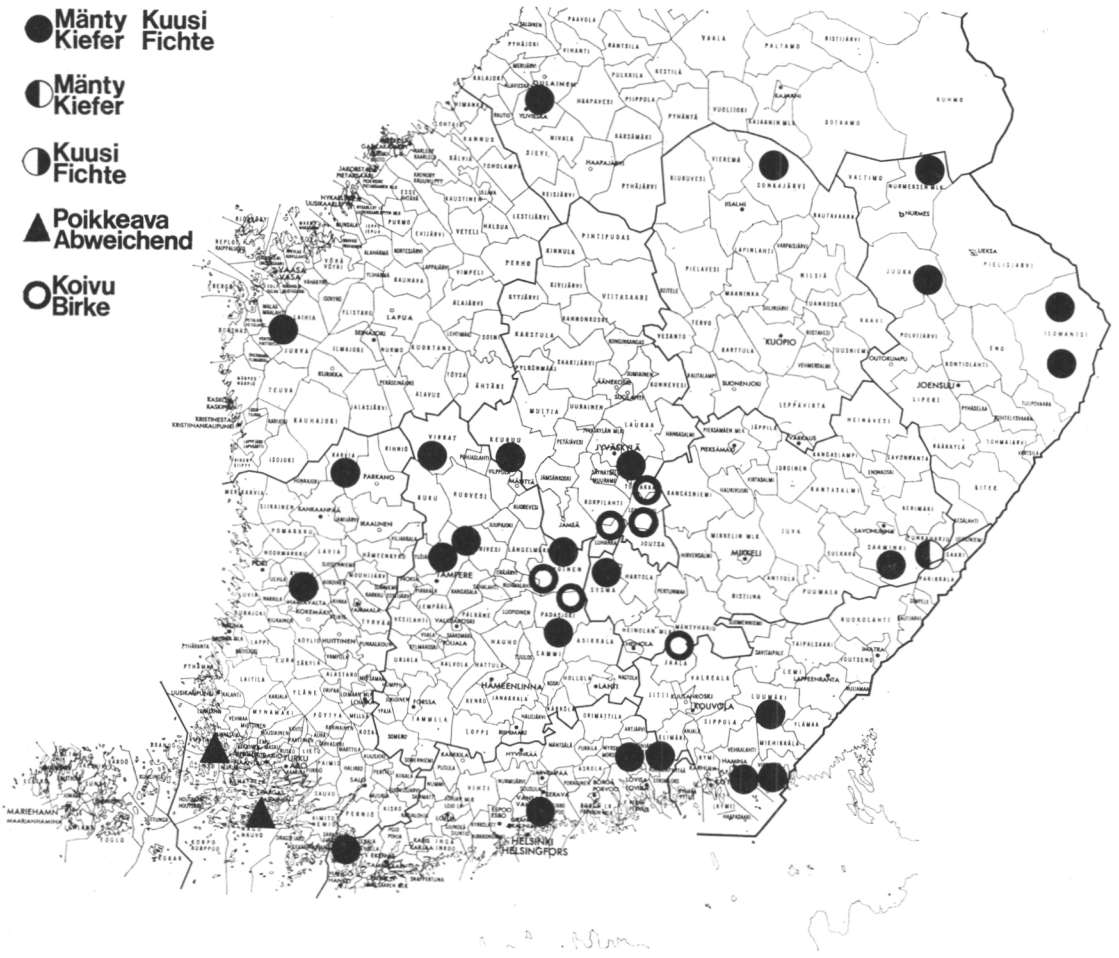
6. Metsähallitus, leimikko n:o 1
7. Metsähallitus, leimikko n:o 2
   G. A. Serlachius Oy
8. Metsähallitus, leimikko n:o 3
   Tehdaspuu Oy
9. Metsähallitus, leimikko n:o 4
   Veitsiluoto Oy
10. Metsäntutkimuslaitos
11. Oy Nokia Ab
    Pirkka-Hämeen pml.
12. Rauma-Repola Oy
    Helsingin ja Lounais-Suomen pml.
13. Riihimäen Saha Oy
    Uudenmaan—Hämeen pml.
14. W. Rosenlew & Co Oy
    Satakunnan pml.
15. Oy Wilh. Schauman Ab
    Keski-Pohjanmaan pml.
16. G. A. Serlachius Oy
    Etelä-Pohjanmaan mhy-liitto
17. Tehdaspuu Oy
    Etelä- ja Pohjois-Savon pml.
18. Yhtyneet Paperitehtaat Oy
    Itä-Hämeen pml.

Leimikot ilmaistaan jäljempänä luettelon mukaisilla järjestysluvuilla. Sekä tutkimus- että tarkistusaineiston koeleimikoiden sijaintia valaisee kuva 1.

V. 1971 suoritettua aineiston keruuta edelsi Jyväskylässä ja sen lähistöllä Tehdaspuu Oy:n eräällä hakkuutyömaalla järjestetty yhteinen koulutustilaisuus. Lisäksi laadittiin mittauksia varten ohjeet (Mänty- ja kuusitukkipuiden kuutioimisperusteiden... 1971). Mittaajilla oli myös käytettävissä edellä (s. 9) mainitut tukkipuiden apteerausta ja laatuluokitusta valaisevat ohjeet. Taulukko- ja tarkistusaineiston keruussa noudatettiin samoja mittausperusteita.

Keskeisimmät osa-aineistot käsittävät seuraavat runkomäärät.

Aineisto *Material*	Mänty *Kiefer*	Kuusi *Fichte*	Koivu *Birke*
	Runkoa — *Anzahl der Stämme*		
Taulukkoaineisto — *Tafelnmaterial*	2 227	2 020	1 761
Pystykoepuut — *Stehende Probebäume*	349	136	—
Tarkistusaineisto — *Kontrollmaterial*	3 421	3 105	1 837
Poikkeukselliset tukkipuut — *Abweichende Blochholzstämme*	520	236	—



Kuva 1. Aineiston keruukohteet.
Abb. 1. Die Lage der Probebestände.

Aineistoon sisältyy lisäksi edellä (s. 8) mainitun mukaisesti eräitä aikaisempien tutkimusten koepuueriä, joiden perusteella on tutkittu erityisesti latvan kokoa.

Kaikki osa-aineistot käsittävät erikokoisia ja erimuotoisia runkoja. Aineiston rakenteen lähempi esittely on runsaasti tilaa vaativana pääosiltaan sivuutettava. Taulukkoaineistoa valaisevat eräät puutavaralajitaulukoiden selostuksen yhteydessä esitettävät keskimääräistiedot, tarkistusaineistoa taasen kuutioimismenetelmän luotettavuuden tarkasteluun liittyvät tulossarjat.

Kaikista taulukko- ja tarkistusaineiston koepuista on tehty kuutioimismenetelmän mukaisia tunnuksia, rinnankorkeusläpimittaa (d), pituutta ja

kapenemista (d—d6 tai 3.5) koskevat mittaukset. Kannon kokoa tutkittiin kaikista kaadetuista koepuista. Koko rungon ja eri puutavaralajien ynnä latvan kuutiomäärä kiintokuutiometreissä laskettiin pätkittäisen kuutioinnin perusteella, pölkkyjen pituuden ollessa 1—2 m. Läpimitat mitattiin millimetrin ja koko pituus senttimetrin tarkkuudella. Tukkiosuudella läpimitat mitattiin kahdessa toisiaan vastaan kohtisuorassa, kuitupuu- ja latvaosuudella vain yhdessä suunnassa. Poikkeuksellisista puista mitattiin edelleen tyveyksen päättymiskorkeus, leikon alku- ja päättymiskorkeus samoin kuin »normaalin» tukkiosuuden latvapäässä olevan vian alkamiskohta tyvestä lukien. Tukkiosuus määritettiin myös uuden mittausjärjestelmän mukaisina teknillisinä kiintokuutiometreinä. Näiden tulosten pohjalta on suoritettu vain vertailuja eräiden muiden tutkimustulosten kanssa. Pystykoepuissa rajoituttiin tukkiosuuteen, joka kaikilla rungoilla käsitti vain yhden tukin.

Pituuden ja läpimittojen mittauksen alkamiskohtana on ollut Ilvessalon (mt.) taulukoiden laadintaperusteiden mukainen puun juurenhaarojen määrittämä alin mahdollinen kantokorkeus (ks. Ilvessalo 1947, s. 9, 1965, s. 56).

KUUTIOIMISMENETELMÄN YLEISPERUSTEET

Johdannossa viitatun mukaisesti tutkimustehtävään sisältyi kolme puulajia, mänty, kuusi ja koivu, sekä kullakin puulajilla edelleen kuitu- ja tukkipuut. Tukkipuiden ryhmittelyä täydennettiin muodostamalla kaksi luokkaa: normaalit ja poikkeukselliset tukkipuut. Jälkimmäiseen kuuluvat sellaiset tukkipuurungot, joissa vikaisen rungonosan pituus on vähintään 60 cm, jolloin yleensä erotetaan 1—2 m:n kuitupuupölkky (tyveys tai leikko). Tätä luokitteluperustetta voidaan tarvittaessa tiukentaa tai lieventää.

Kuutioimismenetelmän varsinainen laadintatyö suuntautui kahdelle taholle: numeerisiin taulukkoihin (puutavaralajitaulukkoihin) ja ATK-laskentaan. Jäljempänä käytetään yksinomaan suluissa esitettyä, puutavaralajitaulukot, nimitystä. Aikaisemmin tehdyn ratkaisun (Nousiainen... 1970) mukaisesti päädyttiin siis kahden vaihtoehtoisen laskentamenetelmän käyttöön (ks. s. 7).

Menetelmää valmistettaessa päätettiin, kuten johdannossa on todettu, että eri vaihtoehdoilla oli päästävä käytännöllisesti katsoen, mieluummin täysin samoihin tuloksiin. Tällainen yleisperuste oli tärkeä erityisesti leimikoiden pystymittausten kannalta. Jäljempänä esitettävistä selostuksista ilmenee, että kuitupuilla ovat kuutioimisperusteet eri vaihtoehdoissa täysin samat, joten tuloksetkin ovat aina samat. Tarkastelu kohdistuikin pääosiltaan tukkipuihin. Päädyttiin ratkaisuihin, että ATK-laskentaan sisällytetään kaksi rinnakkaismenetelmää: pölkytys- ja erotusmenetelmä. Edellinen valmistetaan aikaisemmin tehdyn tutkimuksen (Nousiainen ... mt.) pohjalta, sitä tarpeellisessa määrin tarkistaen ja täydentäen. Runsaasti koepuita käsittäneen aineiston avulla voitiinkin suorittaa varsin laaja ja monipuolinen selvitys. Erotusmenetelmää sovellettaessa lasketaan tukkiosuus erotuksena, vähentämällä koko rungon kuutiomäärää osoittavasta Ilvessalon (mt.) taulukoiden yksikkökuutiosta (+1—1½ %) ensin kuutioitavan rungon tunnusten mukainen latvaosuus ja sitten vastaava kuitupuuosuus. Laskemalla tukkipuutaulukoiden tukkiosuudet erotusmenetelmällä ja käyttämällä samoja latva- ja kuitupuuosuuksia saadaan eri vaihtoehdoilla samat tulokset.

Lähempi tarkastelu osoitti, että tehty ratkaisu soveltui sellaisenaan vain männylle ja kuuselle, edelleen vain normaaleille rungoille. Koivun tukkipuutaulukoissa olisi pitänyt ottaa neljänneksi tunnukseksi tukkiosuuden pituus. Mäntyyn ja kuuseen verrattuna taulukoista olisi tullut huomattavasti laajemmat. Koska koivutukkipuiden kuutioinnin luotettavuuden tutkimista oli edelleen jatkettava, katsottiin, että toistaiseksi oli syytä rajoittua vain pölkytysmenetelmään. Tähän mennessä suoritetut lisäselvitykset antavat aiheen otaksua, että koivullekin voidaan ilmeisesti valmistaa kohtuullisen suppeat tukkipuutaulukot.

Poikkeuksellisten tukkipuiden kuutioinnissa päätettiin samoin rajoittua vain ATK-laskennan pölkytysmenetelmään, sekä edelleen mäntyyn ja kuuseen. Näyttää ilmeiseltä, että puutavaralajitaulukoiden laadinta poikkeuksellisille tukkipuille ei ole perusteltua. Taulukoista tulisi hyvin laajat, ja toisaalta vertailulaskelmat voidaan tarvittaessa perustaa yleensä pystyapteeraukseen. Sen sijaan on aiheellista jatkaa poikkeuksellisten koivutukkipuiden kuutiointia koskevia tutkimuksia. Normaalien koivutukkipuiden tarkistuslaskelmien tulosten perusteella voidaan otaksua, että laadittu kuutioimismenetelmä soveltuu, vähäisessä määrin täydennettynä, myös poikkeuksellisille koivutukkipuille. Kysymystä tarkastellaankin jo syyskaudella 1972.

Kuutioimismenetelmän yleisperusteista mainittakoon vielä eri puutavaralajien minimimitat ja laatuvaatimukset (ks. s. 8). On syytä korostaa, että kuutioimismenetelmän laadinta perustuu tiettyjen m i n i m i r u n g o l l e asetettavien vähimmäisvaatimusten soveltamiseen. Erityisesti tukkipuiden mittauksessa mainittuun perusteeseen on kiinnitettävä erityistä huomiota.

Kuutioimisperusteita käsitellyt työryhmä laati kokouksessaan toukokuussa 1972 menetelmien perusteita käsittelevän suppean yhdistelmän. Siinä kiinnitetään päähuomio tukkipuiden kuutiointiin. Perusajatuksena on kaikkia osapuolia palveleva laskentajärjestelmä, johon tukkipuiden kuutioinnin osalta sisältyy pölkytys- ja erotusmenetelmä. Tämän kahdesta perättäisestä, erilaisesta laskentamenettelystä koostuvan kuutioimismenetelmän keskeisimmät perusteet ovat, kuutioimis- ja kapenemistaulukoiden lisäksi, seuraavat:

— latvaosuuksien taulukot,

— kuitupuuosuuksien taulukot,

— samasta leimikosta lasketaan vain yksi todellisissa ja vain yksi teknillisissä k-m^3:ssä ilmaistu tulostus,

— järjestelmään sisältyy erotusmenetelmän mukainen tarkistusmahdollisuus,

— leimikoiden, erityisesti maatilametsälöiden leimikoiden puutavaralajeittainen kuutiointi on mahdollista perustaa erotusmenetelmän käyttöön,

— erotusmenetelmää käytettäessä tulostetaan todellisissa k-m³:ssä ilmaistut tulokset vain tällä menetelmällä,

— erotusmenetelmän yhteydessä saadaan haluttaessa pölkytysmenetelmällä tukkiluettelo, jossa yksikkönä on teknillinen kiintokuutiometri,

— käytettäessä yksinomaan pölkytysmenetelmää tapahtuvat kaikki tulostukset tämän menetelmän mukaisesti todellisina tai teknillisinä k-m³:nä,

— jos siis tukkiluetteloa tai tukkien keskilukuja ei tarvita, voidaan laskenta ja tulostus rajoittaa erotusmenetelmän käyttöön, tai

— vastaavasti voidaan keskittyä vain pölkytysmenetelmään, laskentajärjestelmän kokonaisuuden siitä kärsimättä.

Yhdistelmässä todetaan lopuksi, että edellä esitetty koskee vain maan eteläpuoliskon normaaleja mäntyjä ja kuusia. Poikkeukselliset havutukkipuut kuutioidaan aina pölkytysmenetelmällä. Koivutukkipuiden kuutiointi edellyttää tukkiosan pituuden mittausta ja tarvittaessa eri osapuolten sopimuksen mukaista vikaisuuksien tarkistusta kaadon yhteydessä.

Vaihtoehtoisia kuutioimismenetelmiä selostetaan yksityiskohtaisemmin seuraavissa kappaleissa.

PUUTAVARALAJITAULUKOT

Taulukoiden laadintaperusteet

Edellä esitetyn mukaisesti oli valmistettava männyn, kuusen ja koivun kuitupuutaulukot sekä männyn ja kuusen tukkipuutaulukot, joiden mittayksikkönä oli kuorellinen (todellinen) kiintokuutiometri. Mainittakoon, että koivun tukkipuutaulukoiden laadintamahdollisuudet selvinnevät talvikautena 1972—73.

Kaikkien taulukoiden keskeisimpänä perusteena on Ilvessalon (mt.) »Pystypuiden kuutioimistaulukoiden» kuorelliset yksikkökuutiot. Uuden mittayksikön valinnan jälkeen nämä taulukot tarjosivatkin entistä edullisemman perustan puutavaralajitaulukoiden valmistamiselle. Aikaisemmasta hyvin myönteisestä kuvasta huolimatta katsottiin taulukoiden luotettavuuden tarkastelun jatkaminen uuden tarkistusaineiston pohjalta silti aiheelliseksi. Suoritettujen vertailujen tuloksia esitellään lähemmin jäljempänä taulukoiden luotettavuuden tarkastelun yhteydessä. Tässä todettakoon, että uusien tarkistuslaskelmien tulokset olivat hyvin yhdenmukaiset aikaisempien tulosten kanssa ja vahvistivat siten osaltaan Ilvessalon taulukoiden luotettavuutta. Vain männyllä päädyttiin vähäiseen muutokseen. Voitiin otaksua, että kannon keskimääräinen koko oli ilmeisesti edelleenkin hieman pienentynyt, joten männyn yksikkökuutioita päätettiin nyt suurentaa 1½ %:lla aikaisemmin Etelä-Suomessa sovelletun 1 %:n asemesta. Kuusella lisäys oli 1 % kuten aikaisemmissa taulukoissakin. Koivun yksikkökuutioihin ei uusienkaan tarkistusmittausten mukaan ollut syytä tehdä lisäyksiä tai vähennyksiä.

Kuitupuutaulukoiden toisena laadintaperusteena olivat taulukoista 1—3 nähtävät keskimääräiset latvaosuudet (dm^3/runko). Niiden valmistamisessa nojauduttiin sekä aikaisempiin tutkimuksiin (Tiihonen 1969 a ja b; Kuronen... 1970) että tämän tutkimuksen aineistoon. Latvaosuudet on ryhmitetty d- ja pituusluokan mukaisesti. Edellä esitetyllä tavalla tarkistetuista Ilvessalon taulukoiden yksikkökuutioista vähennettiin sitten vastaavat keskimääräiset latvaosuudet, jolloin erotuksena saatiin sovelletun luokituksen mukaiset kuitupuuosuudet. Tulok-

Taulukko 1. Mäntyjen keskimääräinen latvaosuus (kuorineen)
Tabelle 1. Durchschnittlicher Zopfanteil der Kiefern (mit Rinde)

Pituusluokka, m *Höhenklasse, m*	d-luokka, cm — *d-Klasse, cm*																			
	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45+
	dm³ kuorineen/runko — *dm³ mit Rinde/Stamm*																			
5	4	4	4	3																
6	5	4	4	3	3															
7	6	5	4	4	3	3														
8	7	5	4	4	3	3	2													
9	9	6	4	4	3	3	2	2	2											
10	10	6	4	4	3	3	2	2	2	2										
11	11	7	5	4	3	3	2	2	2	2	2	2								
12	12	8	5	4	3	3	2	2	2	2	2	2	2	2						
13	12	9	5	4	3	3	2	2	2	2	2	2	2	2	2	2				
14	13	10	5	4	4	3	3	2	2	2	2	2	2	2	2	2	2	2		
15		10	6	4	4	4	3	2	2	2	2	2	2	2	2	2	2	2	2	2
16			6	5	4	4	3	3	2	2	2	2	2	2	2	2	2	2	2	2
17				5	4	4	3	3	3	2	2	2	2	2	2	2	2	2	2	2
18					5	4	3	3	3	3	2	2	2	2	2	2	2	2	2	2
19					5	4	3	3	3	3	3	2	2	2	2	2	2	2	2	2
20						5	4	3	3	3	3	3	2	2	2	2	2	2	2	2
21							4	3	3	3	3	3	2	2	2	2	2	2	2	2
22							4	3	3	3	3	3	3	2	2	2	2	2	2	2
23							4	3	3	3	3	3	3	3	2	2	2	2	2	2
24							4	3	3	3	3	3	3	3	3	2	2	2	2	2
25								3	3	3	3	3	3	3	2	3	2	2	2	2
26								3	3	3	3	3	3	3	3	3	3	2	2	2
27									3	3	3	3	3	3	3	2	3	3	2	2
28										3	3	3	3	3	3	3	3	3	3	2
29											3	3	3	3	3	3	3	3	3	3
30+												3	3	3	3	3	3	3	3	3

sia tarkasteltiin ensin graafisesti. Lisäksi suoritettiin vertailuja tarkistusaineiston avulla.

Mainittakoon, että samat latvaosuudet sisällytettiin myös toiseen vaihtoehtoiseen laskentamenetelmään, puutavaralajien ATK-laskentaan. Kun tietokonelaskenta perustuu lisäksi I l v e s s a l o n (mt.) taulukoiden käyttöön, saadaan molemmilla vaihtoehdoilla täysin samat kuitupuiden kuutioimistulokset.

Lopulliset männyn, kuusen ja koivun kuitupuutaulukot on julkaistu metsäntutkimuslaitoksen Folia Forestalia -sarjan niteessä n:o 154 (T i i h o n e n 1972 a).

Männyn ja kuusen t u k k i p u u t a u l u k o i d e n valmistamisessa nojauduttiin I l v e s s a l o n (mt.) kuutioimistaulukoiden ja 1—2 taulukoiden latvaosuuksien lisäksi taulukoista 4 ja 5 nähtäviin k e s k i m ä ä-

Taulukko 2. Kuusien keskimääräinen latvaosuus (kuorineen)
Tabelle 2. Durchschnittlicher Zopfanteil der Fichten (mit Rinde)

Pituusluokka, m *Höhenklasse, m*	d-luokka, cm — *d-Klasse, cm*																		
	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45+
	dm³ kuorineen/runko — *dm³ mit Rinde/Stamm*																			
5	5	4	3	3																
6	5	4	3	3	3															
7	6	4	4	3	3	3														
8	6	5	4	3	3	3	3	3												
9	6	5	4	3	3	3	3	3	3	2										
10	7	6	4	4	3	3	3	3	3	2	2									
11	8	6	5	4	4	4	3	3	3	2	2	2								
12	8	6	5	5	4	4	3	3	3	3	2	2	2							
13	8	7	6	5	4	4	3	3	3	3	2	2	2	2						
14		7	6	5	4	4	4	3	3	3	3	2	2	2	2	2				
15		7	6	6	4	4	4	3	3	3	3	2	2	2	2	2	2			
16			7	6	5	4	4	4	3	3	3	3	2	2	2	2	2	2	2	
17			7	6	5	5	4	4	4	3	3	3	2	2	2	2	2	2	2	2
18				6	5	5	4	4	4	3	3	3	2	2	2	2	2	2	2	2
19					5	5	4	4	4	3	3	3	3	2	2	2	2	2	2	2
20						5	4	4	4	3	3	3	3	3	2	2	2	2	2	2
21							4	4	4	4	3	3	3	3	3	2	2	2	2	2
22							4	4	4	4	3	3	3	3	3	3	2	2	2	2
23								4	4	4	3	3	3	3	3	3	2	2	2	2
24								4	4	4	3	3	3	3	3	3	3	2	2	2
25								4	4	4	3	3	3	3	3	3	3	3	2	2
26								4	4	4	4	3	3	3	3	3	3	3	3	2
27									4	4	4	3	3	3	3	3	3	3	3	3
28									4	4	4	3	3	3	3	3	3	3	3	3
29										4	4	3	3	3	3	3	3	3	3	3
30+										4	4	3	3	3	3	3	3	3	3	3

räisiin kuitupuuosuuksiin. Näiden keskimääräistulosten määrittäminen tapahtui pääasiassa taulukkoaineiston perusteella. Tuloksia verrattiin tarkistusaineiston vastaaviin keskimääräislukuihin. Lopuksi suoritettiin graafinen tasoitus. Taulukoiden 4 ja 5 keskimääräisluvut vähennettiin Ilvessalon taulukoiden yksikkökuutioista, joihin oli tehty edellä mainitunlaiset tarkistukset ja joista oli myös vähennetty taulukoiden osoittamat latvaosuudet. Tuloksia tarkasteltiin graafisesti kuten kuitupuutaulukoidenkin yhteydessä. Samoin tehtiin vertailuja tarkistusaineiston perusteella. Tukkipuutaulukoiden tukki- ja kuitupuuosuudet saatiin siis kahdella perättäisellä vähennyslaskulla, erotuksella. Edellä (s. 13) esitetyn mukaisesti laadintatapaa kutsutaan erotusmenetelmäksi. Viitaten jäljempänä tarkasteltavaan ATK-laskentaan mainittakoon, että erotusmenetel-

Taulukko 3. Koivujen keskimääräinen latvaosuus (kuorineen)
Tabelle 3. Durchschnittlicher Zopfanteil der Birke (mit Rinde)

Pituusluokka, m *Höhenklasse, m*	d-luokka, cm — *d-Klasse, cm*																			
	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45+
	dm³ kuorineen/runko — *dm³ mit Rinde/Stamm*																			
5	7	6	6																	
6	8	7	7	6																
7	9	8	8	7																
8	10	8	8	7	6															
9	11	9	8	7	6	6														
10	12	9	8	7	7	6	5	4												
11	13	10	8	7	7	6	5	4	4	4										
12	14	11	9	7	7	6	5	4	4	4	4	4								
13	16	13	9	8	7	6	5	4	4	4	4	4	4	4						
14	17	14	10	8	7	6	5	4	4	4	4	4	4	4	4	4				
15	17	15	11	9	8	6	5	4	4	4	4	4	4	4	4	4	4	4		
16		16	12	10	8	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4
17		16	12	10	8	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4
18			13	11	9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
19				12	9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
20					9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
21					9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
22						7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
23						7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
24							5	4	4	4	4	4	4	4	4	4	4	4	4	4
25							5	4	4	4	4	4	4	4	4	4	4	4	4	4
26							5	4	4	4	4	4	4	4	4	4	4	4	4	4
27								4	4	4	4	4	4	4	4	4	4	4	4	4
28								4	4	4	4	4	4	4	4	4	4	4	4	4
29									4	4	4	4	4	4	4	4	4	4	4	4
30+									4	4	4	4	4	4	4	4	4	4	4	4

män mukainen mänty- ja kuusitukkipuiden kuutiointi sisällytettiin myös tietokoneohjelmaan, joten eri vaihtoehdot johtavat täysin samoihin tuloksiin.

Tukkipuutaulukoiden »perusmenetelmän» rinnalla määritettiin tukkiosuus myös aikaisemmissa taulukoissa käytettyä menetelmää soveltaen, tasoittaen siis luokittaiset keskiarvot graafisesti (vrt. Nousiainen... 1970, s. 5). Sivuuttamalla laadinnan yksityiskohdat todettakoon, että näin saadut tulokset lähenivät erotusmenetelmällä saatuja tukkiosuuksia. Katsottiin, että erotusmenetelmän käyttö oli kuitenkin aikaisempaa tapaa edullisempi, joten se valittiin tukkipuutaulukoiden perustaksi.

Lopulliset tukkipuutaulukot on esitetty metsäntutkimuslaitoksen Folia Forestalia -sarjan niteessä n:o 155 (Tiihonen 1972 b).

Taulukko 4. Mäntytukkipuiden keskimääräinen kuitupuuosuus (kuorineen)
Tabelle 4. Durchschnittlicher Faserholzanteil des Kiefernblochholzes (mit Rinde)

Pituusluokka, m *Höhenklasse, m*	d-luokka, cm — *d-Klasse, cm*													
	19	21	23	25	27	29	31	33	35	37	39	41	43	45+
	dm³ kuorineen/runko — *dm³ mit Rinde/Stamm*													
10	42	44	47	52										
11	48	51	54	59	62	62								
12	57	59	60	61	62	62	64	67						
13	68	66	63	62	62	61	63	67	72	74				
14	76	70	64	63	62	61	63	67	71	73	74	74		
15	82	74	65	63	62	61	63	67	71	73	74	74	75	77
16	88	77	66	64	63	62	64	67	70	72	74	74	75	77
17	93	81	68	65	64	63	65	67	70	72	74	75	77	79
18	97	83	71	66	65	64	65	67	70	73	75	76	79	82
19	101	87	75	67	66	65	66	67	70	73	75	77	81	85
20	103	91	80	70	68	66	66	68	71	75	77	80	85	88
21	104	93	84	73	70	68	67	69	74	78	81	84	88	93
22	104	95	88	77	73	70	68	70	76	81	85	89	93	98
23	105	97	92	82	77	72	69	72	78	83	89	94	99	104
24	105	99	95	87	82	75	72	75	81	86	93	98	103	108
25		100	97	91	86	80	76	78	83	89	96	102	106	112
26		100	98	93	89	85	80	83	86	91	98	104	110	115
27			99	95	91	88	86	88	89	93	101	107	114	118
28				97	93	91	89	92	94	96	102	110	118	123
29					96	93	91	95	96	99	105	113	120	128
30+						96	94	98	99	102	108	115	123	130

Taulukko 5. Kuusitukkipuiden keskimääräinen kuitupuuosuus (kuorineen)
Tabelle 5. Durchschnittlicher Faserholzanteil des Fichtenblochholzes (mit Rinde)

Pituusluokka, m *Höhenklasse, m*	d-luokka, cm — *d-Klasse, cm*													
	19	21	23	25	27	29	31	33	35	37	39	41	43	45+
	dm³ kuorineen/runko — *dm³ mit Rinde/Stamm*													
10	60	60	58	57	56									
11	65	65	63	61	63	65								
12	70	70	69	70	72	74	77							
13	78	77	76	76	76	78	80	81						
14	85	84	83	83	81	81	82	83	84	84				
15	93	92	91	89	86	85	83	85	86	86	86			
16	103	103	102	95	90	87	85	87	88	88	88	90	91	
17	115	114	108	98	91	89	86	88	88	88	89	91	92	93
18	130	125	111	98	92	90	88	89	89	89	89	91	92	93
19	138	131	112	99	93	91	90	90	90	90	91	92	93	94
20	142	133	113	101	95	94	91	92	92	92	92	93	93	94
21	144	135	115	104	98	95	93	94	94	94	94	94	94	95
22	145	136	117	107	100	97	95	96	96	95	94	95	95	96
23		136	119	110	103	99	97	99	97	95	95	96	96	97
24		136	120	113	105	102	100	100	99	97	97	97	97	98
25		136	121	115	107	105	102	103	102	100	99	98	99	99
26		137	122	118	109	107	104	104	103	101	101	99	100	100
27			124	120	112	109	105	105	104	102	101	100	101	101
28			125	121	114	110	106	105	104	102	102	101	102	102
29				123	117	112	107	106	105	103	102	101	102	103
30+				125	119	114	108	106	105	103	102	102	103	103

Taulukoiden rakenne

Kuitupuutaulukoista ilmenee sovelletun luokituksen mukaisista rungoista keskimäärin saatava kuitupuuosuus kuorellisina (todellisina) kiintokuutiometreinä 6 cm:n minimiläpimittaan (kuoren alta) saakka.

Tukkipuutaulukot ilmaisevat nimensä mukaisesti rungoista keskimäärin saatavan tukkiosuuden ja latvaosista kertyvän kuitupuuosuuden, molemmat kuorellisina (todellisina) kiintokuutiometreinä.

Toistettakoon, että tukkipuiksi on luettu rungot, jotka ovat täyttäneet lähinnä seuraavat m i n i m i r u n g o l l e asetettavat vaatimukset:

— männyllä rungosta saadaan 490 × 15 cm:n kokoinen, II laatuluokan tukki,
— kuusella vähimmäisvaatimukset ovat 490 × 17 cm, oksaisuus II—III, muutoin II laatuluokka, ja
— koivulla 340 × 17 cm (III laatuluokka).

M i n i m i t u k i t ovat seuraavat: männyllä 430 × 15 cm (alaraja 14 cm), kuusella 430 × 17 (alaraja 16), ja koivulla 310 × 17 cm. Näiden perusmittojen lisäksi voidaan soveltaa eräitä apteeraus- ja luokitusohjeista ilmeneviä pituuden ja läpimitan ynnä laadun yhdistelmiä.

Tukkien keskipituudeksi pyrittiin saamaan 460—490 cm. Apteerauksen ja laatuluokituksen yksityiskohtaisen suorituksen suhteen viitataan edellä (s. 9) mainittuihin ohjeisiin. Tukkien keskilukuja esitellään suppeasti ATK-laskentaa käsittelevässä kappaleessa.

Luokitusperusteet ovat molemmissa taulukoissa samat, luokkien lukumäärät ovat sen sijaan erilaiset. Toistettakoon, että luokitusperusteet eli tunnukset ovat samat kuin I l v e s s a l o n (mt.) taulukoissa. Luokitus on seuraava.

R i n n a n k o r k e u s l ä p i m i t t a (d-) luokat: kuitupuilla 7—49, tukkipuilla 19—45 cm, 2 cm:n tasaava luokitus.

P i t u u s l u o k a t: kuitupuilla 5—27, mäntytukkipuilla 10—27 ja kuusitukkipuilla 10—30 m, metrin luokkavälein, tasaava luokitus.

K a p e n e m i s l u o k a t (d—d6 tai 3.5): kuitupuutaulukoiden kaikilla puulajeilla 1—10 cm, mäntytukkipuiden taulukoissa 2—10 ja kuusitukkipuilla 1—8 cm, senttimetrin luokkavälein, tasaava luokitus.

Läpimittojen ja pituuden mittauksen alkamiskohta on sama kuin aikaisemmissakin taulukoissa eli I l v e s s a l o n (mt.) soveltama puun juurenhaarojen määrittämä alin mahdollinen kaatokorkeus. Suoritettujen selvi-

tysten perusteella voidaan arvioida, että taulukoita käytettäessä kannon osuudeksi jää männyllä ehkä runsaat 0.5 % ja kuusella korkeintaan 0.5 %, koivulla ei mitään puun alimman kaatokorkeuden mukaisesti määritetystä rungon kuutiosta.

Taulukoiden käyttö

Taulukot on laadittu suurehkojen kuitu- ja tukkipuuerien kuutiointia varten. Kuitupuutaulukoita voidaan käyttää sekä maan etelä- että pohjoispuoliskossa, tukkipuutaulukoita suositetaan sen sijaan käytettäväksi vain maan eteläpuoliskossa. Lapissa koivukuitupuiden kuutiointiin liittynee muihin kuutioimistehtäviin verrattuna keskimääräistä enemmän virhemahdollisuuksia. Maan eteläpuoliskon pohjoisrajaksi on katsottu Oulun läänin eteläraja. Taulukot on tarkoitettu terveiden »normaalien» runkojen kuutiointiin. Vikaisuuksien vaikutus on siten otettava erikseen huomioon.

Tukkipuiden mittauksessa suositetaan erotettavaksi kaksi luokkaa, normaalit ja poikkeukselliset rungot. Jälkimmäiset voidaan kyllä kuutioida taulukoilla, mutta tulokseen on tehtävä maastossa suoritettujen mittausten osoittama siirto tukkipuuosuudesta kuitupuuhun. On mahdollista nojautua myös pystyapteeraukseen. Poikkeukselliset rungot saatetaan kuutioida myös ATK-laskentana. Tärkeintä on, että mieluummin ennen mittauksia, viimeistään mittausten yhteydessä sovitaan, erotetaanko vikaiset rungot ja miten ne kuutioidaan.

Taulukoiden käyttö edellyttää kuutioitavien puiden d (rinnankorkeusläpimitta)-, pituus- ja kapenemisluokan (d—d6 tai d3.5) määrittämistä, mieluimmin mittauksiin perustuen, d-luokka kuoren päältä usein kaikista rungoista, pituus ja kapeneminen yleensä vain sopivasti valituista koepuista. Taulukoiden tunnusten mittauksen yksityiskohtien suhteen viitataan kenttä- ja laskentatöiden ohjeisiin (K u r o n e n . . . 1970; PMP-systeemin kenttäohje 1971).

Jos taulukot eivät sisällä kuutioitavan rungon mukaista luokkaa, voidaan nojautua ekstrapolointiin tai määrittää ko. kuitu- tai kuitu- ja tukkipuuosuus taulukoiden laadinnassa käytetyllä menetelmällä. Tällöin siis I l v e s s a l o n (mt.) taulukoiden yksikkökuutioista, joihin männyllä ja kuusella on tehty 1½—1 %:n lisäys, vähennetään taulukoiden 1—5 mukaiset latva- ja kuitupuuosuudet. Pienehköt tukkien minimimittojen muutokset voidaan myös ottaa huomioon, tekemällä tarpeelliset siirrot kuitu- ja tukkipuuosuuksien välillä.

Suoritetut tutkimukset (esim. T i i h o n e n 1970) osoittavat, että taulukoita käytettäessä suurimmat virhemahdollisuudet aiheutuvat yleensä maastotöissä syntyvistä mittausvirheistä. Onkin syytä viitata mittaajien valinnan ja koulutuksen keskeiseen merkitykseen.

PUUTAVARALAJIEN ATK-LASKENTA

Yleistä

Puutavaralajien ATK-laskennan perustaksi valittiin aikaisemmin kehitetty menetelmä (Sorsa 1969; Örn ja Nousiainen 1970; Nousiainen... 1970). Sitä oli kuitenkin monilta osin tarkistettava ja täydennettävä. Uuden mittayksikön, kiintokuutiometrin valinta edellytti erityisesti tukkipuiden kuutioimismenetelmän uusimista. Tukkien mittasuhteissa tapahtui eräitä muutoksia. Toiminta laajeni myös entisestään. Kuutioimisperusteiden yhdenmukaistamista käsitellyt työryhmä sisällytti tehtäviinsä normaalien mänty- ja kuusitukkipuiden lisäksi myös poikkeukselliset havutukkipuut, kuitupuut ja koivutukkipuut. Menetelmän piiriin tulivat siten käytännöllisesti katsoen kaikki tavalliset puutavaralajit.

Muutoksista huolimatta eräät yksityiskohdat säilyivät entisellään. Ilvessalon (1947) »Pystypuiden kuutioimistaulukot» ovat myös uuden ATK-laskentamenetelmän keskeisin peruste. Muista aikaisemmin käytetyistä perusteista mainittakoon kapenemistaulukot, kuoren paksuutta osoittavat sarjat, tukkien lukumäärää ja pituuksia osoittavat matriisit jne. Perusteita käsitellään lähemmin jäljempänä.

Laaditun ATK-menetelmän tekninen suunnittelu ja valmistaminen on tapahtunut valtion tietokonekeskuksen Oulun aluekeskuksessa allekirjoittaneen Nousiaisen johdolla. Tehtävässä on avustanut fil. maisteri Juha Puranen (metsäntutkimuslaitos).

Lähtötiedot

ATK-laskennassa sovelletaan aikaisemmin kehitettyjä PMP-systeemin lomakkeita (PMP-systeemin kenttätyöohje 1971).

Koepuut merkitään siten pystymittauksen yhteydessä PMP-2-lomakkeelle. Kuitu- ja tukkikoepuut voidaan merkitä samalle lomakkeelle.

Runkolukusarjat kootaan puiden luvun yhteydessä läpimittaluokittain ja runkolajeittain PMP-1-lomakkeelle.

Tietokonekäsittelyä varten tiedot lävistetään lomakkeilta reikäkorteille, joilta ne siirretään tarkistuksia suorittavalla ohjelmalla magneettilevymuistille. Ennen varsinaisten kuutiointiohjelmien ajoa aineisto lajitellaan perusrekisteriksi.

Tietokonekäsittelyn logiikka

Edellä esitetyn mukaisesti ATK-laskentaan sisältyy sekä erotus-, että pölkytysmenetelmä. Seuraavassa esitetään molempien menetelmien tietokonelaskennan suoritustapa.

Erotusmenetelmä, jonka perustan muodostavat Ilvessalon »Pystypuiden kuutioimistaulukot» ja edellä taulukoissa 1—5 esitetyt keskimääräiset latva- ja kuitupuuosuudet, sisältää seuraavat toiminnot.

1) Rungon kuutioimistunnuksilla (rinnankorkeusläpimitta d, pituus h ja kapeneminen d—d6) haetaan Ilvessalon »Pystypuiden kuutioimistaulukoista» kuorellinen yksikkökuutio, johon männyllä tehdään 1½ %:n ja kuusella 1 %:n lisäys kannon osuutena. Latvaosuus vähennetään taulukoiden mukaisesti.
   Tuloksena saadaan rungon käyttöosan tilavuus V todellisina k-m³:nä. Kuitupuille ei suoriteta muita toimintoja. Tukkipuilla laskenta jatkuu seuraavasti:

2) Kuutioimistunnuksilla d ja h haetaan taulukoista 4 ja 5 rungon keskimääräinen kuitupuuosuus L todellisina k-m³:nä.

3) Tukkipuuosuus J saadaan todellisina k-m³:nä erotuksella J = V—L.

Pölkytysmenetelmä, jonka perustan muodostavat Ilvessalon »Pystypuiden kuutioimistaulukot» ja kapenemistaulukot (Tiihonen 1961), sisältää vuorostaan seuraavat toiminnot.

1) Suoritetaan täsmälleen samat toimenpiteet kuin erotusmenetelmän kohdassa 1. Saadaan siis rungon käyttöosan tilavuus V todellisena k-m³:nä. Kuitupuille ei suoriteta muita toimintoja. Jäljempänä esitetty koskee jälleen vain tukkipuita.

2) Rungon kuutioimistunnuksilla (d, h ja d—d6) haetaan kapenemistaulukoista puun runkomuotoa kuvaava prosenttisarja. Sitä täydennetään seuraavilla 0,5 m:n korkeuden läpimittaa kuvaavilla keskimääräisillä sadanneksilla: mänty 112 %, kuusi 109 % ja koivu 109 %.

3) Lasketaan prosenttilukuja vastaavat määrälliset läpimitat, joihin tehdään ns. d6-korjaus (täsmennetään 2 cm:n kapenemisluokan osoittamaa runkoviivaa)

— välillä 2—6 m kaavan $\frac{100-Pi}{100-P6} \cdot d$ mukaan

— välillä 7 m + kaavan $\frac{Pi}{P6} \cdot d$ mukaan

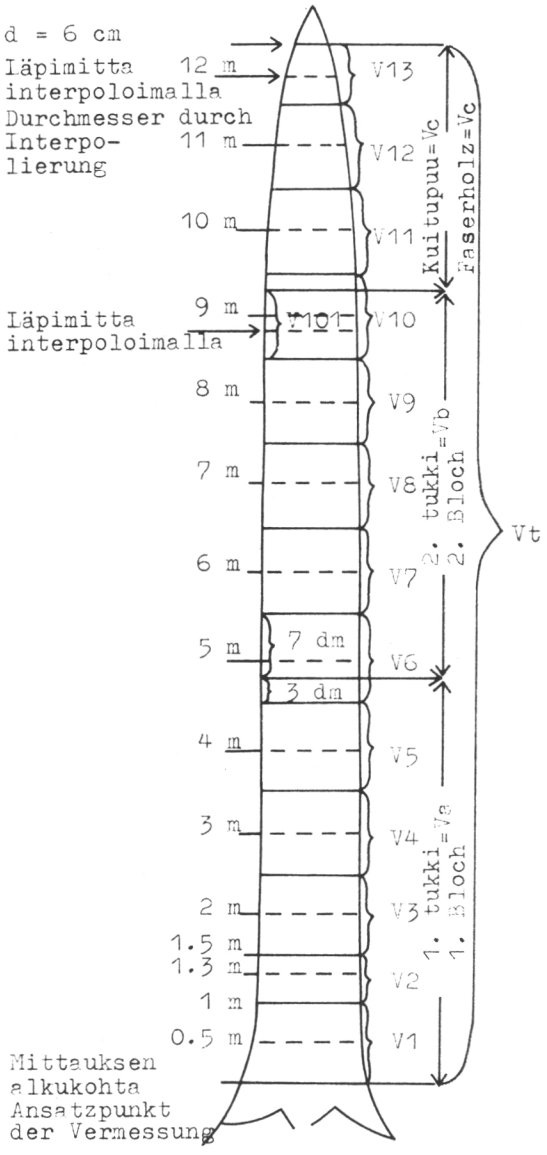
Pi = prosenttiluku i-metrin korkeudella
P6 = prosenttiluku 6 m:n korkeudella
d = lasketun d6 ja mitatun d6 ero millimetreissä.

4) Täsmennettyjä läpimittoja käyttäen lasketaan ko. rungonosan todellinen kiintokuutiomäärä 6 cm:n latvaläpimittaan (kuoren alta) saakka. Laskentatapa on esitetty kuvassa 2. Tuloksena saadaan puun käyttöosan tilavuus Vt todellisina k-m³:nä.

5) Lasketaan normaalien mänty- ja kuusitukkipuiden tukkiosan pituus desimetreinä kohdan 3 läpimittoja käyttäen. Määrittämisessä nojaudutaan d- ja pituusluokittain ryhmitettyihin keskimääräisiin latvatukin latvaläpimittoihin (kuoren päältä), ns. tukkiosan päättymisläpimittoihin. Seuraavan asetelman lukusarjat havainnollistavat päättymisläpimitan suuruutta eräissä esimerkeiksi valituissa luokissa.

Puulaji *Holzart*	Pituusluokka, m *Höhenklasse, m*	d-luokka, cm — *d-Klasse, cm*				
		19	23	29	35	41
Mänty *Kiefer*	—13	154	169	188	210	210
	14—15	153	158	172	200	210
	20—21	150	154	167	182	205
	26—27	151	158	168	184	203
	28+	152	158	168	186	203
Kuusi *Fichte*	—13	171	174	195	210	210
	14—15	170	173	195	205	210
	20—21	171	174	180	187	195
	26—27	171	174	179	185	192
	28+	171	174	179	186	193

Koivutukkipuiden tukkiosuuden päättymiskorkeus mitataan maastossa, joten laskennassa käytetään tätä pituutta. Samoin menetellään niiden poikkeuksellisten havutukkipuiden osalta, joille tukkiosan päättymiskorkeus on mitattu. Saatu tukkiosuus pölkytetään matriiseilla, joista ilmenee ko. pituutta vastaavat tukit. Seuraavassa esitetään männyn ja kuusen matriisit.



Vt = TIIHOSEN (1961b) kapenemissarjan avulla laskettu käyttöosan k-m³-määrä - fm-Menge des mit Hilfe von TIIHONENS (1961b) Ausbauchungstafeln berechneten Nutzteils

Va = 1. tukin k-m³-määrä - fm-Menge des 1. Blochs.

Vb = 2. tukin k-m³-määrä - fm-Menge des 2. Blochs.

Vc = Kuitupuun k-m³-määrä - fm-Menge des Faserholzes.

V1, V2, ... V13 = Pätkien k-m³-määrät fm-Menge der Abschnitte.

V101 = Ylimmän tukin viimeinen laskentapätkä silloin, kun tukki ei pääty tasan jonkin 0.5 m:n kohdalle - letzter mitgerechnter Abschnitt des obersten Blochs, wenn der Bloch nicht genau bei einem 0.5 m endigt.

$Vt = V1 + V2 + \ldots V13$

$Va = V1 + V2 + V3 + V4 + V5 + (\frac{3}{10} \cdot V6)$

$Vb = (\frac{7}{10} \cdot V6) + V7 + V8 + V9 + V101$

$Vc = Vt - (Va + Vb)$

Kuva 2. Pölkytysohjelman mukainen kuutiointi.
Abb 2. Kubierung nach der Ablängungsmethode.

Tukkiosa, dm *Blochholzanteil, dm*	Tukkien pituudet dm [1]) *Blochholzlängen, dm* [1]) I	II	III
141	49	46	46
138	49	46	43
135	46	46	43
132	46	43	43
129	43	43	43
126	40	43	43
123	40	40	43
119	61	58	
116	61	55	
113	58	55	
110	58	52	
107	55	52	
104	55	49	
101	52	49	
98	49	49	
95	49	46	
92	46	46	
89	46	43	
86	43	43	
83	40	43	
80	37	43	
79	61		
76	61		
73	61		
70	61		
67	61		
64	61	Latvaläpi-	
61	61	mitta, mm	
58	58	*Oberstärke, mm*	
55	55		
52	52	Mänty	Kuusi
49	49	*Kiefer*	*Fichte*
46	46		
43	43		
40	40	160	180
37	37	180	200
34	34	180	
31	31	200	

Tukkiosa, dm *Blochholzanteil, dm*	Tukkien pituudet dm [1]) *Blochholzlängen, dm* [1]) I	II	III	IV	V
254	61	52	49	46	46
251	58	52	49	46	46
248	58	49	49	46	46
245	55	49	49	46	46
242	55	49	49	43	46
239	55	49	49	43	43
236	52	49	49	43	43
233	52	49	46	43	43
230	52	46	46	43	43
227	49	46	46	43	43
224	49	46	43	43	43
221	46	46	43	43	43
217	61	58	49	49	
214	61	55	49	49	
211	58	55	49	49	
208	58	52	49	49	
205	55	52	49	46	
202	55	52	49	46	
199	55	52	46	46	
196	55	49	46	46	
193	52	49	46	46	
190	52	49	46	43	
187	52	46	46	43	
184	49	46	46	43	
181	49	46	43	43	
178	49	43	43	43	
175	46	43	43	43	
172	43	43	43	43	
168	61	55	52	—	
166	40	40	43	43	
162	58	52	52		
159	55	52	52		
156	55	52	49		
153	52	52	49		
150	52	49	49		
147	52	49	46		
144	49	49	46		

[1]) I = tyvitukki — *Wurzelbloch.*

6) Kohdassa 3 laskettuja läpimittoja ja kohdassa 5 laskettuja tukkien pituuksia käyttäen lasketaan vastaavat pölkkyjen todelliset kiintokuutiomäärät (ks. kuva 2). Näiden summana saadaan tukkiosan koko kuutiomäärä Jt todellisina k-m³:nä.

7) Kuitupuuosuus Lt saadaan todellisina k-m³:nä kaavalla:

$$Lt = Vt—Jt$$

8) Kapenemissarjoilla lasketut tukki- ja kuitupuuosuudet korjataan kertomalla ko. arvot osamäärällä $\frac{V}{Vt}$. Tässä V on kohdassa 1 I l v e s-

salon taulukoilla saatu käyttöosan tilavuus ja Vt kohdassa 4 kapenemissarjalla saatu vastaava arvo. Laskennan jälkeen tukki- ja kuitupuuosuuksien summa on Ilvessalon taulukoiden rungon käyttöosan tilavuus V.

9) Havutukkien teknilliset latvaläpimitat määritetään kohdassa 3 lasketuista läpimitoista, joista ensin interpoloidaan kuorellinen latvaläpimitta millimetreissä. Tästä vähennetään kuoren osuus seuraavien lukujen mukaisesti:

	d-luokka, cm											
	19	21	23	25	27	29	31	33	35	37	39	41+
	Kaksinkertainen kuoren vahvuus, mm											
Mänty												
tyvitukki	6	6	7	8	9	9	9	10	11	12	13	14
välitukki	6	5	5	5	5	6	6	6	6	6	7	7
latvatukki	6	5	5	5	5	5	5	5	5	5	6	6
Kuusi												
tyvitukki	9	9	10	10	11	11	12	12	13	14	15	16
välitukki	9	8	9	9	10	10	11	11	11	11	12	12
latvatukki	9	8	9	9	9	9	9	10	10	10	10	10

Tulokseksi saadaan kuoreton latvaläpimitta. Tulokset luokitellaan seuraavasti:

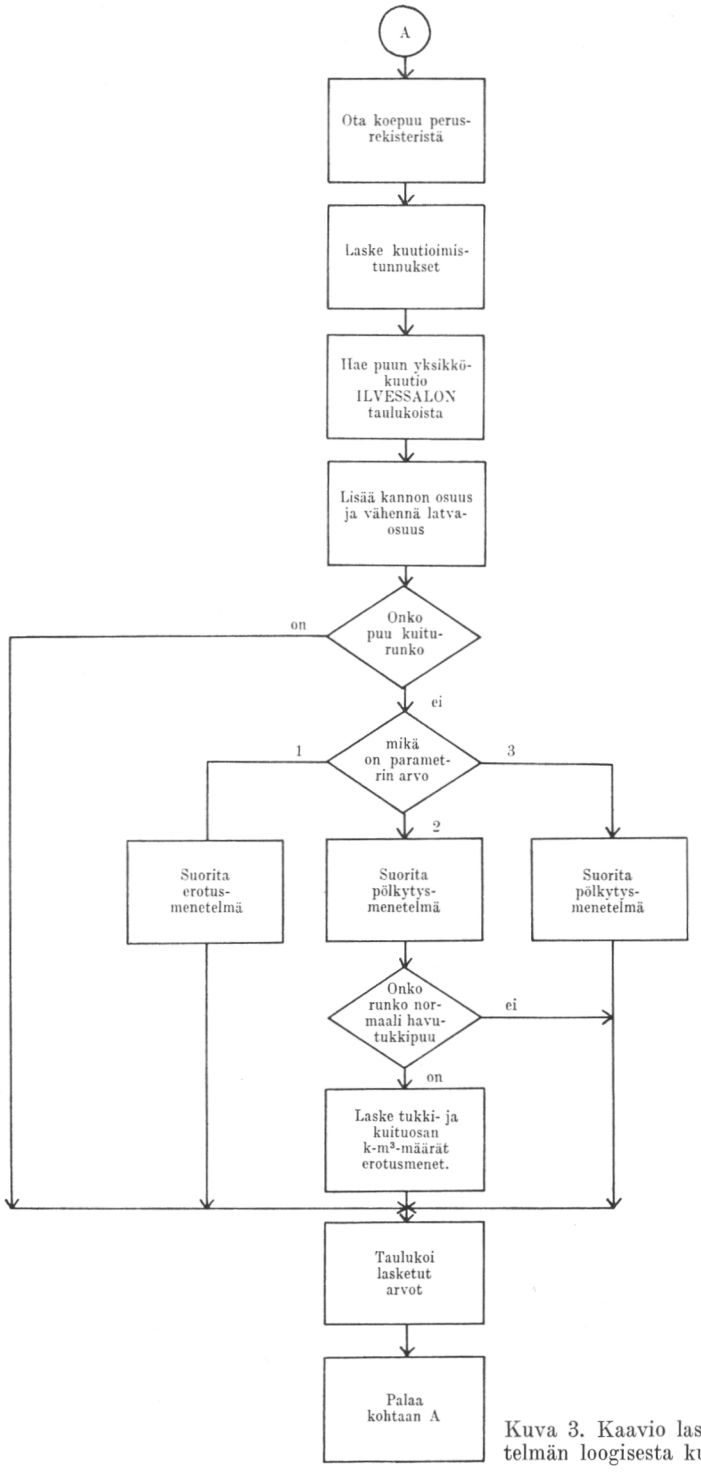
120—139 mm = 13 cm:n luokka
140—159 » = 15 » »
160—179 » = 17 » »
jne.

Koivutukeille ei teknillistä latvaläpimittaa lasketa. Sen sijaan tukit sijoitetaan esim. tulostusta varten läpimittaluokkiin keskeltä kuoren päältä lasketun läpimitan (interpoloitu kohdan 3 läpimitoista) perusteella.

Molemmat edellä kuvatut menetelmät on laadittu yhdeksi laskentajärjestelmäksi, jota tukkipuiden osalta voidaan ohjata parametritiedolla. Ko. tieto voi saada kolme eri arvoa, joiden merkitys esitetään seuraavassa:

Parametri on 1:

Kaikki havutukkipuut käsitellään vain erotusmenetelmällä. Mikäli laskennassa on mukana poikkeuksellisia havutukkipuita (ks. s. 14), käsitellään ne runkomittojen mukaisina normaaleina runkoina. Kaikki koivutukkipuut käsitellään pölkytysmenetelmällä.



Kuva 3. Kaavio laskentajärjestelmän loogisesta kulusta.

Parametri on 2:

Kaikki tukkipuut käsitellään pölkytysmenetelmällä, mutta normaaleille havutukkipuille lasketaan eri puutavaralajien osuudet todellisina k-m³:nä erotusmenetelmällä.

Parametri on 3:

Kaikki tukkipuut käsitellään vain pölkytysmenetelmällä.

Laskentajärjestelmän looginen kulku on esitetty kaavioilla kuvassa 3.

Tulostus

Leimikoittaisen tulostuslistan (PMP:n tulostus E 3) yläosasta nähdään runkolukusarjat ja yksikkökuutiot, alaosasta puutavaralajeittaiset tulokset. Alaosaa valaistaan lähemmin seuraavassa.

Runkolaji				Sahatukkia/vko			Erikois-	Kuitua		
Lyhenne	n:o	Tukkeja kpl	Tod k-m³	Dm³/R	Dm³/kpl	Dm/kpl	puu k-m³	Mäp	Kup	Kop
A	B	C	D	E	F	G	H	I	J	K

A = runkolajin nimi lyhennettynä
B = runkolajin koodi
C = tukkien lukumäärä (vain parametrin arvoilla 2 ja 3)
D = tukkiosuuden k-m³-määrä
E = tukkiosuuden k-m³-määrä runkoa kohden
F = D/C (vain parametrin arvoilla 2 ja 3)
G = tukkien keskipituus (vain parametrin arvoilla 2 ja 3)
H = tukkiosuuden erikoispuun k-m³-määrä
I = mäntykuitupuun k-m³-määrä
J = kuusikuitupuun k-m³-määrä
K = koivukuitupuun k-m³-määrä

KUUTIOIMISMENETELMÄN LUOTETTAVUUDESTA

Ilvessalon »Pystypuiden kuutioimistaulukoiden» keskeinen asema uudessa kuutioimismenetelmässä antoi aiheen jatkaa taulukoiden luotettavuuden tutkimista. Tarkastelu rajoitettiin kuitenkin vain tukkipuun mitat täyttäviin runkoihin. Pienin d-luokka oli siten 19 cm. Sekä taulukko- että tarkistusaineiston mittaustietojen perusteella kuutioitiin jokainen koepuu Ilvessalon (mt.) taulukoilla ja toisaalta pätkittäisen kuutioinnin mukaisesti. Ilvessalon taulukoilla saatuja männyn kuutiomääriä suurennettiin edellä (s. 16) mainitun mukaisesti 1½ %:lla, kuusella vuorostaan 1 %:lla. Pätkittäisessä kuutioinnissa jäi kannon osuudeksi männyllä runsaat ½ % ja kuusella korkeintaan ½ %. Koivun tulokset luonnehtivat juurenniskan yläpuolelle jäävää kuutiomäärää, jossa kannolle ei ole jäänyt mitään osuutta.

Laskentatavasta johtuen saatuja tulospareja voitiin tarkastella jokaisen koepuun osalta erikseen ja edelleen d-, pituus- ja kapenemisluokittain sekä koeleimikoittain. Vertailumahdollisuudet olivat jälleen laajat ja monipuoliset. Runsaasti tilaa vievien tulossarjojen esittelyssä onkin rajoituttava vain suppeisiin esimerkkeihin. Taulukkoaineiston osalta esitetään tarkistusaineiston keruun ajankohtana, kesä—syyskaudella 1971, mitattujen mäntyjen ja kuusien sekä koivun kapenemistaulukoiden laadinnassa käytettyjen runkojen kokonaiskuutiomäärät ja d-luokittaiset tulokset. Vertailu nähdään taulukosta 6.

Tarkistusaineiston avulla tehtyjen vertailujen tuloksia valaistaan ensin taulukossa 7, josta nähdään »normaalien» mäntyjen ja kuusien koeleimikoittaiset kokonaiskuutiomäärät. Poikkeuksellisten mäntyjen ja kuusien kokonaiskuutiomäärät muodostuivat seuraaviksi. Pääosa koepuista koostuu tehdyn suunnitelman mukaisesti Rauma-Repola Oy:n metsäosaston tarkistusleimikosta (leimikko n:o 12).

Puulaji *Holzart*	Runkoluku *Anzahl der Stämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Taulukot *Tabellen*
		k-m³ kuorineen — *fm m. R.*	
Mänty — *Kiefer*	520	264.8	262.0
Kuusi — *Fichte*	236	120.4	119.3

Taulukko 6. Ilvessalon (1947) »Pystypuiden kuutioimistaulukoilla» ja pätkittäisellä kuutioinnilla saatujen tulosten vertailua. — Taulukkoaineisto

Tabelle 6. Vergleich zwischen den mit den »Massentafeln für stehende Bäume» von Ilvessalo (1947) und den mit sektionsweiser Kubierung erzielten Resultaten. — Tafelnmaterial

d-luokka, cm *d-Klasse, cm*	Mänty — *Kiefer*			Kuusi — *Fichte*			Koivu — *Birke*		
	Runkoluku *Anzahl der Stämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Taulukot *Tafeln* (Ilvessalo 1947)	Runkoluku *Anzahl der Stämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Taulukot *Tafeln* (Ilvessalo 1947)	Runkoluku *Anzahl der Stämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Taulukot *Tafeln* (Ilvessalo 1947)
19	72	18.4	18.4	59	17.4	17.2	52	14.6	14.4
21	102	32.9	32.5	233	78.4	78.5	150	55.3	55.2
23	182	71.8	70.0	273	115.3	114.6	312	133.3	132.7
25	169	82.5	80.9	236	124.5	124.3	331	169.5	169.7
27	230	138.8	137.1	209	129.2	129.5	290	172.5	174.1
29	237	170.5	169.4	146	109.7	109.7	234	157.1	159.0
31	182	150.3	150.1	125	109.8	110.5	147	112.0	113.2
33	158	149.6	148.9	79	79.9	80.8	105	91.4	92.9
35	135	147.1	147.6	72	82.2	83.1	59	57.8	58.0
37	100	123.4	124.2	43	54.6	56.0	45	48.8	49.3
39	44	61.8	62.2	30	44.0	44.4	21	25.4	25.5
41+	36	59.4	59.7	21	35.4	34.9	15	22.1	21.8
Yhteensä — *Insgesamt*	1 647	1 206.5	1201.0	1 526	980.4	983.5	1 761	1 059.8	1 065.8

Koivun tarkistusaineiston kolmen koeleimikon tulokset esitetään seuraavassa asetelmassa.

Koeleimikko *Probebestand*	Runkoluku *Anzahl der Stämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Taulukot *Tabellen*
		k-m³ kuorineen — *fm m. R.*	
Kouvola 1967	660	295.1	295.9
Padasjoki 1968	531	296.0	297.0
Toivakka 1972	646	310.0	310.6
Yhteensä — *Insgesamt*	1 837	901.1	903.5

Esittelyn ulkopuolelle jääneet muut tulossarjat ovat hyvin yhdenmukaiset esimerkkeinä esitettyjen taulukoiden ja asetelmien tulosten kanssa. Suoritetut vertailut vahvistavat siten osaltaan jo aikaisemmin »Pystypuiden kuutioimistaulukoiden» laadinnan yhteydessä (Ilvessalo mt., s. 32—36) ja myöhemmin muissa tutkimuksissa (esim. Tiihonen 1966 a, 1966 b, 1970; Nousiainen... 1970) todettua taulukoiden erinomaista luotettavuutta.

Toisena tarkastelukohteena olivat puutavaralajeittain saadut tulokset. Lisäksi tehtiin keskimääräisten latvaosuuksien luotettavuutta koskevia vertailuja.

Taulukko 7. Ilvessalon (1947) »Pystypuiden kuutioimistaulukoilla» ja pätkittäisellä kuutioinnilla saatujen tulosten vertailua. — Tarkistusaineiston normaalit männyt ja kuuset

Tabelle 7. Vergleich zwischen den mit den »Massentafeln für stehende Bäume» von Ilvessalo (1947) und den mit sektionsweiser Kubierung erzielten Resultaten. — Normale Kiefern und Fichten des Kontrollmaterials

Koeleimikko [1] *Ausgezeichneter Probebestand* [1]	Mänty — *Kiefer*			Kuusi — *Fichte*		
	Runkoluku *Anzahl der Stämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Taulukot *Tafeln* (Ilvessalo 1947)	Runkoluku *Anzahl der Stämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Taulukot *Tafeln* (Ilvessalo 1947)
1	57	42.6	41.8	54	31.9	30.6
2	172	140.6	139.1	179	79.1	79.2
3	197	100.0	100.0	166	117.8	121.8
4	239	197.7	198.1	239	123.6	124.8
5	193	132.3	133.0	147	84.6	85.7
6	134	98.2	98.7	196	138.6	144.6
7	178	87.6	88.9	182	94.8	94.9
8	88	55.7	54.3	148	81.0	81.2
9	179	111.4	109.0	20	9.1	9.2
10	180	193.5	192.0	32	24.5	24.8
11	230	105.4	104.9	198	133.4	131.5
13	204	102.2	101.5	255	153.9	151.6
14	273	150.3	149.6	251	168.1	169.1
15	477	230.7	233.2	472	206.2	205.8
16	207	95.4	95.4	180	90.3	90.6
17	221	191.0	190.7	205	77.1	76.7
18	192	132.5	135.2	181	118.8	120.2
Yhteensä — *Insgesamt*	3 421	2 167.1	2 165.4	3 105	1 732.8	1 742.3

[1]) Koeleimikoiden esittely, ks. s. 9—10. — *Probebestände s. S.* 9—10.

Kuitupuiden kuutioimismenetelmän luotettavuuden osalta rajoitutaan vain viittaamaan edellä tarkasteltuun, koko rungon kuutiomääriä luonnehtivien Ilvessalon (mt.) taulukoiden yksikkökuutioiden luotettavuuteen, latvaosuuksien tarkkuudesta saatuihin myönteisiin tuloksiin ja aikaisemmin tehtyjen paperipuutaulukoiden luotettavuutta valaiseviin vertailuihin (Tiihonen 1966 a, 1969 b, 1970). Vielä mainittakoon jäljempänä esitettävät tukkipuiden tukki- ja kuitupuuosuuksia koskevat tulokset, jotka yhdistämällä saadaan kuva järeiden kuitupuiden kuutioinnin luotettavuudesta. Vertailu on mahdollinen siitä syystä, että sekä kuitu- että tukkipuiden kuutioimismenetelmässä on edellä esitetyn mukaisesti nojauduttu samoihin latvaosuuksiin. Kaikki tulokset ovat varsin yhdenmukaiset ja antavat aiheen päätellä, että kuitupuiden kuutioimismenetelmällä saadaan varsin hyviä tuloksia.

Taulukko 8. Mänty- ja kuusitukkipuiden [1]) tarkistuslaskelmien tulokset koeleimikoittain

Tabelle 8. Resultate der Kontrollberechnungen von Kiefern- und Fichtenblochholz [1]) in ausgezeichneten Probebeständen

Puulaji *Holzart*	Koeleimikko *Probebestand*	Runkoluku *Anzahl der Stämme*	Tukkiosuus *Blochholzanteil*			Kuitupuuosuus *Faserholzanteil*		
			Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotusmenet. ja taulukot *EDV, Abzugsmethode und Tafeln*	Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotusmenet. ja taulukot *EDV, Abzugsmethode und Tafeln*
			k-m³ kuorineen — *fm m. R.*					
Mänty *Kiefer*	1	57	38.2	37.8	37.6	4.3	3.9	4.1
	3	197	86.8	85.4	85.4	12.7	13.9	14.0
	4	239	182.1	179.7	178.7	15.1	17.7	18.7
	5	193	118.9	117.8	118.3	12.9	14.6	14.2
	7	178	74.9	75.8	75.7	12.2	12.5	12.6
	8	88	50.9	48.4	47.8	4.6	5.7	6.2
	9	179	100.0	96.5	95.7	11.1	12.1	12.9
	10	180	172.9	171.2	172.6	16.8	17.4	16.0
	11	230	86.5	88.3	88.4	18.3	15.9	15.9
	13	204	86.3	87.4	86.8	15.4	13.5	14.0
	14	273	131.3	127.3	128.1	18.4	21.4	20.6
	15	477	193.6	197.4	197.2	35.6	34.3	34.6
	16	207	82.9	79.8	80.0	12.1	14.9	14.7
	17	221	174.6	173.6	173.1	16.0	16.5	17.0
	18	192	115.4	119.9	120.2	16.6	14.7	14.4
	Yhteensä— *Insgesamt*	3 115	1 695.3	1 686.3	1 685.5	222.1	229.0	229.9
Kuusi *Fichte*	1	54	25.0	24.5	24.6	5.5	5.6	5.4
	2	179	61.1	58.2	58.6	17.4	20.4	20.0
	4	239	96.0	97.7	98.3	26.8	26.2	25.6
	5	147	70.0	69.8	70.3	14.0	15.4	14.9
	7	182	76.0	76.2	76.1	18.3	18.1	18.3
	8	148	64.1	66.0	65.0	16.4	14.7	15.7
	9	20	6.7	7.1	7.1	2.3	2.0	2.0
	10	32	20.9	20.9	21.1	3.5	3.8	3.5
	11	198	112.8	110.6	110.6	20.0	20.3	20.3
	13	255	127.0	124.5	124.1	25.5	25.7	26.2
	14	251	142.7	141.0	141.9	24.6	27.3	26.4
	15	472	157.5	156.5	156.8	46.8	47.4	47.1
	16	180	73.0	72.2	71.8	16.8	17.8	18.2
	17	205	56.9	54.9	54.9	19.5	21.0	21.0
	18	181	99.6	100.1	100.6	18.7	19.5	19.0
	Yhteensä— *Insgesamt*	2 743	1 189.3	1 180.2	1 181.8	276.1	285.2	283.6

[1]) Normaalit tukkipuut. — *Normale Blochholzstämme.*

Tukkipuiden kuutioimismenetelmällä saatavien eri puutavaralajien osuuksien tarkastelu kohdistuu kuten edellä koko rungoillakin kolmelle taholle: normaalit männyt ja kuuset, poikkeukselliset männyt ja kuuset sekä koivut. Suoritetut laskelmat tarjoavat jälleen erittäin runsaasti erilaisia vertailumahdollisuuksia. Esityksen supistamista silmällä pitäen on nytkin rajoituttava vain esimerkkeihin.

Tukkipuiden keskeisintä ryhmää, normaaleja mäntyjä ja kuusia koskevat esimerkit on koottu taulukkoihin 8—11. Pituusluokittaisten tulosten esittelyssä on rajoituttu vain mäntyyn, kapenemisluokittaisten tulossarjojen osalta vuorostaan kuuseen. Taulukoiden sarakkeissa »mittaus» olevat lukusarjat tarkoittavat kaadetuista koepuista tehdyn apteerauksen ja kuitupuuosuuden erottamisen mukaisesti pätkittäisellä kuutioinnilla saatuja tuloksia. Koska ATK-laskennan erotusmenetelmällä ja tukkipuutaulukoilla saadaan, samoista laadintaperusteista johtuen, aina samat tulokset, on taulukossa rajoituttu näiden vaihtoehtojen osalta yhteen sarakkeeseen: ATK-laskenta, erotusmenetelmä ja taulukot. Mäntytukkipuiden taulukosta puuttuu koeleimikoiden n:o 2, 6 ja 12 tulokset. Viimeksi mainittu on jäljempänä tarkasteltaviin poikkeuksellisiin tukkipuihin sisältyvä Rauma-Repola Oy:n metsäosaston koeleimikko. Kahdessa muussa koeleimikossa (2 ja 6) oli sovellettu muihin verrattuna hieman poikkeavia apteerausperusteita. Samasta syystä johtuen taulukkoon ei ole myöskään sisällytetty kahden kuusileimikon (3 ja 6) tuloksia.

Taulukoiden 8—11 esimerkit osoittavat, että molemmilla vaihtoehtoisilla laskentatavoilla on päästy sekä tukki- että kuitupuuosuudessa hyvin yhdenmukaisiin tuloksiin. Erot todellisiin, mittaukseen perustuviin tuloksiin ovat molemmilla puutavaralajeilla yleisesti pieniä ja vaihtelevat lisäksi sekä + että — suuntaan. Keskimääräispiirteenä havaitaan kuitenkin lievä aliarviointi tukkiosuudessa ja määrällisesti likimäärin samansuuruinen yliarviointi kuitupuuosuudessa. Koska tarkistusaineiston koepuut ovat maastossa suoritettujen arviointien mukaan laadullisesti pikemminkin keskitasoa hieman parempia kuin huonompia, ei tukkiosuudessa ilmenevä vähäinen aliarviointi ole haitallinen piirre. Näyttää ilmeiseltä, että normaalien mänty- ja kuusitukkipuiden kuutioimismenetelmä johtaa varsin luotettaviin tuloksiin.

Todettakoon, että taulukoiden 8—11 tuloksiin on tehty ATK-laskennan erotusmenetelmällä ja taulukoilla saatujen männyn tukkiosuuden kohdalla aikaisemmin julkaistuihin (Tiihonen 1972 b, s. 8) lukuihin verrattuna vähäinen tarkistus, mikä johtuu tietokonekäsittelyssä todetun pienen häiriön poistamisesta.

Yksinomaan ATK-laskentana suoritetussa poikkeuksellisten mänty- ja kuusitukkipuiden kuutioinnissa saatiin tulossarjoja, jotka ilmaisevat tukkien, tyveyksien ja leikkojen sekä latvoista kertyvän kuitupuun kuutio-

Taulukko 9. Mänty- ja kuusitukkipuiden [1]) tarkistuslaskelmien tulokset d-luokittain. — Kaikki koeleimikot yhteensä

Tabelle 9. Resultate der Kontrollberechnungen von Kiefern- und Fichtenblochholz [1]) in den verschiedenen d-Klassen. — Alle Probebestände zusammen

Puulaji *Holzart*	d-luokka, cm *d-Klasse, cm*	Runkoluku *Anzahl der Stämme*	Tukkiosuus *Blochholzanteil*			Kuitupuuosuus *Faserholzanteil*		
			Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotusmenet. ja taulukot *EDV, Abzugsmethode und Tafeln*	Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotusmenet. ja taulukot *EDV, Abzugsmethode und Tafeln*
			k-m³ kuorineen — *fm m. R.*					
Mänty *Kiefer*	19	154	23.8	23.5	23.8	13.6	14.0	13.7
	21	302	64.7	63.6	63.8	23.5	24.4	24.2
	23	415	121.0	119.3	118.8	28.5	29.4	29.9
	25	401	151.3	149.6	149.2	26.5	27.1	27.4
	27	459	215.4	214.6	214.5	30.6	31.3	31.5
	29	395	228.2	226.0	225.9	25.9	26.8	26.9
	31	303	208.7	208.7	208.6	20.4	20.7	20.8
	33	239	195.6	194.8	194.3	15.8	16.7	17.3
	35	186	176.7	175.9	175.9	14.1	14.6	14.7
	37	124	133.7	133.5	133.4	10.1	10.4	10.4
	39	89	107.4	107.9	108.2	8.6	8.4	8.1
	41+	48	68.8	68.9	69.1	4.5	5.2	5.0
	Yhteensä— *Insgesamt*	3 115	1 695.3	1 686.3	1 685.5	222.1	229.0	229.9
Kuusi *Fichte*	19	111	15.7	15.4	15.5	12.1	12.4	12.3
	21	389	74.8	74.5	74.8	45.2	45.5	45.2
	23	555	154.3	151.2	152.7	60.9	62.5	61.1
	25	472	172.3	169.5	170.3	46.1	48.2	47.4
	27	415	194.8	193.0	192.9	39.1	40.0	40.1
	29	338	196.8	195.8	195.8	31.6	32.5	32.5
	31	214	151.8	151.7	151.4	19.2	20.3	20.6
	33	129	105.7	106.1	105.9	11.6	12.5	12.7
	35	61	57.0	56.6	56.4	5.2	5.8	6.0
	37	37	39.2	39.1	38.9	3.1	3.4	3.6
	39	22	26.9	27.3	27.2	2.0	2.1	2.1
	Yhteensä— *Insgesamt*	2 743	1 189.3	1 180.2	1 181.8	276.1	285.2	283.6

[1]) Normaalit rungot. — *Normale Stämme.*

määriä. Tulosten esittelyssä rajoitutaan vain taulukosta 12 nähtäviin, kaikki osa-aineistot yhdistäen saatuihin tuloksiin.

Molempien puulajien tulossarjat viittaavat vähintään kohtuullisen luotettaviin tuloksiin. Lähinnä männyn kokonaismäärään sisältyvien osa-aineistojen samoin kuin d-, pituus- ja kapenemisluokittaiset tulossarjat vahvistavat asetelman osoittamaa myönteistä kuvaa myös pienempien runko-

Taulukko 10. Mäntytukkipuiden tarkistuslaskelmien tulokset pituusluokittain. — Kaikki koeleimikot yhteensä

Tabelle 10. Resultate der Kontrollberechnungen des Kiefernblochholzes in den verschiedenen Höhenklassen. — Alle Probebestände zusammen

Pituusluokka, m *Höhenklasse, m*	Runkoluku *Anzahl der Stämme*	Tukkiosuus *Blochholzanteil*			Kuitupuuosuus *Faserholzanteil*		
		Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotus menet. ja taulukot *EDV, Abzugsmethode und Tafeln*	Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotusmenet. ja taulukot *EDV, Abzugsmethode und Tafeln*
11	4	0.6	0.6	0.6	0.2	0.2	0.2
12	16	2.9	2.9	2.9	1.0	0.9	1.0
13	40	7.3	7.3	7.5	3.0	2.8	2.6
14	67	14.6	14.5	14.6	4.7	4.6	4.6
15	129	30.5	29.5	29.5	8.5	9.1	9.0
16	187	50.0	49.0	48.7	12.5	13.0	13.3
17	275	87.8	85.8	86.3	19.5	20.2	19.7
18	365	134.4	134.6	133.4	25.8	24.6	25.8
19	402	177.7	176.5	176.1	27.3	28.0	28.6
20	400	211.4	210.6	209.5	27.4	27.6	28.6
21	324	198.9	196.5	196.3	22.1	23.3	23.4
22	284	197.2	197.0	196.5	20.0	20.7	21.1
23	206	162.3	162.2	162.3	14.6	15.9	15.9
24	149	132.4	132.2	132.4	11.0	12.1	12.0
25	98	100.5	100.8	101.4	8.6	9.1	8.4
26	64	63.3	63.2	63.6	5.6	6.0	5.6
27+	105	123.5	123.1	123.9	10.3	10.9	10.1

Taulukko 11. Kuusitukkipuiden tarkistuslaskelmien tulokset kapenemisluokittain. — Kaikki koeleimikot yhteensä

Tabelle 11. Resultate der Kontrollberechnungen des Fichtenblochholzes in den verschiedenen Ausbauchungsklassen. — Alle Probebestände zusammen

Kapenemisluokka, cm *Ausbauchungsklasse, cm*	Runkoluku *Anzahl der Stämme*	Tukkiosuus *Blochholzanteil*			Kuitupuuosuus *Faserholzanteil*		
		Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotusmenet. ja taulukot *EDV, Abzugsmethode und Tafeln*	Mittaus *Messung*	ATK-lask., pölkytysmenet. *EDV, Ablängungsmethode*	ATK-lask., erotusmenet. ja taulukot *EDV, Abzugsmethode und Tafeln*
1— 2	219	89.2	91.1	88.9	24.2	22.8	25.0
3	798	314.1	312.2	312.3	84.3	86.8	86.9
4	916	393.9	391.0	391.1	91.0	93.7	93.6
5	531	252.7	247.3	249.6	50.1	54.3	52.0
6	188	91.7	91.4	92.1	17.9	18.5	17.8
7	69	35.3	35.1	35.6	6.6	6.9	6.3
8	15	8.4	8.2	8.3	1.4	1.5	1.4
9	5	3.4	3.3	3.3	0.4	0.5	0.4
10	2	0.6	0.6	0.6	0.2	0.2	0.2

Taulukko 12. Poikkeuksellisten mänty- ja kuusitukkipuiden tarkistuslaskelmien tuloksia

Tabelle 12. Resultate der Kontrollberechnungen des abweichenden Kiefern- und Fichtenblochholzes

Puulaji *Holzart*	d-luokka, cm *d-Klasse, cm*	Runkoluku *Anzahl der Stämme*	Tukkiosuus *Blochholzanteil*		Tyveykset ja leikot *Fehlerhaftes Ausschussholz*		Latvakuitupuu *Faserholz vom Zopf*	
			Mittaus *Messung*	ATK-laskenta *EDV*	Mittaus *Messung*	ATK-laskenta *EDV*	Mittaus *Messung*	ATK-laskenta *EDV*
			k-m³ kuorineen — *fm m. R.*					
Mänty *Kiefer*	19	3	0.4	0.4	0.2	0.2	0.3	0.3
	21	31	4.7	4.4	0.6	0.6	2.5	2.5
	23	74	13.5	13.1	1.5	1.4	7.0	7.0
	25	86	18.2	17.6	2.4	2.3	9.1	9.2
	27	73	20.0	19.3	3.5	3.4	7.9	7.7
	29	69	23.0	22.8	3.2	3.0	8.8	9.0
	31	66	27.2	26.6	3.4	3.3	8.3	8.6
	33	49	23.7	23.5	3.8	3.6	7.5	7.4
	35	37	20.8	20.3	2.2	2.2	6.5	6.5
	37+	32	22.7	22.4	2.7	2.5	8.3	8.5
	Yhteensä *Insgesamt*	520	174.2	170.4	23.5	22.5	66.2	66.7
Kuusi *Fichte*	19	1	0.1	0.1	0.0	0.0	0.1	0.1
	21	26	4.3	4.2	0.9	0.9	3.1	3.0
	23	42	7.7	7.5	2.1	2.0	4.5	4.5
	25	48	12.6	12.4	3.0	2.9	5.4	5.3
	27	47	14.5	14.4	3.5	3.5	5.6	5.6
	29	36	13.8	13.6	3.7	3.8	3.9	4.0
	31	16	7.9	7.8	1.7	1.6	2.2	2.2
	33	10	5.3	5.3	1.3	1.2	1.0	1.0
	35+	10	7.5	7.9	2.5	2.4	1.2	1.3
	Yhteensä *Insgesamt*	236	73.7	73.2	18.7	18.3	27.0	27.0

erien puitteissa. Poikkeuksellisten tukkipuiden lukeminen puidenluvussa eri luokkaan ja kuutioiminen eri kuutioimismenetelmällä on siten perusteltua.

Koivun kuutioimismenetelmällä saatavien puutavaralajeittaisten tulosten luotettavuuden tutkimisessa keskityttiin vain tukkiosuuteen. Kysymystä tarkasteltiin tarkistusaineiston lisäksi myös kapenemistaulukoiden laadintaa käytetyn aineiston avulla. Edellä esitetyn mukaisesti kuutiointi suoritetaan toistaiseksi yksinomaan ATK-laskentana, jonka avulla voidaan määrittää tukkiosan kuutio tyvestä lukien osuuden päättymiskorkeudelle asti. Nyt suoritetuissa laskelmissa rajoituttiin, koepuiden läpimittojen mittauskohdista johtuen, parittomien täysien metrien pituisiin pölkkyihin. Taulukossa

Taulukko 13. Koivutukkipuiden tarkistuslaskelmien tuloksia
Tabelle 13. Resultate der Kontrollberechnungen des Birkenblochholzes

Aineisto *Material*	Runkoluku *Anzahl der Stämme*	Laskentaperuste *Berechnungsmethode*	Etäisyys tyvestä m — *Abstand vom Wurzelende m*				
			9	11	13	15	17
			k-m³ kuorineen — *fm m. R.*				
Kapenemistaulukot (Tiihonen 1961) *Ausbauchungstafeln*	1 761	Mittaus *Messung*	747.4	853.4	935.3	993.6	1 030.3
		ATK-laskenta EDV	746.6	851.8	933.6	992.0	1 028.6
Tarkistusaineisto 1 .. *Kontrollmaterial*	660	Mittaus	223.0	250.9	271.0	283.8	290.6
		ATK-laskenta	221.1	249.5	269.9	282.9	289.6
» 2 ..	531	Mittaus	206.1	236.0	259.1	275.3	285.5
		ATK-laskenta	207.7	237.5	260.6	277.0	287.2
» 3 ..	646	Mittaus	221.6	252.4	276.1	292.6	302.6
		ATK-laskenta	221.0	252.1	276.2	293.3	303.4

13 esitetään esimerkkeinä eräille pituuksille saadut tulossarjat. Kuutioimismenetelmällä saadun tuloksen yläpuolella nähdään vastaava pätkittäisen kuutioinnin mukainen kuutiomäärä.

Taulukon 13 tulossarjojen vertailu antaa aiheen otaksua, että koivutukkipuiden kuutioimismenetelmällä saadaan tukkiosuudesta erittäin luotettavia tuloksia. Koko rungon ja tukkiosuuden tulosten pohjalta voidaan päätellä, että myös kuitupuuosuuden kuutioinnissa päädytään hyviin tuloksiin. Koivun kuutioinnissa saadut erittäin hyvät tulokset puoltavat siis laaditun menetelmän soveltamista käytännön mittauksissa.

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MTJ = Metsäntutkimuslaitoksen julkaisuja
FF = Folia Forestalia

EIN MASSENERMITTLUNGSVERFAHREN FÜR FASER- UND BLOCHHOLZ MIT DEM FESTMETER ALS MASSEINHEIT

KIEFER, FICHTE UND BIRKE

Deutsches Referat

ZUR EINLEITUNG

Der von den Organisationen der Holzverkäufer und Abnehmer gefasste Beschluss, die Einführung des Festmeters m. R. ab 1. Juli 1972 als gemeinsame Masseinheit für Faser- und Blochholz zu empfehlen, hat dazu geführt, dass die technischen Grundlagen der Messung von stehenden Bäumen, insbesondere der zum Hiebe ausgezeichneten Bestände grösstenteils revidiert oder umgearbeitet werden mussten. Mithin mussten auch die vorher aufgestellten Holzsortimententafeln umgestaltet werden.

Die Arbeit an den neuen Holzsortimententafeln, deren Verfertigung in der Holzvermessungsanweisung (163/69) vom Jahre 1969 vorgesehen war, wurde Anfang 1971 an der Forstlichen Forschungsanstalt angefangen. Die direkte Anregung, die Messgrundlagen zu revidieren, kam von einem durch die Hauptinteressenten am Holzhandel für diese Frage eingesetzten Ausschuss. Auch die i. J. 1970 zur Standardisierung der Kubierungstechnik am Blochholz zusammengestellte Arbeitsgruppe (s. Nousiainen 1970) war der Ansicht, dass die vorgesehene Änderung der Masseinheit auch eine Nachprüfung der Messgrundlagen erforderte. Es erschien zweckmässig, diese Aufgabe einer Arbeitsgruppe zu übertragen. Im Programm der erwähnten Arbeitsgruppe war auch eine Klarlegung über die Kubierungsgrundlagen beim Faserholz inbegriffen. Das Projekt sollte das ganze Land umfassen.

Betreffs der Südhälfte Finnlands war die Untersuchung im Juni 1972 abgeschlossen. Es erwies sich, dass das neu ausgearbeitete Massenermittlungsverfahren für die forstliche Praxis, und zwar besonders für die Messung von stehenden Bäumen sowie bei sonstigen Aufgaben, die eine Verteilung von Holz auf die Sortimente voraussetzen, gut brauchbar war.

Es wurde vereinbart, jede Teilaufgabe des Projektes in einer Veröffentlichung für sich zu besprechen. Dementsprechend werden in der vorliegenden Publikation lediglich die Grundlagen der in Frage stehenden Kubierungsmethode mit einer Übersicht über ihre praktische Anwendung und Zuverlässigkeit dargelegt.

DAS UNTERSUCHUNGSMATERIAL

Das Untersuchungsmaterial setzt sich aus fünf Teilmaterialien zusammen:

1. das zur Ausarbeitung der Kubierungsmethode für Blochholz und speziell für die betreffenden Blochholztafeln von Kiefer und Fichte gebrauchte Material = Tafelnmaterial

2. die Messdaten über den Blochholzanteil bei stehenden (Höhe 10 bis 13 m) Bäumen, die nur auf 1 Stück Blochholz zugeschnitten werden, und an Hand deren die aufgrund des 1. Materiales durchgeführte Extrapolation überprüft wurde
3. die Messresultate über Hiebsrückstände
4. das Kontrollmaterial
5. das Material der abweichenden Blochholzstämme.

Im Zusammenhang mit der Darlegung des Materials wird auf Mindestdurchmesser und Qualitätsklassen eingegangen. Es wird auf die Veröffentlichungen verwiesen, wo die von den beiden Parteien — Verkäufern und Abnehmern — zusammen festgelegten Grundsätze besprochen sind. Die Holzverarbeitungsgesellschaften und die Organisationen der Holzverkäufer, die sich beim Sammeln des Kontrollmaterials beteiligt haben, sind im Verzeichnis auf S. 9—10 aufgezählt. Die Mengen der Probestämme sind aus der Zusammenstellung auf S. 10 ersichtlich. Die Abb. auf S. 11 zeigt die Lage der ausgezeichneten Probebestände, die als Tafeln- und Kontrollmaterial dienten.

DIE GRUNDLAGEN DES MASSENERMITTLUNGSVERFAHRENS

Die Untersuchung betraf die drei Holzarten: Kiefer, Fichte und Birke und bei jeder Holzart das Faser- und Blochholz. Das Blochholz wurde noch in zwei Gruppen unterteilt: die normalen und die abweichenden Blochholzstämme.

Die Arbeit an der Kubierungsmethode wurde auf zwei Ziele ausgerichtet: Holzsortimententafeln und EDV. Gemäss vorheriger Abmachung wurden zwei alternative Berechnungsmethoden (Nousiainen 1970) befolgt. Desweiteren enthielt die EDV betreffs Blochholz zwei parallele Methoden: Abläng ungs- und Abzugsmethoden. Von diesen wurde die erste aufgrund einer früheren Untersuchung (Nousiainen op.cit.) ausgearbeitet. Bei der zweiten Methode wird der Blochholzanteil als eine Differenz ausgedrückt, wozu von den Einheitsmassenwerten (abzulesen aus den Tafeln von Ilvessalo, die auf die Gesamtkubikmasse eines Baumes hinauslaufen) der Zopf und Faserholzanteil (abzulesen aus den in vorliegender Publikation herausgegebenen Tabellen) abgezogen wird. Die Blochholztafeln sind nach der gleichen Abzugsmethode aufgestellt worden, desgleichen die Faserholztafeln, sodass die zwei Alternativen ganz übereinstimmende Resultate ergeben. Auch die Ablängungs- und Abzugsmethoden führen praktisch genommen zu denselben Resultaten.

An sich kann das Verfahren nur für normale Kiefern und Fichten angewandt werden. Auf die Aufstellung von Tafeln für abweichende Nadelholzstämme dürfte man jedoch wenigstens vorläufig verzichten können. Betreffs Birkenblochholz wird die Untersuchung in der Herbst- und Wintersaison 1972—73 fortgesetzt.

Die beiden alternativen Berechnungsmethoden werden in der Publikation kurz dargelegt. Die Holzsortimententafeln wurden nach der obenerwähnten Abzugsmethode angefertigt, der in erster Linie die Tafeln von Ilvessalo zugrundegelegt waren. Über die anderweitigen Grundlagen wird in der vorliegenden Veröffentlichung (S. 16) sowie im Zusammenhang mit der Herausgabe der Faser- und Blochholztafeln (Tiihonen 1972 a und b) berichtet.

Auch der EDV lagen zuvörderst die Tafeln von Ilvessalo zugrunde. Herangezogen wurden ferner: die Ausbauchungstafeln (Tiihonen 1961), die die Schaftform des Baumes beschreiben; die Zahlenreihen, die die Rindenstärke an verschiedenen

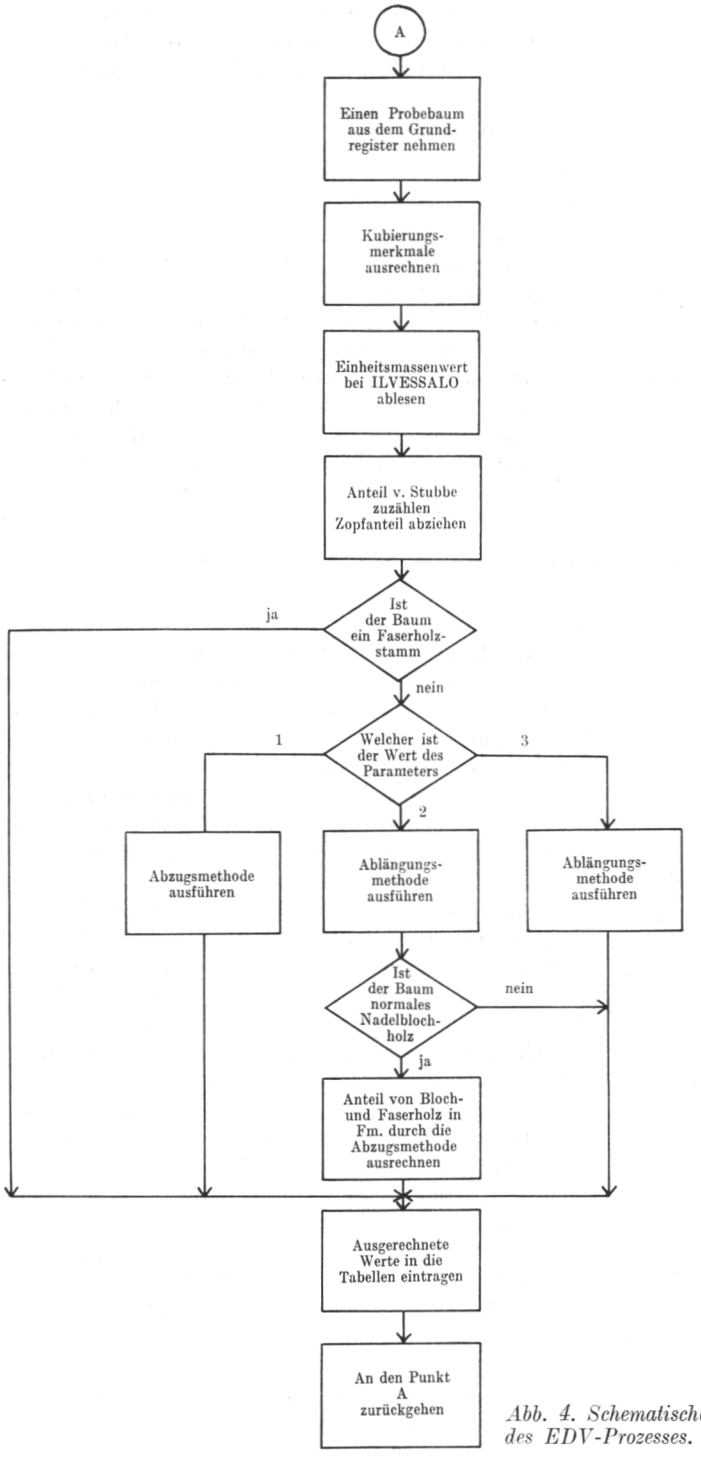


Abb. 4. Schematische Darstellung des EDV-Prozesses.

Baumhöhen angeben; die Matrizen, die die Dimensionen beim Blochholz darstellen. Die Abb. auf S. 26 veranschaulicht die Kubierung nach dem Ablängungsprogramm. Aus dem Schema auf S. 29 geht der EDV-Prozess hervor.

VERLÄSSLICHKEIT DES VERFAHRENS

Da die Tafeln von Ilvessalo in der neuen Kubierungsmethode eine ausschlaggebende Rolle spielen, wurde die Verlässlichkeit dieser Tafeln weiterhin geprüft. Die Untersuchung wurde jedoch auf die Stämme beschränkt, die die an Blochholz gestellten Mindestdimensionen erfüllen. Die Ergebnisse der diesbezüglichen Vergleiche sind aus den Tabellen und Zusammenstellungen auf SS. 32—33 ersichtlich. Die Resultatserien, die hierin nicht einbegriffen sind, stimmen mit den hier vorgelegten Daten gut überein. Die Vergleiche bestätigen abermals die hervorragende Zuverlässigkeit der Tafeln von Ilvessalo, die auch früher in verschiedenem Zusammenhang festgestellt worden ist.

Das zweite Betrachtungsobjekt waren die nach Holzsortimenten eingeteilten Resultate. Betreffs Faserholz wird auf die oben angeführten, die Gesamtmasse des ganzen Stamms betreffenden Resultate, sowie auf die in den Tabellen eingetragenen Resultate über die Präzision der Zopfanteile verwiesen. Man kann sagen, dass das Massenermittlungsverfahren für Faserholz — beurteilt nach den Kontrollen — recht gute Resultate liefert.

Über die Präzision des Massenermittlungsverfahrens für Blochholz wurde eine umfassende Kontrolle vorgenommen. Beispiele für diesbezügliche Resultate sind in den Tabellen auf SS. 34—39 angeführt. Bei normalem Kiefern- und Fichtenblochholz scheint die Methode zu recht guten Resultaten zu führen. Auch die bei Birkenblochholz erzielten Ergebnisse rechtfertigen die Anwendung des besprochenen Massenermittlungsverfahrens in der praktischen Forstwirtschaft.

REACTION OF SCOTS PINE ON VARIOUS NITROGEN FERTILIZERS ON DRAINED PEATLANDS

EERO PAAVILAINEN

SELOSTE:
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PREFACE

The first fertilization experiments established in Finland especially for forestry purposes were made under the direction of Prof. O. J. Lukkala soon after the Department of Peatland Forestry of the Forest Research Institute had been founded in 1929. When at the beginning of the 1950's the mechanization of drainage proved successful and drainage expenses were simultaneously lowered, experimental activity concerning fertilization was expanded by every available means. From the very beginning, phosphorus and potassium fertilizers appeared to be suitable for practical use, whereas the use of nitrogen fertilizer seemed virtually impossible, because it was then believed that nitrogen fertilization had a favorable effect on the growth for only one year. In Germany information was obtained that the effect of nitrogen fertilizers in the forest lasted for many years. Director Väinö Suontaa, the representative of Berner Oy, which imports nitrogen fertilizers, provided us with the opportunity in 1954 of consulting with Mr. Herman Mayer-Krapoll, agronomist, and after him Dr. H. A. Gussone, the representatives of Ruhr-Stickstoff AG. Ruhr-Stickstoff AG via Berner Oy presented Finland with nitrogen fertilizers, which were used in 1956 for establishing extensive fertilization experiments on the estates of Dr. N. A. Osara in Siikainen and, with the strong, personal support of Mr. Hannu Tengman, Chief Forester, on land owned by H. G. Paloheimo Oy in Loppi. Simultaneously, large experiments were set up on land owned by Enso-Gutzeit Oy in Eräjärvi. The results of these experiments soon confirmed that nitrogen fertilization had a long-lasting effect. Equal dosages of ammonium sulphate saltpeter (Montan saltpeter 25 % N, 3/4 of which is ammonium nitrogen and 1/4 nitrate nitrogen) and ammonium sulphate (21 % N, all ammonium nitrogen) resulted in an equally rapid response with the same duration.

As far as acid soils were concerned, it was thought that nitrification could not take place in such soil. This led to the conclusion that trees were able to use ammonium nitrogen directly without necessarily requiring nitrate nitrogen. With the help of Mr. Mayer-Krapoll and Mr. Kimmo Paarlahti, Lic.Sc.(For.), I designed the experimental plan in order to find out the suitability of various types of nitrogen fertilizers for fertilizing

forests on peat soils, and which type of nitrogen is used by trees. Ammonium sulphate, ammonium sulphate saltpeter, calcium ammonium nitrate, nitrogen solution, ammonia gas, and crystalline urea spread on the soil, urea solution spread on the needles and leaves, and calcium nitrate were all included in the fertilization experiments. Thus a series, as complete as possible, was obtained which ranged from pure ammonium nitrogen to pure nitrate nitrogen with the inclusion of urea nitrogen and ammonia gas. Rikkihappo Oy supplied funds for an injection spray (lent by Ruhr-Stickstoff AG) with which the spreading of ammonia gas was performed during the fertilization operations.

The experimental fields, presented in detail in the following publication, were established on land owned by A. Ahlström Oy in Noormarkku and Sonkajärvi, on land owned by H. G. Paloheimo Oy in Loppi and in the experimental areas of the Forest Research Institute in Muhos.

According to the variance analysis which was based on results from the first three years, it seems (Huikari 1964) that urea was very well qualified to compete with ammonium and nitrate nitrogen fertilizers as far as the effect was concerned. Only ammonia gas fertilization and the spraying of urea solution onto the needles and leaves differed significantly from other types of fertilizers, because of the difficulty in their technical realization. With the help of Mr. Pertti Östman, B. For., and several others, I drew up a temporary summary and manuscript, which have been available for the use of researchers in the archives of the Department of Peatland Forestry (Huikari 1973) and which have served as a basis for practical instructions concerning fertilization. Now, as the experiments concerning nitrogen fertilizers have been carried out long enough for reliable conclusion to be drawn from them, Dr. Eero Paavilainen has designed the following publication according to the data. The statistical treatment of the data has been performed by Mr. Jaakko Simpanen, M.Sc. (Soc.).

I thank Dr. Paavilainen and all the other people concerned in establishing and maintaining the experiments, and in measuring and calculating the results.

Helsinki, October 1972

Olavi Huikari

CONTENTS

	Page
1. Introduction	7
2. Material and methods	9
21. Experimental fields	9
22. Fertilization treatments	11
23. Measurement and calculation	13
3. Results	16
31. The effect of nitrogen, phosphorus and potassium fertilizations on the growth of pine	16
311. The effect of various nutrients	16
312. The effect of the amount of nitrogen	17
32. The dependence of the growth reaction caused by fertilization on the type of nitrogen fertilizer	24
4. Discussion	30
5. Summary	37
6. References	39
7. Suomenkielinen seloste	45

1. INTRODUCTION

Research activity in peatland fertilization has very much increased in our country since the beginning of the 1950's when extensive and systematic fertilization experiments were set up all over Finland by the Department of Peatland Forestry of the Finnish Forest Research Institute. The results of the experiments by the Forest Research Institute (e.g. Lukkala 1935, 1936, 1949, 1951, 1955, Huikari 1961, 1964, 1967, Huikari and Paarlahti 1966, Paarlahti 1967, Karsisto 1967, 1968, Paavilainen 1968, 1969, 1970 b, Paarlahti and Karsisto 1968, Kaunisto 1971, 1972 a, b, Paarlahti, Reinikainen and Veijalainen 1971) and the results of the experiments carried out by the Department of Peatland Forestry of the University of Helsinki (Heikurainen, Päivänen and Seppälä 1966, Heikurainen 1967, Mannerkoski and Seppälä 1970, Heikurainen and Veijola 1971, Seppälä 1971, 1972, Mannerkoski 1971) show that on peatlands naturally rich in nitrogen the growth of trees can be best stimulated by phosphorus and potassium fertilization. The most oligotrophic peatlands require nitrogen in addition to phosphorus and potassium, since the minimum factor, in these cases, affecting the growth of trees is the lack of available nitrogen. Corresponding results have been obtained from several experiments in Sweden (Malmström 1935, 1952, 1956, Björkman 1941, Tamm 1956, 1965, Malmström, Tamm and Hansson 1956, Tamm and Carbonnier 1961, Johansson and Åhgren 1962), in Norway (Thurman-Moe 1956, Berg 1958, Meshechok 1956, 1957, 1968, Haveraaen 1967, Ødelien and Jerven 1968) and in Great Britain (Zehetmayr 1954, Edwards 1958, 1959, Parker 1962, Jack 1965, Dickson 1972, Mackenzie 1972). Recent discoveries imply that nitrogen fertilization would also be necessary in the dense forests covering old drainage areas in order to ensure good growth (Huikari and Paavilainen 1972).

When the experiments have found a solution to the problem of the nutrient combination applicable in various cases, there remains the problem of determining in what form each nutrient would be most profitably used. To illustrate this problem the Department of Peatland Forestry of the Forest

Research Institute has established many comparative experiments on the types of fertilizers employing phosphorus, potassium and nitrogen as well as multinutrient fertilizers (Huikari 1964).

In order to compare various nitrogen fertilizers with regard to their profitability, it is necessary to define the form of nitrogen in a fertilizer that has the most favorable effect on the growth of trees. The choice can be made between ammonium nitrogen (N_4^+), nitrate nitrogen (N_3^-) and urea nitrogen ($CO(NH_2)_2$). According to the results and the experiments performed, it is known that the binding of ammonium nitrogen, nitrate nitrogen and urea nitrogen into the organic matter of soil varies greatly and there might be considerable differences, due to the method of application, between leaching and evaporation and the amount of nitrogen used by plants (e.g. Nömmik 1957, 1966, 1970, Salonen 1958, Kaila 1962, 1965, Nömmik and Nilsson 1963 a, 1963 b, Salonen *et.al.* 1968, Overrein 1968, 1969, 1970 a, 1970 b, Nömmik and Popovic 1971, Viro 1972). These results are not directly applicable to forest drained peatlands, but they do show that choosing the proper type of nitrogen fertilizer is of utmost importance also on peatlands, which are made up entirely of organic matter.

Nitrogen fertilization experiments established on peatlands drained for forestry by the Forest Research Institute include ammonium nitrogen, nitrate nitrogen and urea nitrogen applied in different ways. Preliminary results of these experiments have already been published (Huikari 1964, Paavilainen 1971). This study reveals the results based on the inventory carried out in 1970 which aimed at producing additional information about the most profitable type of nitrogen fertilizer for the fertilization of peatland forests.

I wish to extend my thanks to Mr. Olli Halonen, Prof. Olavi Huikari, Mr. Kimmo Paarlahti, Dr. Yrjö Pessi, Mr. Kalervo Salonen and Mr. Veli Tuomikoski for their invaluable advice and help that I received while preparing this publication.

2. MATERIAL AND METHODS

21. Experimental fields

The data used in this study were collected from the experiments on the type of nitrogen fertilizer which were established in May, 1960 at five different locations. The experimental fields of Lampi in Ahlainen, Sulkava in Pielavesi and Jyrkkä in Sonkajärvi were situated on land owned by A. Ahlström Oy, the experimental field of Aittoniemi in Loppi on land owned by Riihimäen Saha Oy, and that of Muhos in the experimental area of Pyhäkoski owned by the Forest Research Institute.

The peatland type of the experimental fields of Loppi, Ahlainen, Pielavesi, and Sonkajärvi was, prior to fertilization, in the tree-growing parts mainly a cottongrass pine swamp with *fuscum*-rich hummocks and in the open parts a cottongrass open swamp (Table 1). The depth of peat in these sites was more than 2 meters. The experimental field in Muhos differed from the other sites by its greater variety of peatland types and the depth of its peat. The experimental field in Muhos had, in addition to cottongrass pine swamp, areas of *Carex globularis* pine swamp and sedge pine swamp. The depth of peat was less than 2 meters and in some places only 0.2 meters.

In order to compare the nutrient content of the surface peat in the various experimental fields, samples were taken from unfertilized plots of each experimental field. A sample representing each field was made up of five partial samples taken from different parts of the sample plot down to a depth of 20 cm from the surface. The samples were collected during October and November in 1970, except those from Muhos which had to be collected the following spring. The nitrogen, phosphorus, and potassium content analyses were performed by Viljavuuspalvelu Oy. The mean figures of the nutrient analyses in different experimental fields are presented in Table 1.

The nutrient content in the surface peat of the unfertilized plots was very low in some fields. The lowest nitrogen content (0.90 %) was found in Ahlainen, the lowest phosphorus content (3.8 mg/l) in Muhos, and the lowest potassium content (25 mg/l) in Pielavesi. In comparison, the results of the analyses presented by the writer on an oligotrophic *fuscum*-rich open swamp in Karvia are worth mentioning (P a a v i l a i n e n 1970 a). There the

Table 1. Information on the investigation material from the experimental fields.
Taulukko 1. Tutkimusaineistoa koskevia koealatietoja.

Experimental field *Koekenttä*	Swamp [1]) type *Suotyyppi*	Thickness of peat, m *Turpeen paksuus, m*	Nutrient content of the surface peat (0—20 cm) on unfertilized experimental plots *Lannoittamattomien koealojen pintaturpeen (0—20 cm) ravinnepitoisuus*			Ditching — *Ojitus*				Experimental plots *Koealoja*		Sample trees *Koepuita*	
						with 80 cm deep ditches *80 cm syvyisin ojin*		with 40 cm deep ditches *40 cm syvyisin ojin*					
			Total nitrogen, % *Kokonaistyppi, %*	P, mg/l	K, mg/l	Year *Vuosi*	Strip width, m *Sarkalev., m*	Year *Vuosi*	Strip width, m *Sarkalev., m*	in broadcast fertil. experim. *hajalann.-kokeissa*	in spot fertil. experim. *laikkulann.-kokeissa*	Height growth measured *Pit. kasvu mitattu*	Radial growth measured *Sädekasvu mitattu*
Loppi (60° 40′)	TR	2 +	1.27	9.7	53	1955	40	1960	20	60		1036	588
Ahlainen (61° 40′)	TR, TN	2 +	0.90	6.9	36	1958	60—120	1960	20	51	41	1688	480
Pielavesi (63° 26′)	TN	2 +	1.91	5.3	25	1959—1960	40	1960	20		36	632	
Sonkajärvi (63° 47′)	TR	2 +	1.35	12.0	47	1957	50	—	—	79		1580	780
Muhos (64° 50′)	TR, PsR, SsR	0.2—1.8	1.15	3.8	36	1933, 1956	50	—	—	101		1985	

[1]) Swamp type (H u i k a r i 1952): TR = cottongrass pine swamp, TN = cottongrass open swamp, PsR = *Carex globularis* pine swamp, SsR = sedge pine swamp

total nitrogen content of the surface peat (0—20 cm) was 0.75 %, the phosphorus content 3.8 mg/l, and the potassium content 28 mg/l.

Most of the experimental fields were drained in 1955—1960. Only in Muhos had a part of the area been drained earlier, starting in 1933. There were differences as regards draining capacity among the experimental fields, as is shown in Table 1. In addition to the actual draining by feeder drains, the experimental plots in Loppi, Ahlainen and Pielavesi were separated from each other by 40 cm deep trenches. This measure improved the effect of drainage.

The planting of pine on open fields was carried out in May, 1960.

22. Fertilization treatments

The effect of eight different types of nitrogen fertilizers was studied. The solid fertilizers included ammonium sulphate, calcium ammonium nitrate, Montan saltpeter, urea and calcium nitrate. They were spread on the surface without disturbing the soil. Some special methods were included. These were the injection of ammonia gas into the soil (to an average depth of 20—30 cm at regular intervals), the spreading of nitrogen solution on the soil surface and the spraying of a solution of urea onto the tree needles. Table 2 presents the nutrient content and other properties of the different types of nitrogen fertilizers included in the study.

Table 2 shows that the experiments included, in addition to urea, pure ammonium nitrogen, almost pure nitrate nitrogen and nitrogen fertilizers containing these ions in different proportions.

The amount of nitrogen fertilizers applied corresponded to 100 kg/ha of N. An exception was the urea solution which was sprayed onto the needles. So much was applied, that the liquid started to drip from the needles onto the ground. In this treatment the amount of nitrogen applied corresponded to 5—15 kg/ha of N.

Nitrogen was applied by itself, in combination with phosphorus or potassium, or with both of these nutrients. Phosphorus was applied as rock phosphate using an amount of 400 kg/ha which corresponds to 132 kg/ha of P_2O_5. Potassium was applied as muriate potash (40 %) using an amount of 100 kg/ha which corresponds to 40 kg/ha of K_2O. There were replications of the various treatments in the experimental fields.

In order to illustrate the effect of the amount of nitrogen used, five different nitrogen levels were included in the experimental field of Sonkajärvi when using calcium ammonium nitrate: 25, 50, 75, 100, and 125 kg/ha N.

Table 2. The types of nitrogen fertilizer used in the experiments.
Taulukko 2. Kokeissa käytetyt typpilannoitelajit.

Type of nitrogen fertilizer *Typpilannoitelaji*	Nutrient content % *Ravinnepitoisuus %*						Hygroscopic *Hygroskooppisuus* 0 = not at all — *ei lainkaan* +++ = highly — *suuri*
	Total N *Kokonais-N*	NH_4-N	NO_3-N	Ca	S	Mg	
N_1 = ammonium sulphate — *ammoniumsulfaatti*	20.5	20.5	—	—	24.0	—	0
N_2 = calcium ammonium nitrate [1] — *kalkkiammonsalpietari*	25.0	12.5	12.5	6.0	—	3.0	++
N_3 = Montan saltpeter [2] — *montansalpietari*	26.0	19.5	6.5	—	24.2	—	0
N_4 = ammonia gas — *ammoniakkikaasu*	82.5	82.5	—	—	—	—	—
N_5 = nitrogen solution — *typpiliuos*	37.0	26.8	12.2	—	—	—	—
N_6 = urea — *urea*	46.3		[1]	—	—	—	+
N_7 = urea-spray — *urearuiskutus*	46.3		[2]				
N_8 = calcium nitrate — *kalkkisalpietari*	15.5	1.0	14.5	20.0	—	0.2	+++

[1]) Calcium ammonium nitrate = ammonium nitrate with lime = Oulu saltpeter.
[2]) Montan saltpeter = ammonium sulphate nitrate.
[3]) Urea is a carbamide which decomposes into ammonia and carbon dioxide in the soil. In addition, urea contains approximately 0.3 % biuret. *Urea on karbamidia, joka hajoaa maassa ammoniakiksi ja hiilidioksidiksi. Ureassa on lisäaineena biureettia n. 0.3 %.*
[4]) Water solution of urea (0.7 %) which was sprayed onto the tree needles. *Urean vesiliuos (0.7 % ureaa), jota ruiskutettiin puiden neulasiin.*

In four experimental fields (Loppi, Ahlainen, Sonkajärvi, Muhos), broadcast fertilization was used, while two experimental fields (Ahlainen, Pielavesi) were spot fertilized, each spot having an area of 0.25 m^2 around the transplant at the time of planting.

Refertilization was carried out on two experimental fields. On broadcast fertilized field in Loppi, 700 kg/ha of PK fertilizer (0—17—15) was applied in the spring of 1968. In the field which was spot fertilized in Ahlainen, refertilization was carried out in the spring of 1967 by applying 500 kg/ha of PK fertilizer (0—17—15).

There were 368 plots in all. 291 plots were broadcast fertilized, while 77 were spot fertilized. The number of plots in different experimental fields is shown in Table 1.

23. Measurement and calculation

The stand volume of the experimental fields was rather small and varied considerably even among the plots within one single experimental field. Thus it would have been very unreliable to interpret the influence of fertilization on the evidence presented by the volume growth of the trees. If volume growth only is measured, then a considerable part of the data would also have to be excluded from the calculations. For this reason, the observations concerning the influence of different types of nitrogen fertilizers are based on the results obtained by measuring the height growth and radial growth as determined from increment cores taken at breast height.

The aim was to measure the height growth of 20 trees on each plot, and to take the required increment cores from 10 trees in order to obtain the radial growth. In those plots which had a less dense tree stand, the number of sample trees remained smaller. Sample trees were selected systematically from the trees belonging to the dominant crown layer in different parts of the plot. Since measurements of the radial growth in Muhos were only partly accomplished, the results of those areas will not be dealt with in this context. Both the height growth and the radial growth were measured annually in 1958—1970. However, on the plots where spot fertilization had been used, it was impossible to start measuring the height growth until 1961. The annual height growth was measured with an accuracy of 1 cm and the radial growth to within 1/100 mm. The height growth was measured from September to December in 1970. Some of the increment cores were also taken at this time in order to measure the radial growth. The rest of them were taken in the spring of 1971. The data include the results of the height growth measurements of 6921 sample trees and those of the radial growth measurements of 1848 sample trees.

The mean values per plot were calculated, and the influence of fertilization was determined by computer. Calculation of the results obtained from the plots with broadcast fertilization using basic amounts of nitrogen, phosphorus, and potassium (100 kg/ha N, 132 kg/ha P_2O_5, 40 kg/ha K_2O), was performed by covariance analysis. The dependent variable was the annual height growth or radial growth during 1960—1970. The independent variables were the mean growth (height or radial growth) during 1958—1959 as regression variable, the experimental area, the nitrogen fertilization, the phosphorus fertilization, the potassium fertilization, and the PK refertilization (only in years 1969—1970). The influence of the main effect was first calculated, and then the interaction between nitrogen and phosphorus fertilization and that between nitrogen and potassium fertilization. Since, however, these interactions proved insignificant, they were excluded from the final calculation of the data.

The model which was used, explained rather well the fluctuations in growth. In order to compare the mean values per plot, calculated according to the height growth measurements, a logarithmic transformation was set up. This transformation, however, did not improve the explanatory power, as can be seen in the following table:

	Year — *Vuosi*										
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
	Explanatory power, % — *Selitysaste*, %										
The model used, height growth *Käytetty malli, pituuskasvu* ..	82.8	66.9	64.5	61.4	63.0	66.2	74.3	78.0	83.1	90.8	92.7
Logarithmic model, height growth *Logaritminen malli, pituuskasvu*	84.1	70.3	68.7	63.6	62.2	63.1	69.0	73.0	79.0	..	..
The model used, radial growth *Käytetty malli, sädekasvu*	79.1	63.4	54.5	54.8	52.8	50.6	44.2	47.7	34.2	35.0	36.8

The decline in the explanatory power of the model as we proceed farther from the time of fertilization is caused, above all, by the weakening influence of the regression variable and various fertilizers.

The influence of different amounts of nitrogen on the growth of tree stands was investigated in the experimental field of Sonkajärvi by using covariance analysis. The dependent variable was the annual height growth or radial growth during 1960—1970, while the independent variables were the

regression variable (the mean height or radial growth during 1958—1959) and the fertilization used.

The influence of spot fertilization was determined by using variance analysis. The dependent variable was the annual height growth of trees during 1961—1967, while the independent variables were the experimental area, the nitrogen fertilization, the phosphorus fertilization, the potassium fertilization, the interaction between nitrogen and phosphorus fertilization, and that between nitrogen and potassium fertilizations.

The significance of the growth differences in trees caused by different types and amounts of nitrogen fertilizers was tested by the Duncan test (Kramer 1957).

3. RESULTS

31. The effect of nitrogen, phosphorus and potassium fertilizations on the growth of pine

311. The effect of various nutrients

Table 3 presents the influence of different factors on the height growth and radial growth of trees. The data are based on covariance analysis (the influence is statistically significant * = 95 % confidence, ** = 99 % confidence, *** = 99.9 % confidence). The results refer to the main data of the study, in which 100 kg/ha of nitrogen (N), 132 kg/ha of phosphorus (P_2O_5) and 40 kg/ha of potassium (K_2O) were used.

Both phosphorus and nitrogen fertilization significantly increased the height growth of trees on fields where broadcast fertilization was used. The influence of potassium fertilization and refertilization with PK on the height growth had no statistical significance. Fertilization did not increase the height growth in the year of application (1960), but it did in the following year. The influence of nitrogen fertilization on the height growth of trees lasted till 1968, that is for eight years. The influence of phosphorus was still significant in 1970. There were significant differences in the height growth of trees between the various experimental fields.

The influence of broadcast fertilization on the height growth of tree stands is investigated according to the results obtained in Loppi, Ahlainen and Sonkajärvi later on in the report. By this arrangement, the reaction of the height growth and radial growth of trees measured in the same plots can be compared with each other and with trees on the plots which are of similar peatland type. This seems to be possible, bacause Table 3 shows that the influence of fertilization on the height growth of trees remains unchanged whether observed on the basis of the entire data or only on the basis of the data obtained from the three experimental areas previously mentioned.

Broadcast fertilization also distinctly improved the radial growth of the trees. Nitrogen fertilization even increased the growth during the year of application and its effect on the radial growth lasted for five years. The influence of phosphorus fertilization on the radial growth was significant during

1961—1970. The effect of potassium fertilization on the radial growth of the trees was significant only in 1962 and in 1970. Refertilization with PK did not significantly improve the radial growth of the trees.

When spot fertilization was used, the influence of nitrogen on the height growth of the trees was statistically significant only in 1961. That same year the interaction between nitrogen and phosphorus, as well as between nitrogen and potassium, proved significant. Phosphorus fertilization very clearly improved the growth of transplants and its influence could still be clearly seen in 1967. The effect of potassium fertilization was significant in 1966. Differences also occured in the growth of trees that received spot fertilization due to local experimental conditions.

According to the results, the duration of the influence of nitrogen with broadcast fertilization as regards the height growth averaged eight years and as regards the radial growth five years. Similar results have been obtained from previous experiments and research. The influence of nitrogen has been found to remain strong for 5—10 years (e.g. Huikari 1961, 1967, Huikari *et.al.* 1963). When spot fertilization was used, the influence of nitrogen, according to this study, was of brief duration, being significant only for one year. Similarly, several studies have shown that as far as fertilization for afforestation purposes is concerned, it is only phosphorus of all the nutrients that plays the decisive role, while the influence of nitrogen is rather negligible except on extremely poor swamps. Spot fertilization using nitrogen may even increase the mortality of transplants (Heikurainen *et.al.* 1966, Huikari and Paarlahti 1966, Mannerkoski and Seppälä 1970, Paavilainen 1970 b, Kaunisto 1971, Seppälä 1971).

Nitrogen fertilization influenced the radial growth of trees earlier than the height growth. The same result, confirming that the radial growth responds sooner to fertilization than the height growth, has been obtained in investigations which illustrate the effect of the time of fertilization on the growth reaction of pine stands on swamps (Paarlahti 1967).

Phosphorus had the influence of the longest duration. Obviously as late as in 1970, that is 11 growing seasons after the application of fertilizers, there was still enough phosphorus in the substratum to ensure the growth of the trees. The influence of phosphorus was still significant, and refertilization with PK had increased neither the height nor the radial growth. The influence of potassium fertilization remained weak, which is at least partly due to the small amount of potassium applied (40 kg/ha K_2O).

312. The effect of the amount of nitrogen

In order to evaluate the results concerning the effect of nitrogen fertilization and various types of nitrogen fertilizers from a practical point of

Table 3. Results of the significance tests for the height and radial growth of pine.
Taulukko 3. Merkitsevyystestien tulokset eri tekijöiden vaikutuksesta männyn pituus- ja sädekasvuun

Independent variable *Selittävä muuttuja*	Year — *Vuosi*										
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
	Influence of broadcast fertilization on the height growth[1]) *Hajalannoituksen vaikutus pituuskasvuun*[1])										
	F value — *F-arvo*										
Regression (growth in 1958—1959) — *Regressio (kasvu vv. 1958 1959)*	705.01***	234.93***	148.51***	73.60***	46.83***	50.49***	63.25***	66.98***	67.04***	82.28***	90.73***
Experimental field — *Koekenttä*	21.53***	18.09***	20.53***	29.10***	51.09***	62.22***	130.15***	191.82***	302.47***	175.29***	230.21***
Nitrogen fertilization — *Typpilannoitus*	1.22	2.94**	5.24***	4.57***	3.36**	3.50***	3.83***	2.99**	2.40*	1.76	1.44
Phosphorus fertilization *Fosforilannoitus*	.01	11.42***	36.30***	60.89***	80.08***	96.05***	86.30***	88.33***	74.69***	53.80***	21.53***
Potassium fertilization *Kalilannoitus*	.93	.01	.18	1.43	.73	.61	.30	.00	.95	1.56	1.12
PK refertilization — *PK-jatkolannoitus*	—	—	—	—	—	—	—	—	—	.61	1.63
	Influence of broadcast fertilization on the height growth[2]) *Hajalannoituksen vaikutus pituuskasvuun*[2])										
	F value — *F-arvo*										
Regression (growth in 1958—1959) — *Regressio (kasvu vv. 1958—1959)*	162.03***	33.12***	22.01***	16.01***	11.11**	6.48*	8.97**	6.82**	11.10**	11.27**	11.83***
Experimental field — *Koekenttä*	28.53***	27.90***	21.48***	27.44***	47.64***	44.16***	68.54***	69.68***	101.29***	82.79***	140.24***
Nitrogen fertilization — *Typpilannoitus*	1.30	2.48*	4.41***	3.58***	3.23**	2.94**	3.46**	2.86**	2.09*	1.35	1.12
Phosphorus fertilization *Fosforilannoitus*	1.78	8.33***	22.23***	35.70***	61.54***	87.47***	86.57***	93.92***	73.00***	43.54***	17.32***
Potassium fertilization *Kalilannoitus*	2.66	.43	.01	1.01	.78	.49	.10	.00	1.03	2.07	1.73
PK refertilization — *PK-jatkolannoitus*	—	—	—	—	—	—	—	—	—	.22	1.09

Influence of broadcast fertilization on the radial growth[2])
Hajalannoituksen vaikutus sädekasvuun[2])

F value — *F-arvo*

Regression (growth in 1958—1959) — *Regressio (kasvu vv. 1958—1959)*	371.68***	63.56***	18.22***	7.64**	8.12**	13.26***	12.28***	8.52**	7.13**	7.56**	13.49***
Experimental field — *Koekenttä*	60.87***	61.52***	32.24***	41.00***	28.82***	9.62***	2.83	18.95***	8.40***	8.43***	6.32**
Nitrogen fertilization — *Typpilannoitus*	3.04**	8.45***	6.20***	5.34***	2.55*	1.29	.51	.68	.31	.26	.29
Phosphorus fertilization *Fosforilannoitus*	.09	7.02**	23.74***	36.69***	60.85***	90.65***	96.38***	78.82***	45.42***	46.90***	14.24***
Potassium fertilization *Kalilannoitus*	.04	2.95	8.07**	2.97	.58	.78	.05	1.83	2.76	2.39	3.97*
PK refertilization — *PK-jatkolannoitus*	—	—	—	—	—	—	—	—	—	1.86	.01

Influence of spot fertilization on the height growth[3])
Laikkulannoituksen vaikutus pituuskasvuun[3])

F value — F-arvo

Experimental field — *Koekenttä*	—	91.97***	16.96***	16.58***	.04	11.12**	.14	7.84**	—	—	—
Nitrogen fertilization — *Typpilannoitus*	—	2.30*	1.47	.69	.71	.77	2.00	1.34	—	—	—
Phosphorus fertilization *Fosforilannoitus*	—	104.98***	130.12***	87.05***	98.68***	88.90***	138.31***	84.66***	—	—	—
Potassium fertilization *Kalilannoitus*	—	.84	.51	.24	.53	1.36	8.44**	.57	—	—	—
N × P fertilization — *N × P lannoitus*	—	2.46*	1.49	.88	.50	.50	.97	.97	—	—	—
N × K fertilization — *N × K lannoitus*	—	2.22*	.77	.62	.36	.59	2.67*	.83	—	—	—

[1]) Loppi, Ahlainen, Sonkajärvi, Muhos
[2]) Loppi, Ahlainen, Sonkajärvi
[3]) Ahlainen, Pielavesi

Table 4. Results of the significance tests for the growth of pine on Sonkajärvi experimental area.

Taulukko 4. Merkitsevyystestien tulokset eri tekijöiden vaikutuksesta männyn kasvuun Sonkajärven koekentällä.

	Year — *Vuosi*										
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
	Height growth — *Pituuskasvu*										
Regression — *Regressio*	58.91***	2.11	.27	1.59	.00	.16	.18	.90	1.63	.56	.35
Fertilization — *Lannoitus*	.88	19.22**	20.27***	18.23***	19.62***	25.17***	19.32***	17.18***	13.40***	11.78***	5.27**
	Radial growth — *Sädekasvu*										
Regression — *Regressio*	66.68***	11.64**	10.12**	9.86**	6.85*	10.08**	9.87**	11.59**	3.40	1.22	.00
Fertilization — *Lannoitus*	1.01	13.20***	28.77***	33.06***	19.55***	14.18***	10.87***	7.52***	3.28*	1.44	.86

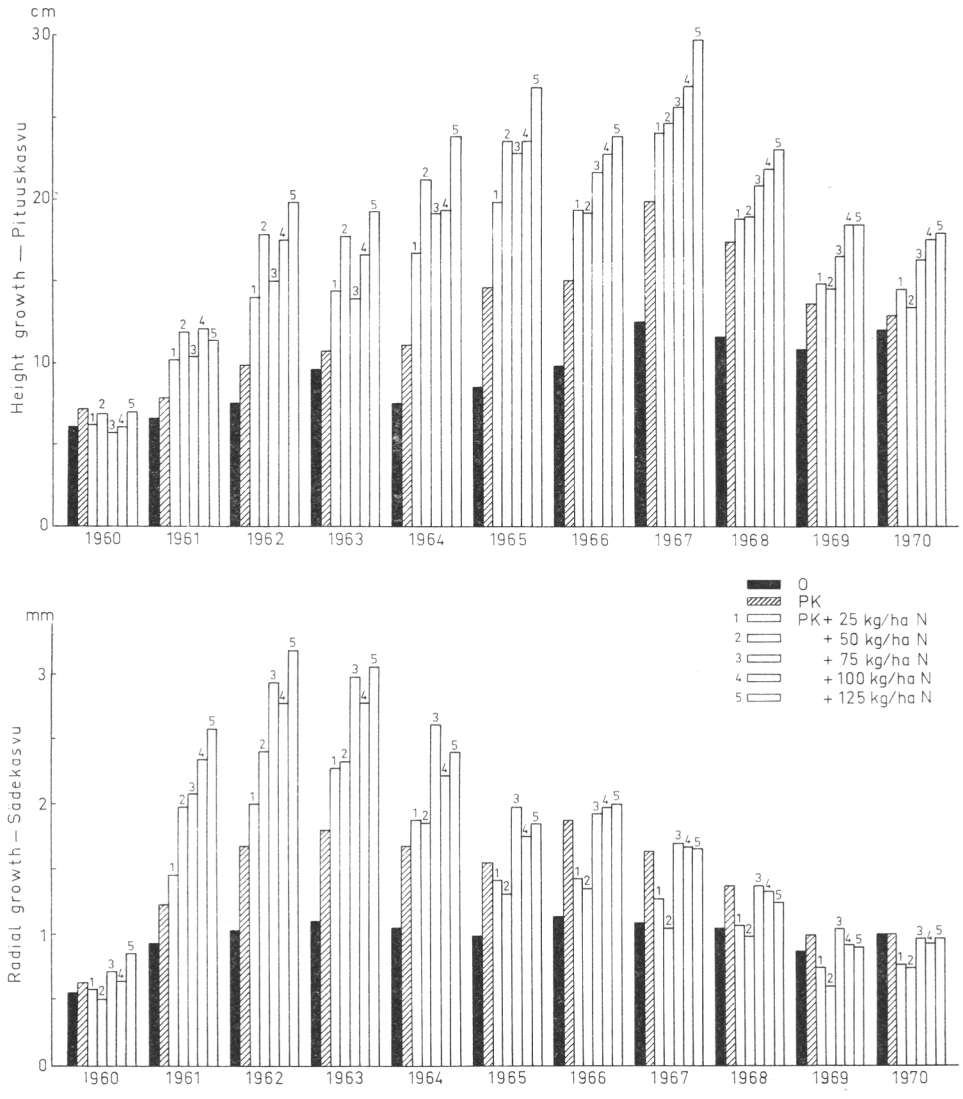


Figure 1. The treatment means of height and radial growth adjusted for regression in Sonkajärvi
Kuva 1. Puuston kovarianssikorjattu pituus- ja sädekasvu Sonkajärvellä.

view, it is important to know what is the significance of the nitrogen application level on the strength and duration of the fertilization. This question can be examined according to the evidence obtained from the experimental field in Sonkajärvi. There, six different amounts of calcium ammonium nitrate were applied (0, 25, 50, 75, 100, 125 kg/ha N) in conjunction with PK fertilizer (132 kg/ha P_2O_5, 40 kg/ha K_2O).

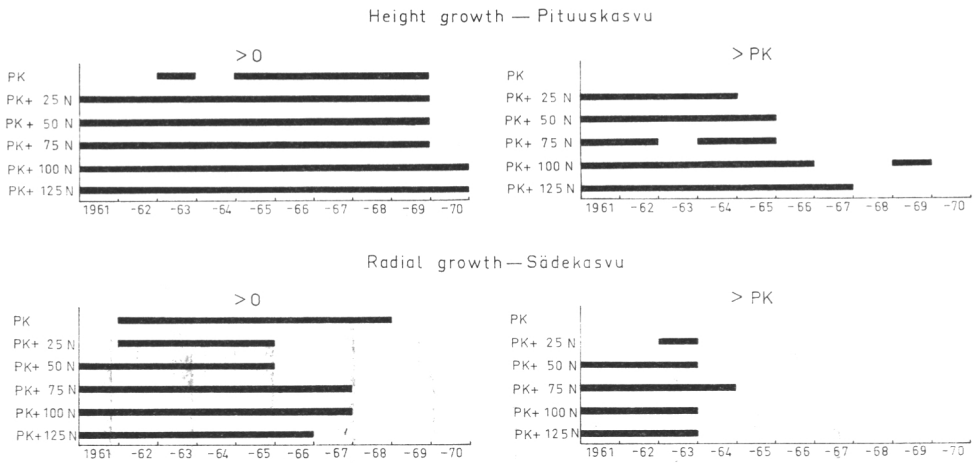


Figure 2. The significance of the growth differences on tree stands in Sonkajärvi.
Kuva 2. Puuston kasvuerojen merkitsevyys Sonkajärvellä.

The fertilization significantly increased the height growth of trees during 1961—1970 and the radial growth till 1968 (Table 4).

Figure 1 presents the height and radial growth in Sonkajärvi (treatment means were adjusted for regression), and Figure 2 shows the significance of the differences in growth due to different application levels of nitrogen as tested by the Duncan test. In Figure 2 the years have been marked in which the influence of fertilization has been significantly better (with the confidence level of 95 %) than in unfertilized plots (> 0) and on plots that have received only PK fertilization (> PK).

The effect of NPK fertilization on the height and radial growth of trees was the better the more nitrogen was applied. Even the lowest nitrogen levels (25 and 50 kg/ha N) improved the growth of the trees, but the increase in growth was distinctly smaller and of shorter duration than when amounts of 75—125 kg/ha N were used. Applying an amount of calcium ammonium nitrate corresponding to 100 kg/ha N in conjunction with PK fertilization, significantly improved the height growth of the trees for 7 years and the radial growth for 3 years (Figure 2) as compared to the sample plots that had received only PK fertilization. The results concerning the radial growth of the trees especially show that as soon as the effect of nitrogen fertilization ended, the effect of PK fertilization on the growth of the trees remained for a short time only. Thus nitrogen deficiency prevented the growth of trees both directly and indirectly by hindering the appearance of the effect of PK fertilization.

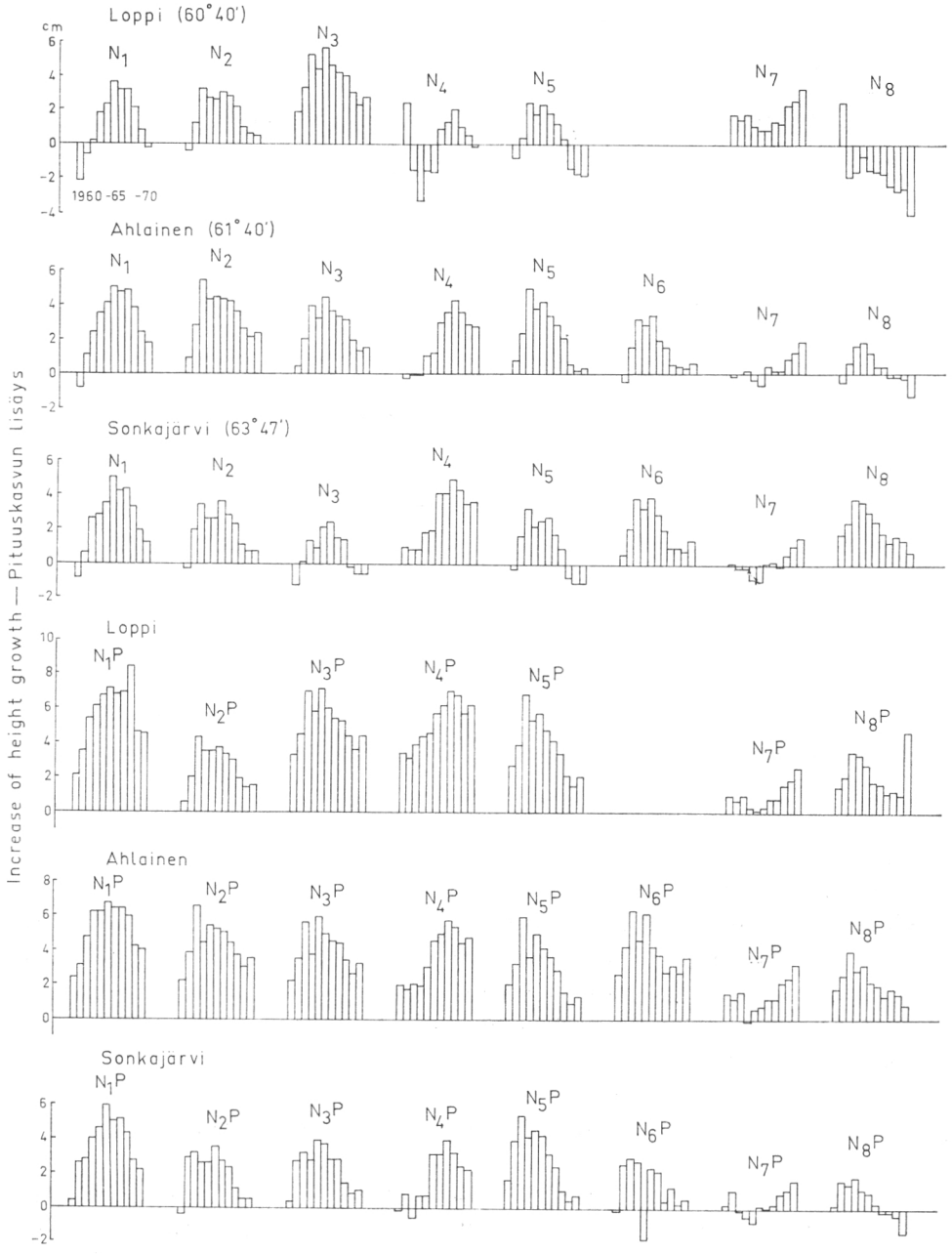


Figure 3. The increase in the height growth of the tree stand with treatment means adjusted for regression. For $N_1 \ldots N_8$, see Table 2 (p. 12).

Kuva 3. Puuston kovarianssikorjatut pituuskasvun lisäykset. $N_1 \ldots N_8$, ks. taulukko 2 (s. 12).

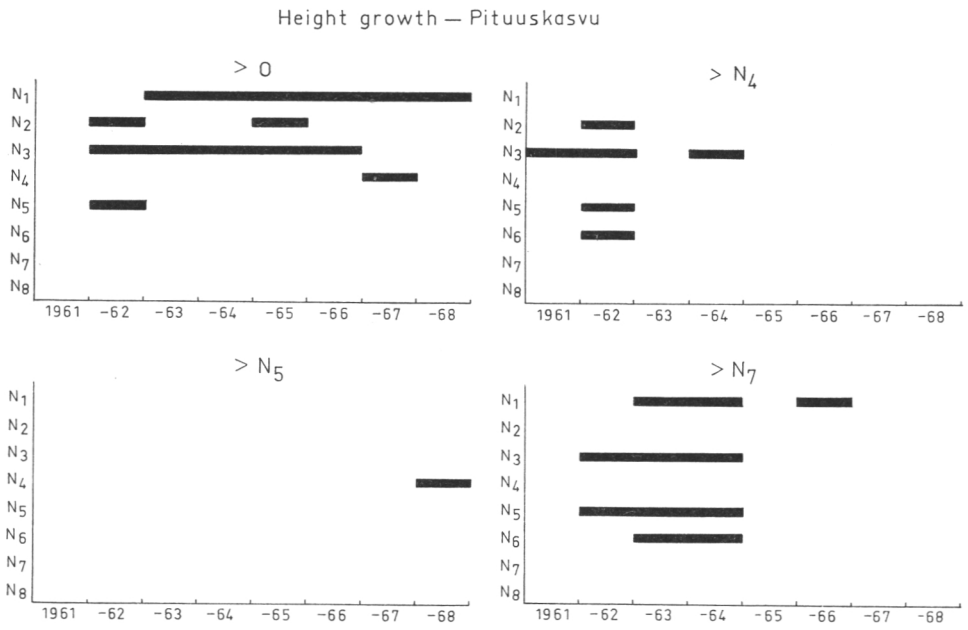


Figure 4. The significance of the differences in the height growth of the tree stand.
Kuva 4. Puuston pituuskasvuerojen merkitsevyys.

32. The dependence of the growth reaction caused by fertilization on the type of nitrogen fertilizer

The growth reaction caused by fertilization was quite clearly dependent on the type of nitrogen fertilizer employed. Figure 3 presents the increase in height growth (treatment means adjusted for regression), when applying both nitrogen alone and in conjunction with phosphorus. Figure 4 shows the significance of the differences caused by various types of nitrogen fertilizers tested with the D u n c a n test. In Figure 4 there are marks against the years in which the effect of the type of nitrogen fertilizer was significant with the confidence level of 95 % as compared with the sample plots that had received no nitrogen fertilization (> 0), and compared with other types of nitrogen fertilizers (> N_4, > N_5, > N_7).

According to the results, it seems that all the types of nitrogen fertilizers which were being tested had a positive effect on the height growth of the trees. The best growth response was given by ammonium sulphate and the effect of calcium ammonium nitrate and Montan saltpeter was also good. The effect of nitrogen solution on the height growth of trees was rapid and differed significantly in 1962 from the growth of the trees that had not

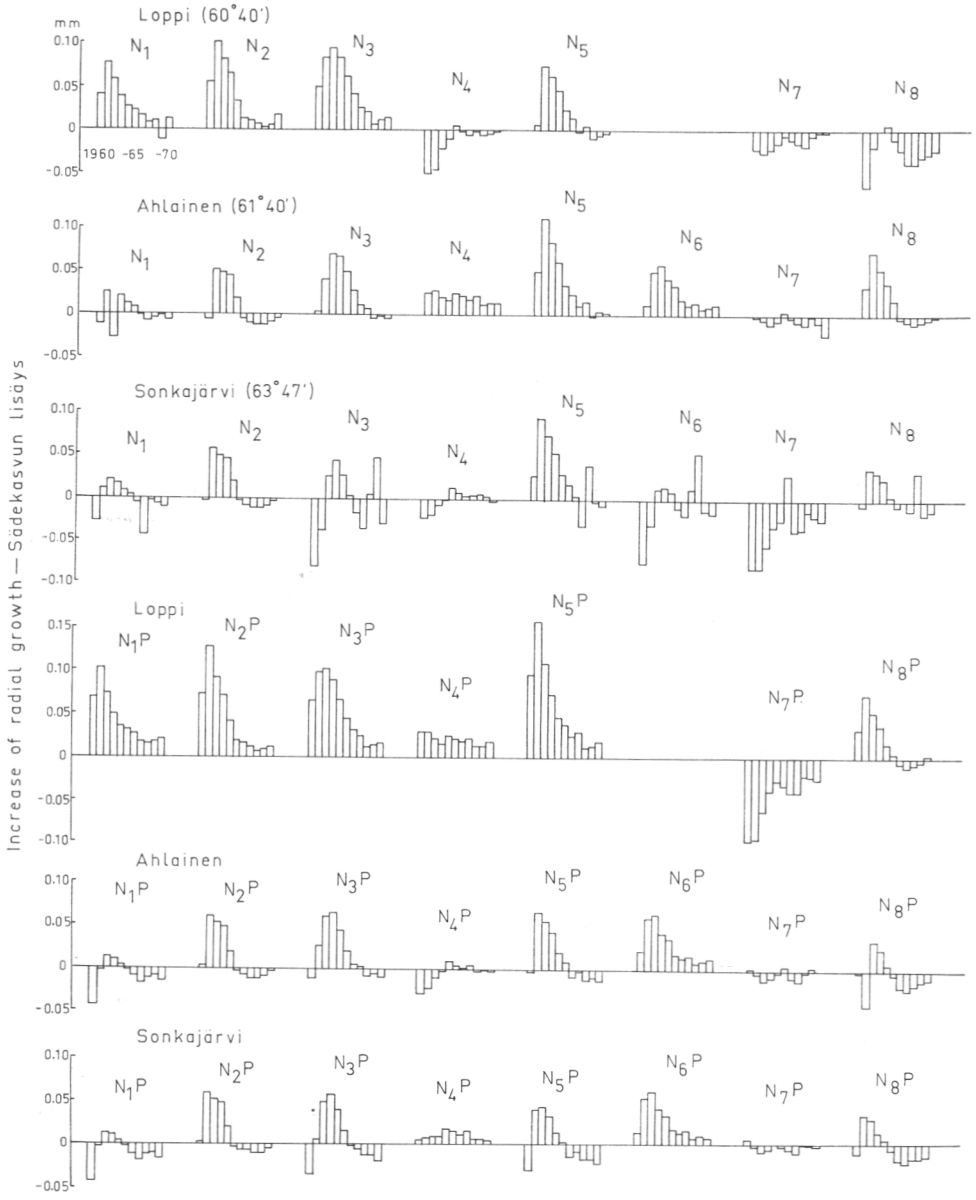


Figure 5. The increase in the radial growth of the tree stand with treatment means adjusted for regression. For $N_1 \ldots N_8$, see Table 2 (p. 12).

Kuva 5. Puuston kovarianssikorjatut sädekasvun lisäykset. $N_1 \ldots N_8$, ks. taulukko 2 (s. 12).

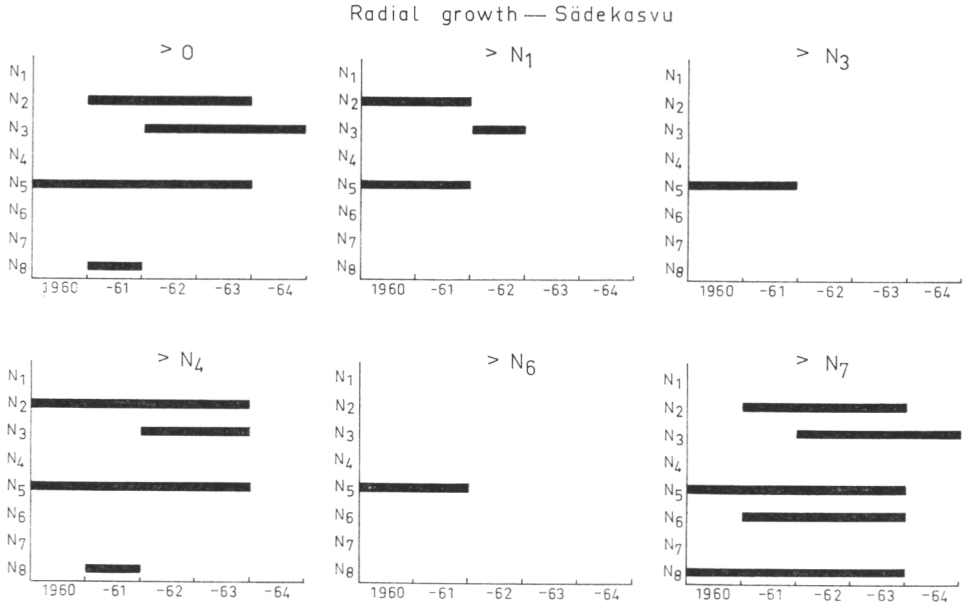


Figure 6. The significance of the differences in the radial growth of the tree stand.
Kuva 6. Puuston sädekasvuerojen merkitsevyys.

received any nitrogen. The effect of ammonia gas injected into the soil was at first rather negligible, but was clearly apparent a few years after the fertilization. The mean effect of urea on the height growth of the trees remained relatively small, but was significantly better than the effect of ammonia gas. Calcium nitrate did not significantly increase the growth of the trees as compared with the sample plots that received no nitrogen. The weakest effect was given when urea was sprayed onto the needles, which is only natural when considering the small amount of nitrogen used.

The effect of different types of nitrogen fertilizers on the radial growth of trees is shown in Figures 5 and 6. When comparing the radial growth of the trees receiving nitrogen with those without nitrogen, it is clear that the best growth was given by nitrogen solution. Almost an equally good response was given by calcium ammonium nitrate and Montan saltpeter. Similarly, calcium nitrate significantly improved the radial growth of the trees. Furthermore, the results show that ammonium sulphate, ammonia gas and urea did not significantly improve the radial growth of the trees as compared with the sample plots that had not received nitrogen. Significantly better growth was given by nitrogen solution than by ammonium sulphate, ammonia gas and urea. A significantly better increase in radial growth was

obtained from calcium ammonium nitrate and Montan saltpeter than from ammonium sulphate and ammonia gas. The spraying of urea did not stimulate the radial growth of the trees.

The results indicate that ammonium sulphate containing exclusively ammonium nitrogen had the strongest effect on the height growth of the trees, whereas fertilizers containing ammonium nitrogen and nitrate nitrogen (nitrogen solution, calcium ammonium nitrate and Montan saltpeter) had the best effect on the radial growth of the trees. Calcium nitrate containing only nitrate nitrogen hardly increased the height growth and increased the radial growth less than fertilizers which contained both nitrate and ammonium nitrogen. The effect of urea spread on the soil was somewhat lower than that of the fertilizers containing ammonium nitrogen and nitrate nitrogen. According to the experiments performed in Norway on firm forest land, nitrogen fertilization (150 kg/ha N) with calcium nitrate increased the annual volume growth of trees during the five years after fertilization on average by 1.63 solid m^3/ha, calcium ammonium nitrate by 1.42 solid m^3/ha and urea by 0.96 solid m^3/ha (Brantseg, Brekka and Braastad 1970). According to the investigations carried out by Viro (1972) on Finnish mineral soil, ammonium sulphate (160 kg/ha nitrogen) gave an annual increase of 3.0 solid m^3/ha during five years and urea on average 2.5 solid m^3/ha.

Table 5 presents the mean figures of total growth according to the results obtained from covariance analysis in the experimental fields of Ahlainen and Sonkajärvi, where all the types of nitrogen fertilizers under investigation were used. The values obtained from the spraying of urea solution were

Table 5. The mean values of the height and radial growth with treatment means adjusted for regression in the experimental fields of Ahlainen and Sonkajärvi
Taulukko 5. Kovarianssikorjattujen pituus- ja sädekasvujen keskiarvot Ahlaisten ja Sonkajärven koekentillä.

Nitrogen fertilizer *Typpilannoitelaji*	Height growth in 1960—1968, cm *Pituuskasvu v. 1960—1968, cm*			Relative value *Suht. arvo*	Radial growth in 1960—1964, mm *Sädekasvu v. 1960—1964, mm*			Relative value *Suht. arvo*
	—P	+P	X		—P	+P	X	
0	107.6	138.9	123.3	100	5.6	8.0	6.80	100
Nitrogen solution — *Typpiliuos*	129.5	170.6	150.1	122	8.8	9.5	9.15	135
Calcium ammonium nitrate — *Kalkkiammonsalpietari*	134.3	164.1	149.2	121	7.2	9.7	8.45	124
Montan saltpeter — *Montansalpietari*	129.4	159.6	144.5	117	6.8	9.7	8.25	121
Urea — *Urea*	124.4	156.9	140.7	114	6.2	10.3	8.25	121
Calcium nitrate — *Kalkkisalpietari*	118.0	145.8	131.9	107	7.1	8.9	8.00	118
NH_3 gas — *NH_3-kaasu*	119.6	155.2	137.4	111	6.1	8.1	7.10	104
Ammonium sulphate — *Ammoniumsulfaatti*	137.4	172.2	154.8	126	6.2	7.8	7.00	103

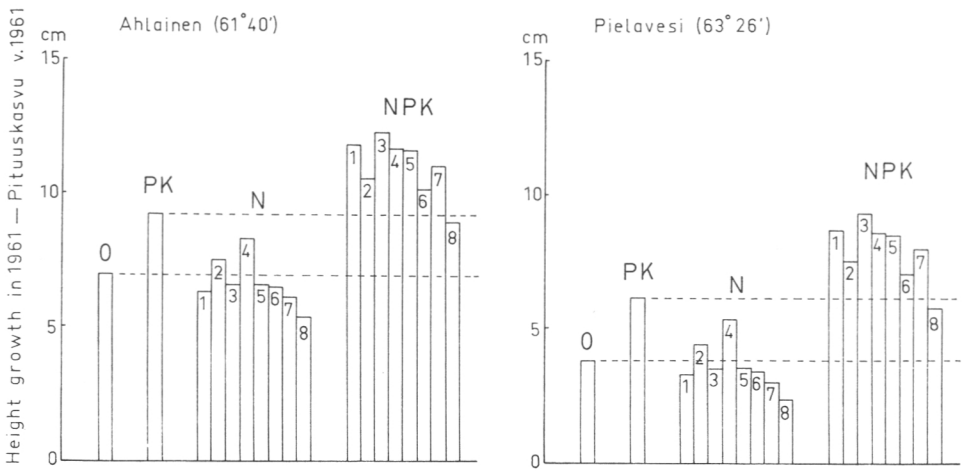


Figure 7. The height growth in the experimental fields with spot fertilization. For $N_1 \ldots N_8$, see Table 2 (p. 12).

Kuva 7. Puuston pituuskasvu laikkulannoitetuilla koekentillä. $N_1 \ldots N_8$, ks. taulukko 2 (s. 12).

omitted, as they were not really comparable with the other methods because of the low amount of nitrogen used.

Table 5 demonstrates that under the most favorable conditions, nitrogen fertilization without phosphorus improved the growth as much as phoshorus fertilization alone. When nitrogen fertilization was used, the relative increase in growth was around 20—30 %, while the absolute increase was rather small owing to the quality of the tree stand.

According to the figures in Table 5, the growth response obtained by using nitrogen, compared with the total growth of tree stands, remained smaller than that which the writer had predicted in his preliminary report (P a a v i l a i n e n 1971). This is due to the fact that in the earlier report the adjustment for regression was done to 0-level and not to the mean level of growth. The absolute increase in growth was naturally the same in both cases.

According to the figures in Table 5, urea fertilization resulted in a relatively better response and nitrogen solution a worse response with than without phosphorus. The effect of various types of nitrogen fertilizers on the growth is, however, generally not dependent on the phosphorus level of the plots. This is also proved by the above-mentioned result obtained from covariance analysis, according to which the interaction between nitrogen and phosphorus was not significant (p. 14). Further investigation was carried out using the covariance analysis to test the effect of various types nitrogen fertilizer on the radial growth of the trees in Ahlainen and Sonkajärvi. Calcu-

lations were performed separately on the plots with and without phosphorus fertilization. In both cases, the type of nitrogen fertilizer affected significantly the growth of the trees, and the influence was of equal duration. When phosphorus fertilization was not used, there was no interaction between the location and the nitrogen type. However, interaction was found when phosphorus fertilization was used. According to this analysis the highly favorable effect of urea and the weak effect of nitrogen solution in conjunction with phosphorus can be attributed to the quality of the plots so that in Ahlainen these treatments produced a different result from the other fields.

When spot fertilization was used, nitrogen increased significantly the growth of pine transplats only in 1961, as previously mentioned. Figure 7 presents the growth of transplants treated with various combinations of fertilizers that same year. Ammonia gas, as compared with other types of fertilizers, gave the best response. The growth of transplants was significantly greater when fertilized with ammonia gas than with calcium ammonium nitrate or without any nitrogen fertilization at all.

4. DISCUSSION

The results of this investigation show, as do several earlier ones as well that at least in the fertilization of peatland forests poor in nutrients, nitrogen in addition to phosphorus and potassium is needed. In the case of a swamp with the nutrient level of a cottongrass pine swamp, nitrogen has such a strong effect on the growth of trees that a decrease in this effect when NPK fertilization is carried out, prevents the influence of phosphorus and potassium from appearing. This observation is by no means new, for in the recommendations for the practical application of fertilization, nitrogen has been considered necessary on swamps with or below the nutrient level of a cottongrass pine swamp (H u i k a r i 1961, 1964, H u i k a r i *et.al.* 1963, H u i k a r i and P a a v i l a i n e n 1972).

According to the results, nitrogen is also important on pine swamps which have a higher nutrient level than a cottongrass pine swamp. Nitrogen fertilization had a clearly positive effect on the growth of the tree stands on a *Carex globularis* pine swamp and on a sedge pine swamp in Muhos. On *Carex globularis* pine swamps the thin peat layer probably increased the need for nitrogen fertilization. According to the present investigation it is impossible to find out exactly where the border limit of the need for nitrogen fertilization lies as regards the peatland type and the thickness of peat. This question requires further investigation.

Although even very small amounts of nitrogen improved the growth of trees on cottongrass pine swamps, a good growth response obviously required at least 75—100 kg/ha of nitrogen. In the afore-mentioned recommendations these or slightly smaller amounts of nitrogen were recommended for practical use. The amount of nitrogen reguired for the biologically optimum response was not determined in this investigation. On a cottongrass pine swamp with a thinly-stocked stand, it could be greater than the greatest amount employed in the experiments (125 kg/ha N), for the growth of trees continued to improve when the amounts of nitrogen increased from 25 kg/ha to 125 kg/ha. The experiments set up in Loppi by the Department of Peatland Forestry of the Forest Research Institute refer also to this possibility. In this case the amount of nitrogen applied reached as high as 600 kg/ha N; however, the results are still unpublished. In dense forests on mineral

soils, the optimum amounts of nitrogen are rather high according to recent investigations. In Sweden, for instance the best response during the first five years in an experimental field was gained by using 450 kg/ha of nitrogen (Möller 1971). According to the investigations performed in Finland the growth of trees increased when the use of nitrogen increased from 80 kg/ha to the highest dosage of 240 kg/ha of N (Viro 1972).

During the first growing season nitrogen fertilization affected only the radial growth of trees, and not their height growth at all. The reason for this was probably that the increasing assimilation activity of trees in the year of application due to the increase in the number of needles and their chlorophyll content (e.g. Viro 1965, 1970, Paarlahti 1967, Paavilainen 1969), had no time to affect the height growth which ends early and which is extremely dependent on the temperature and other growth factors of the previous summer (Kramer and Kozlowski 1960, Kozlowski 1964, Gaertner 1964, Huikari and Paarlahti 1967). On the contrary, nitrogen fertilization has time to affect, during the year of application, the radial growth which is of longer duration and especially dependent on the changes occuring in various growth factors in the current year.

The investigations concerning the duration of the effect of nitrogen fertilization show that when using broadcast fertilization, refertilization with nitrogen should take place within 5—10 years after the first application. It is evident that refertilization should be carried out before the influence of fertilization has worn off. In forests on mineral soil, refertilization is recommended 3—5 years after the first fertilization (Viro 1965) when the influence of fertilization can still be observed in the needles. The trees may then store large amounts of nutrients which may be utilized for new growth because the trees do not have immediately to increase their foliage.

According to this investigation the significance of nitrogen was considerably smaller in spot than in broadcast fertilization. Although this same conclusion has been reported in earlier investigations (see p. 17), one has to look at the results of this investigation with a certain reserve. This is because the data was gathered from two experimental fields only, one of which (Pielavesi) is naturally rich in nitrogen. On *Sphagnum fuscum* swamps nitrogen certainly is of greater importance, as is shown by the field as well as by the pot experiments established by the Forest Research Institute (e.g. Paavilainen 1965, 1970 b, Kaunisto 1971, 1972 a, b). Since the effect of spot fertilization is of short duration, refertilization is needed very soon, obviously 5 years after the afforestation fertilization at the latest.

The experiments described in this report involved fertilizers containing both ammonium, nitrate, and urea nitrogen. Of these, ammonium sulphate contained only ammonium nitrogen, Montan saltpeter or ammonium sulphate saltpeter $^3/_4$ ammonium nitrogen and $^1/_4$ nitrate nitrogen, Oulu salt-

peter or calcium ammonium nitrate ½ ammonium nitrogen and ½ nitrate nitrogen, and calcium nitrate almost completely nitrate nitrogen. Urea was the fifth solid nitrogen fertilizer.

Ammonium nitrogen had the strongest effect on the height growth of the trees and nitrate nitrogen on the radial growth. The best response was given by fertilizers that contained both ammonium nitrogen and nitrate nitrogen They affected strongly the radial growth of trees, which is of utmost importance as regards the volume growth for it thus makes fertilization economically profitable. The effect of a fertilizer containing both ammonium and nitrate nitrogen did not depend on the fact whether the fertilizer contained calcium or not, for both calcium ammon nitrate and Montan saltpeter gave nearly as large an increase in growth. Urea also improved the growth, although to a somewhat lesser extent than the fertilizers containing ammonium and nitrate nitrogen. The effect of calcium nitrate containing only nitrate nitrogen was rapid, although its total effect remained poor.

The results of this investigation agree in some respects with those made on firm land forests in Finland. According to the experiments of Viro (1972), ammonium sulphate or calcium ammonium nitrate proved better than urea. The weak effect of urea is predictable, especially if it is applied in early spring or during a hot and dry summer. A corresponding conclusion about urea as compared with the other types of nitrogen has been reached e.g. in Norway (Brantseg, Brekka, and Braastad 1970) and in Sweden (Möller 1971). According to Salonen (1968) in agricultural fertilization experiments, the use of small amounts of urea did not have as favorable an effect as calcium nitrate. The presence of ammonium nitrogen in multinutrient fertilizers resulted in a good response, but it led to a later increase in soil acidity and a decrease in the yield of crops (Salonen *et.al.* 1968). When the nitrogen fertilizer contained at least ¼ nitrate nitrogen, there was a better response than when using only ammonium nitrogen.

According to the experiments, all the solid nitrogen fertilizers under study — except perhaps calcium nitrate — are suitable for the fertilization of swamp forests. The fertilizers containing both ammonium nitrogen and nitrate nitrogen (e.g. calcium ammonium nitrate) seem to give the biologically best response. Urea, because it is inexpensive, can also be considered to be a suitable fertilizer, although its effect is weaker than that of calcium ammonium nitrate. However, further investigations are required in order to determine the profitability of the use of different types of fertilizers, i.e. which fertilizer gives the best response in various swamp types and stands.

When studying the reason for the different responses given by various nitrogen sources, one has to pay attention to their behaviour in the nitrogen cycle. When comparing ammonium nitrogen and nitrate nitrogen, it has been observed that trees, as well as most plants, are able to absorb and

use both types of nitrogen (e.g. Tiedjens 1934, Addoms 1937, Street and Sheat 1958, Michael *et.al.* 1965). The pH and aeration of the substratum, the carbohydrate relations of the plant, the growth phase and the species of plant together have an influence on how effectively the plants use nitrogen. When the soil is acid and contains little oxygen, the plants usually absorb nitrate nitrogen more effectively than ammonium nitrogen. This leads to the conclusion that the improvement of nitrogen conditions in peat soils that are acid and may at certain times, despite drainage have a low oxygen content, is best carried out by applying nitrate nitrogen. Obviously almost no nitrification, the conversion of ammonium nitrogen into nitrate nitrogen, can occur under the acid conditions prevailing in swamps (Ömmik 1956, Smith and Pritchett 1968, Overrein 1970 a) so the trees are forced, when ammonium fertilizer is applied, to absorb nitrogen in the form of ammonium ions. Urea changes into ammonium through hydrolysis and is available to trees both as urea and ammonium nitrogen.

The usability of various types of nitrogen is greatly dependent on how strongly they become bound in the soil or disappear from it through leaching or evaporation. Several investigations have proved that ammonium nitrogen becomes strongly bound to the organic matter in the soil (e.g. Burge and Broadbent 1961, Nömmik and Nilsson 1963 a, 1963 b, Nömmik 1967, 1970, Overrein 1967, 1968, Nyborg 1969, Parr 1969). The binding of ammonium ions into the organic matter of the soil is directly dependent on the organic carbon content of soil and is usually larger the lower the pH value of the soil is. According to Ömmik and Nilsson (1963 a), in slightly humified virgin peat the binding of ammonium nitrogen is twice as strong as its binding to the fully humified peat of a cultivated swamp. The compound formed between ammonium and the organic matter is very resistant to decomposition by microbes (Ömmik and Nilsson 1963 b, Nömmik 1967). Retention of nitrogen applied as urea which changes into ammonium ions is probably even stronger, whereas that of nitrate nitrogen is weaker. According to the lysimetric experiments carried out by Overrein (1967, 1968) where 250 kg/ha of nitrogen was applied, within three months 1.6 % of the nitrogen had leached out when using urea, 21.6 % when using ammonium nitrogen and 92.0 % when using nitrate nitrogen. After urea fertilization, ¼ of the leached nitrogen originated from the fertilizer, the rest form the nitrogen compounds of the humus layer. Correspondingly, when using ammonium nitrogen ¾ of the nitrogen originated from the fertilizer, but when using nitrate nearly all the nitrogen originated from the fertilizer. According to the experiments performed by Ömmik and Popovic (1971) there remained in the field layer, litter and soil 23 % of the calcium nitrate, 63 % of the ammonium sulphate and 76 % of the urea. These results indicate that unless the trees use nitrate

nitrogen within the first growing season after fertilization, the danger of it being leached away is very great.

It may be assumed that the rather strong initial effect of nitrate nitrogen on the radial growth of trees has resulted from the fact that the trees on the peatlands have absorbed very effectively the nitrogen given in the form of nitrate. The rapid weakening of its effect after the first growing season may, at least partly, be due to leaching. However, the leaching of nitrate nitrogen on peatlands drained for forestry may be considerably less than that on mineral soils.

A rapid initial effect, however, plays no decisive role in the nitrogen fertilization of peatlands. Trees take up the nitrogen given by fertilization at least during the first three years (e.g. Viro 1965). In addition, nitrogen fertilization increases the mineralization of nitrogen in the humus layer and thus also enhances the amount of nitrogen available to the trees (Viro 1963, Overrein 1967, 1970 a, b). If the leaching losses of nitrogen are only slight, nitrogen fertilization has an after-effect that stimulates the release of natural nitrogen in the humus layer. This is of great importance especially on peatlands whose peat contains plenty of nitrogen which is bound in such a way that it is not available to trees.

The effect of ammonium nitrogen was of long duration, which was obviously due to its strong binding to the peat and slight leaching. When ammonium nitrogen only was used, the uptake of nitrogen by the trees remained so low that nitrogen fertilization only improved the height growth of the trees, and had very little effect on the radial growth. The best response was given by both nitrate and ammonium nitrogen together, thus combining the strong initial effect of nitrate nitrogen and the after-effect of ammonium nitrogen of long duration.

The effect of urea was on average somewhat weaker than that of fertilizers containing ammonium and nitrate nitrogen. However, urea is not really comparable with a fertilizer containing pure ammonium nitrogen, for urea also affected the radial growth in the same way as nitrate nitrogen did, and on some plots fairly strongly. The reason for this cannot be determined from the material of this investigation.

When trying to find possible reasons for the weaker effect of ammonium nitrogen and urea, as compared with the ammonium and nitrate compounds, attention should be paid to the fact that fertilizer nitrogen may be lost through evaporation. The urea and ammonium compounds are especially liable to evaporation, particularly in soils with a high pH (e.g. Nömmik 1966, Overrein 1968). According to Nömmik (1966), evaporation losses within the first four days were 1 % when using Na nitrate, 18 % when using calcium ammonium nitrate, 41 % when using ammonium sulphate and 21 % when using urea. The increase in the soil moisture content strongly

contributed to the evaporation of urea. The evaporation of nitrate may occur under the influence of denitrification. Favorable conditions for denitrification occur when the ground water is close to the soil surface (Nömmik 1956, Overrein 1970 a) as is often the case on peatlands. Thus there may occur nitrogen losses owing to the evaporation of all types of nitrogen sources, and especially in the case of fertilizers containing urea or ammonium. Thus, the somewhat weaker influence of pure ammonium nitrogen and urea as compared with the ammonium and nitrate compounds may have been at least partly due to the evaporation of nitrogen. However, it must be stated that the loss of nitrogen through evaporation may well be much smaller on peatlands drained for forestry than on mineral soils.

The above-mentioned ideas about the reasons for the differences in the influence between various types of nitrogen fertilizers are only assumptions. Their validity may be proved by further investigations. An investigation on the utilisation of urea by pine on peatland has already been started (Paavilainen 1972).

The other methods being tested were the spraying of an urea solution onto the needles, the injection of ammonia gas into the soil, and the spreading of nitrogen solution on the ground. Technically, they are very difficult to realize for they are expensive specialised methods which should, in order to be profitable, give a better response than the ordinary methods.

The spraying of urea onto tree leaves has been used as a fertilization method in orchards especially in the U.S.A. and also in Finland (Säkö 1959). In forestry, the spraying of urea has been used to some extent in the nurseries (Stoate 1950, Asanova 1962). The present experiments in which urea was sprayed, yielded no remarkable increase in growth, the reason for which was probably the small amount of nitrogen used. Furthermore, it is possible that even though the trees are capable of absorbing urea through the stomatas and directly through the epidermis (e.g. Roodney 1952), the amount of nitrogen which becomes available to the trees in this way was small compared with the amount of nitrogen that was leached or evaporated from the needles. The present results show that the use of urea spray, used in this manner, is not profitable in the fertilization of peatland forests.

Ammonia gas has been used for soil amelioration and to increase the growth of forests especially in Germany, where the method has given good response in the fertilization of firm forest soils (e.g. Mayer-Krapoll 1956, Wittich, Ronde and Hausser 1958, Zöttl and Kennel 1962, Baule and Fricker 1967). Liquid ammonia has also been used as a fertilizer in agriculture (e.g. Nömmik and Nilsson 1963 a, Jansson 1966, Papendick and Parr 1966, Parr and Papendick 1968, Parr 1969). According to the experiments carried out

in Finland, liquid ammonia is considered as good as calcium ammonium nitrate when giving in conjunction with sowing and soil preparation (P e s s i *et.al.* 1971). According to the present study, ammonia gas improved the growth of trees on peatlands, although in broadcast fertilization it resulted in a weaker response compared with ammonia given in solid form as ammonium sulphate. On the other hand, spot fertilization with ammonia gas resulted in a slightly better response on average than the other types of nitrogen fertilizers which were being studied. It is likely that the ammonia gas applied to a small area of the substratum was absorbed by transplants more effectively than in ordinary spot fertilization, where the fertilizer is carefully placed in a circle around the transplant and kept out of touch with the transplants.

According to the results received from the experimental fields where broadcast fertilization was carried out, ammonia gas improved the growth of trees rather slowly, for it did not become apparent until several years after fertilization. This implies that ammonia was bound to the peat very effectively and only gradually became available to the trees. As mentioned before (pp. 33), the binding of ammonium nitrogen to the organic matter of soil is strong. Ammonia gas has improved the growth of trees so slowly and so little that this method cannot be considered better than the ordinary methods used in the fertilization of peatland forests.

This investigation involved also the use of nitrogen solution, which contained 65.9 % of ammonium nitrate and 16.7 % of ammonia. It affected the radial growth of trees quickly and effectively, which made it, on average, the best type of nitrogen fertilizer under study. It seems possible that the effect of nitrogen fertilizers applied in a liquid form is better than when solid fertilizers are used. Although the application of this method involves many technical difficulties, it might be necessary to determine what possibilities there are of developing the fertilization techniques so as to make possible the use of nitrogen fertilizers in solution.

5. SUMMARY

The purpose of this study is to illustrate how the different types of nitrogen fertilizers affect the growth of pine on peatlands drained for forestry. The types of nitrogen fertilizers under study (Table 2) were as follows: ammonium sulphate, calcium ammonium nitrate, Montan saltpeter, ammonia gas, nitrogen solution, urea, the spraying of urea solution onto the tree needles and calcium nitrate. The experiments were established in five different locations in 1960 (Table 1).

There were 368 plots in all. 291 plots received broadcast fertilization and 77 plots spot fertilization. The height and radial growth of trees on each plot was measured in 1970. The data contain the measurement of the height growth of 6921 sample trees and that of the radial growth of 1848 sample trees. The effect of different nutrients, amounts of nitrogen and the types of nitrogen fertilizers on the growth of the trees were calculated by means of the covariance analysis in broadcast fertilized areas and by means of the variance analysis in spot fertilized areas.

According to the results, the duration of the effect of nitrogen fertilization in broadcast application when using NPK fertilization (100 kg/ha N, 132 kg/ha P_2O_5 and 40 kg/ha K_2O) was, on the average eight years when the height growth and five years when the radial growth was concerned (Table 3). When spot fertilization was used, the effect of nitrogen was significant only for one year. Phosphorus had an effect of a longer duration than nitrogen, for it continued to exert a significant effect even at the time of measurement which was 11 growing seasons after the fertilization. The effect of potassium fertilization was weak, which is at least partly due to the small amount of potassium used.

NPK fertilization affected the height and radial growth of trees the better the more nitrogen was used in the fertilization, when the amount of nitrogen was increased from 25 kg/ha N to 125 kg/ha N (Figures 1 and 2, Table 4).

The growth reaction caused by fertilization was distinctly dependent on the type of nitrogen fertilizer used (Figures 3—7). In the case of broadcast fertilization, ammonium sulphate containing only ammonium nitrogen had the strongest effect on the height growth of trees. As fas as the radial growth was concerned, the best response was given by the fertilizers containing both ammonium and nitrate nitrogen: nitrogen solution, Oulu saltpeter and Montan saltpeter. Calcium nitrate containing only nitrate nitrogen did only slightly increase the height growth of trees, and produced a lower

increase in radial growth than the fertilizers which in addition to nitrate nitrogen also contained ammonium nitrogen. The effect of urea spread on the ground was weaker than that of the fertilizers containing ammonium and nitrate nitrogen. The weakest response was obtained when an urea solution was sprayed onto the tree needles. This was understandable when the small amount of nitrogen used is taken into consideration. As far as spot fertilization was concerned, the injection of ammonia gas resulted in the best response. However, the effect was significant only for one year.

When using the results of the experimental fields where all the types of nitrogen fertilizers were used (Table 5), it seems that in the best case nitrogen fertilization without phosphorus fertilization (during the time nitrogen did increase the growth) improved the growth as much as phosphorus fertilization alone. The maximum relative increase in growth were about 20—30 % when nitrogen fertilizers were used, whereas the absolute increase in growth remained rather small owing to the quality of the tree stand.

The results of this investigation indicate that all the solid fertilizers which were tested — excluding perhaps calcium nitrate — are suitable for the fertilization of swamp forests. The use of the fertilizers containing both ammonium and nitrate nitrogen, such as calcium ammonium nitrate, seems to produce the biologically best response. Due to its low price urea may also be considered to be a suitable fertilizer, although its influence remained weaker than that of calcium ammonium nitrate. The comparison of the profitability between various types of nitrogen fertilizers needs, however, further investigations in order to prove which fertilizer gives economically the best response in various cases. Of the special methods studied, only the use of nitrogen solution seems to be possible. Its use, however, presupposes the development of fertilization techniques.

It is assumed that the strong initial effect of nitrate nitrogen on the radial growth is due to the fact that trees growing on peatlands have absorbed nitrogen in its nitrate form very effectively. The rapid decline of its influence after the first growing season might have been due to leaching. The long-lasting effect of ammonium nitrogen may be due to its strong binding to peat and only slight leaching. When ammonium nitrogen only is used, the uptake of nitrogen by trees remained so low that although nitrogen fertilization improved the height growth of the trees, it hardly improved the radial growth .Applying both nitrate and ammonium nitrogen, means that the strong initial effect of nitrate nitrogen and the long-lasting aftereffect of ammonium nitrogen are combined, and thus the best response is obtained. The somewhat weaker influence of urea as compared with the ammonium and nitrate compounds may have been at least partly due to the evaporation of this type of nitrogen. The validity of these various assumptions will not, however, be proved until further investigations have been carried out.

6. REFERENCES

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7. SUOMENKIELINEN SELOSTE

Tutkimuksen tarkoituksena on ollut selvittää erilaisten typpilannoitelajien vaikutusta männyn kasvuun metsäojitetuilla soilla. Tutkittavia typpilannoitelajeja olivat (taulukko 2): ammoniumsulfaatti, kalkkiammonsalpietari (Oulun salpietari), ammonsulfaattisalpietari (montansalpietari), ammoniakkikaasu, typpiliuos (sis. 65.9 % ammoniumnitraattia ja 16.7 % ammoniakkia), urea, urean vesiliuoksen ruiskutus puiden neulasille sekä kalkkisalpietari. Kokeet on perustettu vuonna 1960 viidelle eri paikkakunnalle (taulukko 1).

Tutkimuksen koealoja oli kaikkiaan 368, joista hajalannoituksen saaneita oli 291 ja laikkulannoituksen saaneita 77. Jokaiselta koealalta mitattiin vuoden 1970 syksyllä puuston pituuskasvu sekä suurimmalta osalta koealoja myös puuston sädekasvu. Aineisto käsittää kaikkiaan 6921 koepuun pituuskasvun mittauksen sekä 1848 koepuun sädekasvun mittauksen tulokset. Eri ravinteiden, typpimäärien sekä typpilannoitelajien vaikutus puuston kasvuun laskettiin mittaustuloksista hajalannoituksen saaneilla koekentillä kovarianssianalyysiä ja laikkulannoituksen saaneilla koekentillä varianssianalyysiä hyväksi käyttäen.

Tulosten mukaan typpilannoituksen vaikutusaika hajalannoituksessa oli käytettäessa NPK-lannoitusta (100 kg/ha N, 132 kg/ha P_2O_5 ja 40 kg/ha K_2O) pituuskasvun osalta keskimäärin kahdeksan vuotta ja sädekasvun osalta viisi vuotta (taulukko 3). Laikkulannoituksessa typen vaikutus oli merkitsevä vain yhtenä vuotena. Fosforilla saavutettiin pitkäaikaisempi vaikutus kuin typellä, sillä fosforin vaikutus jatkui merkitsevänä vielä mittaushetkellä eli 11 kasvukautta lannoituksesta. Kalilannoituksen vaikutus kasvuun oli vähäinen, mikä johtunee ainakin osaksi käytetystä alhaisesta kalimäärästä.

Typpilannoitus paransi puiden kasvua jo varsin pieniä typpimääriä (25—50 kg/ha) käytettäessä. NPK-hajalannoituksen vaikutus puiden pituus -ja sädekasvuun oli kuitenkin sitä parempi, mitä enemmän typpeä käytettiin, typpimäärän noustessa 25 kg/ha N:stä 125 kg/ha N:n (kuvat 1—2, taulukko 4).

Lannoituksen aikaansaama kasvureaktio oli varsin selvästi riippuvainen käytetystä typpilannoitelajista (kuvat 3—7). Hajalannoituksessa oli yksinomaan ammoniumtyppeä sisältävällä ammoniumsulfaatilla voimakkain vaikutus puiden pituuskasvuun, kun taas sädekasvun osalta antoivat parhaan tuloksen sekä ammonium- että nitraattityppeä sisältävät lannoitteet: typpiliuos, kalkkiammonsalpietari ja montansalpietari. Pelkästään nitraattityppeä sisältävä kalkkisalpietari ei lisännyt juuri lainkaan puiden pituuskasvua ja sädekasvuakin vähemmän kuin ne lannoitteet, joissa nitraattitypen ohessa oli annettu ammoniumtyppeä. Sekä ammonium- että nitraattityppeä sisältävän lannoitteen vaikutus näytti olevan riippumaton siitä, oliko lannoitteessa mukana kalsiumia vai ei, sillä kalkkiammonsalpietari ja montansalpietari antoivat jokseenkin yhtä suuren kasvunlisäyksen. Maahan levitetyn urean vaikutus jäi jonkin verran jälkeen sekä ammonium- että nitraattityppeä sisältävien lannoitteiden vaikutuksesta. Heikoimman tuloksen antoi urean vesiliuoksen ruiskutus puiden neulasille, mikä olikin

luonnollista, kun otetaan huomioon tätä menetelmää käytettäessä annettu vähäinen typpimäärä. Laikkulannoituksessa saatiin paras tulos ammoniakkikaasun injektoinnilla maahan. Vaikutus oli kuitenkin merkitsevä vain yhtenä vuotena.

Tarkasteltaessa niiltä koekentiltä saatuja tuloksia, joilla käytettiin kaikkia tutkittuja typpilannoitelajeja (taulukko 5) todetaan, että pelkällä typpilannoituksella aikaansaatu puuston kasvun lisäys oli sinä aikana, jolloin typpi vaikutti kasvua parantavasti, jokseenkin yhtä suuri kuin pelkän fosforilannoituksen aiheuttama kasvunlisäys. Suhteelliset kasvunlisäykset olivat typpilannoitusta käytettäessä suurimmillaan 20—30 %:n luokkaa, mutta absoluuttiset kasvunlisäykset jäivät puuston laadusta johtuen verraten pieniksi.

Tutkimustulosten perusteella voidaan todeta, että kaikki tutkitut kiinteät typpilannoitteet — kalkkisalpietaria ehkä lukuunottamatta — soveltuvat suometsien lannoitukseen. Sekä ammonium- että nitraattityppeä sisältävien lannoitteiden, kuten kalkkiammonsalpietarin, käyttö näyttää antavan biologisesti parhaan tuloksen. Hinnaltaan edullisena on myös ureaa pidettävä sopivana lannoitteena, vaikkakin se on jäänyt vaikutukseltaan esimerkiksi kalkkiammonsalpietaria heikommaksi. Eri typpilannoitelajien keskinäisen edullisuuden selvittäminen edellyttää kuitenkin vielä tutkimusta mm. siitä, mikä lannoitteista antaa edullisimman taloudellisen tuloksen eri suotyypeillä ja erilaisissa puustoissa. Tutkituista erikoismenetelmistä voinee vain typpiliuoksen käyttö olla mahdollista. Sen käyttöönotto edellyttää sopivan lannoitustekniikan kehittämistä.

Eri typpilannoitelajien aiheuttamien kasvureaktioerojen syitä pohdittaessa on kiinnitetty huomiota mm. siihen, miten eri typpilajit pidättyvät turpeeseen ja tulevat puiden käyttöön. Nitraattitypen puiden sädekasvussa aiheuttaman melko voimakkaan alkuvaikutuksen syynä on mahdollisesti ollut, että puut ovat ottaneet suolla erikoisen tehokkaasti nitraattimuodossa annettua typpeä. Ammoniumtypen vaikutus on ollut pitkäaikainen, mikä on saattanut johtua sen voimakkaasta pidättymisestä turpeeseen sekä vähäisestä huuhtoutumisesta. Annettaessa lannoituksessa sekä nitraatti- että ammoniumtyppeä on nähtävästi yhdistetty nitraattitypen voimakas alkuvaikutus ja ammoniumtypen pitkäaikainen jälkivaikutus ja näin saatu paras tulos. Pelkän ammoniumtypen sekä urean jossain määrin ammonium-nitraattiyhdisteitä heikompi vaikutus on voinut ainakin osaksi johtua typen haihtumisesta. Näiden erilaisten oletusten mahdollinen paikkansa pitävyys selviää kuitenkin vasta jatkotutkimuksissa.

PROFITABILITY COMPARISONS IN TIMBER GROWING: UNDERLYING MODELS AND EMPIRICAL APPLICATIONS

JOUKO HÄMÄLÄINEN

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PREFACE

In 1967, Prof. Yrjö Vuokila suggested that I should join him in carrying out a research project concerned with the comparison of cutting and silvicultural alternatives of the Vaccinium type pine stand. As soon as Vuokila had finished the collection and treatment of the relevant yield data, I could start planning and carrying out the business-economic calculations. This study report contains a description of the premises underlying the models considered necessary for these calculations, and of the empirical application of the models.

My teacher, Prof. Päiviö Riihinen, of the Helsinki University, who is well known for his training of research workers, has given me valuable advice and instructions, encouraged me and, in numerous tangible ways, efficiently contributed to the completion of my study.

My chief, Prof. Lauri Heikinheimo, Head of the Department of Forest Economics, of the Finnish Forest Research Institute, has guided my work with the skill of a seasoned researcher, and unremittingly stimulated and encouraged me in all stages of my work.

I am greatly indebted also to acting Prof. Jouko Lehtovuori, of the Helsinki School of Economics. The discussions I have had with him have widened my views and helped me to draw the main outline of how to treat my study problem. Sparing no pains, he has familiarized himself with my manuscript and given me valuable advice and directives.

The harmonius collaboration with Prof. Yrjö Vuokila has convinced me of the usefulness of cooperative work projects, not least from the point of view of the research worker's own development.

With the skill of an experienced research worker, assoc. Prof. Pekka Kilkki, having read my manuscript, offered me much valuable advice concerning the contents of the study. I have gratefully followed his suggestions. He has also in practical ways kindly contributed towards the completion of my work.

Assoc. Prof. Jouko Manninen, an expert in the branch, helped me with the mathematical problems of the combined model. The manuscript of the study was also read by Prof. Lorenzo Runeberg. My best thanks are due to Eero Larmola, M.Sc.Econ., for his help in solving the terminological and other comparable problems.

I cordially thank all the personnel of the Department of Forest Economics of the Forest Research Institute for the help they have given me. I have special reason to be grateful to Yrjö Sevola, B.Sc. (Forestry), who did the computer programming for the study and in addition, with exceptional skill and in a spirit of cooperation, undertook a major part of the treatment of the study material. I thank my friend and colleague Sampsa Sivonen, B.Sc. (Forestry) for his ready assistance and guidance, in different connections, in the collecting of price and cost materials. In the modification and use of the yield series, I have availed myself of the expertise of Jouko Laasasenaho, B.Sc. (Forestry). Many jobs of the manuscript and printing phase have been skilfully handled by Jukka Pietilä, B.Sc. (Forestry). Mrs. Laura Colliander assumed responsibility for preparing the manuscript and for many other tasks involved in the research project, totally disregarding the official hours of a working day and cheerfully adapting herself to the varying situations. Mrs. Maija-Liisa Soveri and Miss Leena Paunola have earned my thanks especially for drawing the figures for the study, and the former also for drawing up the clear copies of the mathematical formulas.

In the various stages of the study, I have received efficient help from the forestry students Vesa Heinonen, Mauri Koskela, Pekka Mäkelä and Jukka Santalahti. I must also name my wife Anita with deepest graditude. She has been a constant source of encouragement, support and understanding. She has also helped me in many technical jobs associated with the study.

The manuscript was translated into English by Mrs. Hilkka Kontiopää, M.A. (Helsinki). The language of the first part (until Chapter 4) was checked by Mr. James Cunningham. The second half has been (hurriedly) read by Mrs. Barbara Rikberg, who suggested some amendments. I am very grateful to all of them for the efficiency and skill of their work.

I wish to thank all the persons mentioned above, and many others whom it has not been possible to mention, for their support and help in the course of my work. Finally, I also wish to thank the Finnish Forest Research Institute and its management for accepting this paper to be published in the Institute's series.

Helsinki, December 1972

Jouko Hämäläinen

CONTENTS

1. Introduction 7
   11. Timber growing as part of the real process of a forestry unit 7
   12. Need and utilization of profitability calculations in timber growing 9
   13. Earlier Nordic studies 10
   14. The purpose and outline of the present study 12

2. The position of an enterprise's ex ante profitability calculations, and the general concepts 14
   21. Profitability calculations for the alternatives facing an economic unit as a part of its decision making process 14
   22. Business economic models 18
      221. Model premises, and principal classes 18
      222. Calculation models serving decision making 25
   23. Derivation of calculation models from the enterprise's objectives and goals 34
      231. Objectives and goals as the basis of calculation models 34
      232. Influence of the enterprise concept on goal formation 39
   24. Principles underlying the planning models for investments and their financing 46
      241. General 46
      242. The idea underlying combined planning models 46
      243. The classical partial models for comparison of the profitability of investments 48

3. Analysis of the concepts and methods of profitability calculations in forestry 59
   31. The special features of forestry 59
   32. Operational goals, and form of ownership 61
   33. The traditional profitability models in forestry 64
   34. Suitability of general profitability models in forestry 69
   35. Essential problems relating to the variables and parameters in the ex ante profitability models of timber growing 70
      351. General 70
      352. Incompleteness in the information and how to allow for it in the model 72
      353. The time problem 85
      354. The calculation rate 92

4. Empirical application of profitability models 100
   41. Activity alternatives of the economic unit 100
      411. Aspects of integrated economy, forest management unit and stand 100
      412. Main assumptions concerning the sectors of the economic unit 101

413. Production alternatives for growing a Vaccinium site type pine stand 102
4131. General presentation of the treatment alternatives per stand, and their silvicultural assumptions 102
4132. Timber crops or yields 106
4133. Profitability calculation situations per stand 107
4134. Forest treatment alternatives of an integrated economic unit (combined model) 109
42. The classical partial models of timber growing 114
43. The combined partial model (forest in a personal enterprise) 122
44. Determination of the variables and parameters of the models 129
441. General 129
442. Price and cost elements in forestry 130
4421. Roundwood prices and harvesting expenditures 130
44211. Principles of determining removal prices 130
44212. Determination of the stumpage price level for roundwood 133
44213. Determination of the cost of roundwood harvesting 142
4422. Other expenditures of the forest holding 149
443. The variables and parameters of the combined model 161
5. Conclusions 163
Bibliography 166

1. INTRODUCTION

11. Timber growing as part of the real process of a forestry unit

Forestry as an industry (a sector of activity) has been defined in many different ways in the course of time (cf. e.g. Grøn 1931, p. 12—13; Holopainen 1956, p. 72; Saari 1928, p. 5—6; Worrell 1963, p. 5 and 9). In its concise form, forestry is understood to comprise timber growing, felling and short-distance haulage. On a broader basis, forestry as an industry might be defined as those activities in which forested areas are used to produce, and/or are themselves made available for human needs: (a) timber and other material commodities originating in the forest; (b) and/or immaterial services based on the existence of the forest. The use of forests for various recreational purposes is of great importance, especially in densely populated areas and their neighbourhood. It may be necessary, in view of this, to reduce some of the goals of roundwood production. The same applies generally to the so-called multiple use of forests, and the beneficial effects of their mere existence on water supplies, air purification, etc. (Davis 1966, p. 3—5; Riihinen 1972; Speidel 1967, p. 24—25). From time immemorial, in the Nordic Countries, among others the berries, mushrooms, game, lichens, etc. available from the forests have been of considerable importance.

The economic process of an enterprise is traditionally considered to consist of two separate parts: real and financial. They are illustrated in the upper part of Fig. 1 (cf. Honko 1969 b, p. 32). The lower part of the same figure shows that the production of a forestry unit producing only wood can be organized according to two main principles:

1. The forestry unit devotes itself to timber growing (primary forestry). Its revenue is obtained from the sale of logging rights for growing stock (stumpage sale).
2. The forestry unit itself processes the stems into assortments of differing degrees of finish, and may even undertake short-distance haulage. The entrepreneur sells various timber assortments (sale by delivery contracts or after conversion).

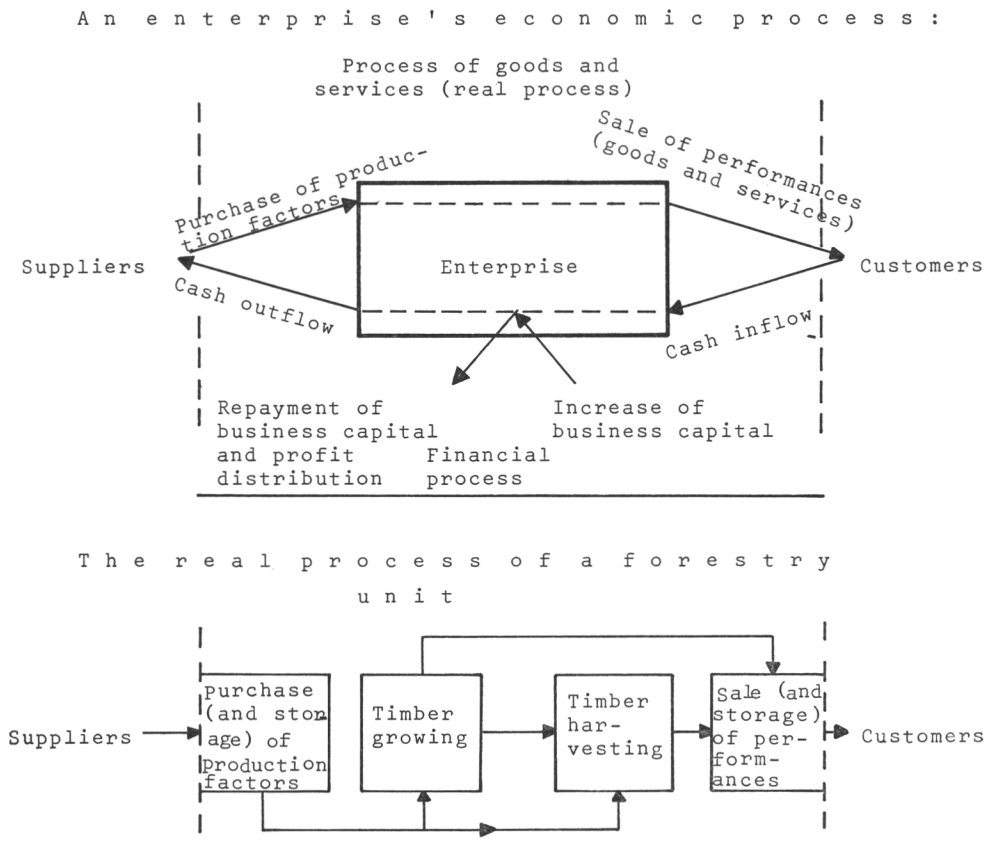


Fig. 1. Simplified description of the economic process of the enterprise and the real process of a forestry unit producing only timber.

The profit obtainable from timber growing and harvesting depends appreciably on a successful reconciliation of their partially conflicting interests. In sales by delivery contracts, the yardsticks for the success of the forest owner's work are the result of the delivery (surplus) and the state of the forest after removals with a view to future incomes. After stumpage sale, the result is indicated by stumpage price. Even then, the success of the work from the forest owner's point of view depends on the characteristics of the stands marked for cutting, taking into account the long-span timber growing on the one hand and timber harvesting on the other. The recent heavy increase in the cost of processes requiring human labour has emphasized the economic aspects of harvesting (large removal per area unit, extensive logging sites, large-size stems, etc.).

In the present study, timber growing is viewed as a part of the economy of a forestry unit and, ultimately, the whole enterprise. It might be termed the forestry of the enterprise. The empirical section of the study presumes that the forest owner carries on »complete» forestry, that is, sells by delivery contracts. Nevertheless, the emphasis in this paper is on timber growing. Operational alternatives are reviewed mainly on the basis of how the different principles of treating and regenerating the growing stock implement the forest owners objectives and goals. The influence of the alternatives of cutting and silviculture (in management) on the cost of timber harvesting is also considered but »only» so that the technology of timber harvesting is standardized.

The significance and value of the multiple use of forests also depends considerably on how the growing stock has been and will be treated. For this reason, timber growing usually pays attention also to aspects other than roundwood production.

12. Need and utilization of profitability calculations in timber growing

The essence of the profitability comparisons of timber growing, constrained as they were in Chapter 11, is to study the influence of alternative cutting and silvicultural methods, applied to a stand or a whole forestry unit, on the degree to which the forest owner's goal variables are achieved. The concept of economic profitability is not unequivocal. It always presupposes one or several subjects from whose viewpoint the profitability is considered. Most profitable is the alternative which, using the agreed criterion or criteria as the basis of evaluation, best fulfils the objectives of the economic subject, either one or several at a time.

Methods of profitability calculations for timber growing, or the results obtained by them, can be used at least for the following purposes:

1. To choose the optimum use of a stand or a whole forest holding in the prevailing planning situation. Profitability calculations per forest owner can be replaced by calculation of the numerical material required by schematic treatment standards to make routine decisions in forestry.
2. To provide a basis for the forest owner, public authority and other interested parties for comparing the profitability of forestry investments with that of investments in other sectors.
3. To provide an approximate basis for determining the value of a stand or perhaps a forest area, or their compoments, i.e. growing stock and land, in the event of a voluntary sale, allotment, distri-

bution of inheritance, expropriation, forest insurance etc., and for estimating the value of various kinds of damage.

4. To provide index figures for the development and application of legislation concerning forest taxation, silviculture etc. An example is the lively discussion in Sweden, in connection with forest legislation, of the definition of a stand still capable of development, of the minimum rate of return of the silvicultural duties imposed legislatively on the forest owner, etc. (e.g. Pettersson 1950; Dickson 1956).

13. Earlier Nordic studies

The profitability of timber growing has been reviewed from many aspects in the various papers. Often the aim has been only to determine the most profitable manner of regeneration, sometimes the profitability calculations concerning thinning methods and rotations, harvesting methods and other similar details. Attempts have also been made to develop methods of optimizing the economic operations of forest holdings. Usually, ex ante calculations have been in question. The profitability of timber growing, however, has also been discussed from the viewpoint of the measurement of business income, that is, in an ex post situation.

Osara (formerly Hilden) (1928, 1936) was among the first to publish articles on economic calculations of forest growing in Finland. Heikkilä (1930) wrote an article on the determination of stand rotation, and Ilvessalo (1939) on revenue from a stand. Saari discussed profitability calculations of forest growing in various studies and papers (e.g. 1940, 1942, 1954, 1968), and so did V. Keltikangas (e.g. 1942 1950, 1962). Kallio (1957) studied the development of Norway spruce stands in Southwest Finland from the angle of forest mensuration and management. Nyyssönen (1958) discussed the determination of rotation mainly on the basis of the marginal rate of return. Einola (1964) defined methods and basic concepts of alternative calculations in private forestry. Riihinen (1966) reviewed the economic problems of forest regeneration in North Finland, and the profitability of the various regeneration methods. Heikinheimo, Kuusela and Sivonen (1967), besides other subjects, also discussed the profitability of forest seeding and planting, a subject Heikinheimo (1968) also reviewed on his own. Kuusela (1968) reported on growing stock management principles in Central European and in British forestry.

M. Keltikangas and Tiililä (1968) studied the mutual profitability of common birch and Norway spruce planted on Oxalis-Myrtillus

type. M. Keltikangas (1971 b) studied the time factor in timber growing, and in another paper (1971 a) the influence of drain spacing on the economic results of forest drainage investment.

In his numerous publications on yield study, Vuokila (e.g. 1965, 1967, 1969, 1970 a) also discussed the economic aspects. Kilkki (1968) studied the compilation of an income-oriented cutting budget for independent forest holdings. In a study published in 1971, Kilkki analyzed the optimization of stand treatment based on the marginal productivity of land and growing stock. Kilkki and Väisänen (1969) discussed the determination of the optimum cutting policy for forest stands by means of dynamic programming. The Committee on the Costs of Forest Planting and Seeding reported on the profitability of forest planting and seeding, and its determinants (Metsänviljelykustannusten ... 1971).

In Sweden, Pettersson (1951, 1964), on the basis of his thorough yield studies, also investigated the economy of stand growing. Streyffert (e.g. 1938, 1965, 1968) viewed these problems mainly from the aspect of economic theory. Stridsberg (e.g. 1956, 1959) also studied problems of timber growing and forestry planning. Fries (e.g. 1959, 1964, 1968), in addition to yield studies, included calculations in terms of money in his research work, as did Carbonnier (e.g. Carbonnier and Hägglund 1969) and S.-O. Andersson (1961, 1963, 1967). Von Malmborg made a special study of farm forestry planning (1967, 1969), and soil value as investment criterion (1968).

Several compilation publications dealing extensively with the economy of stand growing have recently appeared in Sweden. They include a collection of articles on thinning problems, entitled »Ska vi gallra?» (»Should we thin?») (1968) and two publications of identical names but different contents »Beståndsvård och produktionsekonomi» (»Stand management and production economics») (1968, 1969).

In Norway, Jørgensen and Seip (1955) studied the determination of maturity in a Norway spruce stand, and Jørgensen and Svendsrud (1957) the money yield of a similar stand. Jørgensen (1964, 1969) discussed the coordinated capital budgeting for a forest holding. Abrahamsen (1966) discussed the yield-theory and economic aspects of thinning cuttings in a study of the literature. Risvand (1969, 1970) studied dynamic programming to be applied to stand cutting budgets.

In Denmark, Grøn (e.g. 1943) discussed these problems in many contexts. Determination of the most profitable rotation in the light of the investment theory was discussed by Jørgensen and Hermansen (1950), and by Hermansen (1953). Long-term planning, especially, the application of dynamic programming to the optimum cutting

budget of a stand, was dealt with by P. Brun Madsen (1964). The theme of Søren Fl. Madsen (1969) was the economy of the European ash. In his paper on a thinning experiment with Norway spruce, Bryndum (1969) also made economic calculations.

14. The purpose and outline of the present study

The present study of profitability components in timber growing has two parts: (1) the underlying models, and (2) the application of certain models, which are found suitable, to calculation situations in which timber growing is at least a part of the enterprise economy. The study of the underlying models tries to create a picture of the basis on which the models of profitability comparisons in timber growing are built, and of the main principles of these models.

The starting point is that the profitability comparison models, including those of a timber grower, are built on more extensive and generalized premises. This is only an assertion, though seemingly logical, as long as the matter is still unproved. For this reason, the present paper first investigates the position of future-oriented business-economic models in the decision making of an enterprise. This motivates the need for calculations. The subject is then treated by progressing from a wider and more generalized sector towards a restricted one. Each phase is intended to contain material that contributes towards the understanding and selection of models suitable for profitability comparisons in timber growing. A noteworthy assertion is that the models should be derived from the enterprise's goals. For this reason, a great deal of attention is devoted to the formation of goals, i.e. their definition in economically meaningful terms, which is necessary also because it classifies the enterprises and constrains their operational sectors. This is a fruitful starting point for the integration of timber growing (and forestry in general) among the other operations of the enterprise.

Mapping the traditional profitability models used in forestry, and comparing them with the long-term models in general business economics, helps to create an idea of the applicability of the general models to profitability calculations in timber growing. After this problem is solved, it is important to investigate the elements of profitability models in timber growing.

It is obvious that numerous theoretical—if this word is permitted—viewpoints must be disregarded in empirical applications. The restriction is imposed even by the empirical material available. The original intention in the present study was to apply the methods of profitability comparisons to the yield series of the Vaccinium site type pine stands which have been

compiled under V u o k i l a 's supervision. These series, which in broad outline will be described in the present study, determine the limits, as far as the production function is concerned, within which profitability calculations can be applied. Within this framework of yield study, the last part of the study is devoted to building certain profitability models of timber growing applicable to the yield material mentioned, by means of which results that are serviceable also in practice can be obtained.

Profitability calculations per stand are used to develop a sequence of covering expenditure by revenue (analytical balance), a sequence to fulfil general business-economic principles and to give the decision maker a good idea of the components of the profitability criterion in stand growing. A model giving a general outline of the whole enterprise is built first to indicate the position of timber growing as a part of the entrepreneur's economy. Furthermore— and above all— this planning model serves the enterprise in the making of decisions which seek to achieve its goals.

The final part of the paper describes the procedures and techniques of determining the most important economic variables and parameters used in the profitability calculations of the present study.

2. THE POSITION OF AN ENTERPRISE'S EX ANTE PROFITABILITY[1]) CALCULATIONS, AND THE GENERAL CONCEPTS

21. Profitability calculations for the alternatives facing an economic unit as a part of its decision making process

Efficiency in both production and consumption requires c h o i c e s among alternatives; these are economic problems. Such choices necessarily involve d e c i s i o n s, which have different consequences in the future. Decisions are made within a more or less organized economic unit, in other words in an organization (H e i n e n 1968, p. 48). Many factors in this organization and its environment affect the shaping of the decision making process. On a very general level those factors and their channels of influence can be grouped for the determinants of decision making. The most essential of these may be contained in the following list (cf. H e i n e n 1968, p. 48—50):

1. The social system:
   The decision maker of an economic unit, i.e. a person or organized group of persons.
2. The goal system; comprising the motives, objectives and goals of the decision makers.
3. The information system responsible for obtaining and processing information for the economic unit.

It should be noted that the determinants of decision making are themselves for the most part objects of decision making (so-called meta-decisions; cf. H e i n e n 1968, p. 50).

Owing to the vast variety of decision making situations, no universally applicable pattern can be drawn. In practice a large proportion of economic decisions apparently are made »by rule of thumb», without any previous preparation. This may be either (a) because the decision maker does not find the preparation »worth his while» (B r o s s 1953, p. 256), or (b) because the problem is a routine one and recurs frequently in much the same form. In case (b) the decision maker seeks to standardize or automatize his proce-

[1]) In this study it is to be understood that the calculation of profitability must take into account constraints (if there are any) which vary from one situation to another.

dure in order to simplify it and to save time (cf. Törnqvist and Nordberg 1968, p. 16—17). Before adopting this method for a particular case, however, the decision maker must somehow ascertain that the problem corresponds to the expected conditions of the standard decision pattern (Wright 1964, p. 43). An organization may find that it is well worth while to create standard operating instructions for such constantly recurring decisions (cf. Simon 1960, p. 10). Cyert and March (1963, p. 103) call these rules, which generally change slowly, »standard operating procedures».

Often it may be very difficult to ascertain the complex of rules and premises on which the decision maker's reactions and behaviour are based (Heinen 1968, p. 44). In such a case no verifiable connection can be observed between the decision maker's impulse and his resulting action; he simply proceeds as he habitually has done in similar situations (Kirsch 1970, p. 66). In other cases the decision maker may base his standard decisions on results of studies concerned with similar problems, on expert opinions and statements, etc. (cf. Törnqvist and Nordberg 1968, p. 17, Speidel 1970, p. 25).

So-called »genuine» decisions (Heinen 1968, p. 21; Törnqvist and Nordberg 1968, p. 11) often require a quite detailed process: the preparation of data and models, making the decision, carrying it into practice and adapting it to generally continuing environmental changes. »In treating decision making as synonymous with managing, I shall be referring not merely to the final act of choice among alternatives, but rather to the whole process of decision» (Simon 1960, p. 1). The decision-making process can be understood as one derived from premises: i.e. goals, values and facts (Simon 1965, p. 322, Kirsch 1970, p. 25).

Basically the decision making process consists of stepwise collection and treatment of information (Heinen 1968, p. 20). One must collect a number of different initial data, and transform them into new information better serving the decision to be made (cf. Kosiol 1966, p. 196). A characteristic of the decision making process is that the picture created of the alternatives becomes more precise as the »main lines» begin to take shape. The process, however, does not advance continuously from one phase to the next. It is often appropriate to return to earlier phases, perhaps because a new piece of information has been obtained. This iteration principle is often worth adopting systematically (cf. Langefors 1966, p. 55; Jahnukainen 1970, p. 31). Bearing in mind these feedbacks, the framework of an idealized design for a »genuine» decision process might be as follows [1]):

[1]) Depending on the decision situation, the various phases of the process could be listed in a different order. Because of this and the numerous feedback possibilities, it was not considered useful to specify the process, for example in the form of a block diagram.

1. Analysis of the influence of operational impulses and operational motivation.
2. Formulation of objectives.
3. Awareness of the problem and expression of the will to make a decision.
4. Formulation of the problem and analysis of the initial situation.
5. Search for operational ideas and possibilities.
6. Outlining the time available for decision making and the permissible cost.
7. Listing the facts influencing or defining possible operational alternatives, and presenting these for example in the form of a system, as well as a preliminary inventory of information available.
8. Detailed development of operational alternatives, and making the necessary prognoses.
9. Final construction of a model for profitability comparison, i.e. description of operational alternatives and their expected consequences, and final gathering and handling of data to be used in the model.
10. Comparison of alternatives: final nomination of the profitability criterion (criteria), and solution of the model.
11. Testing the model and its results, and making corrections and amendments which may be required.
12. Choice of the alternative, i.e. the decision.
13. Definition of operational targets (budgets, standards), and organization of guidance and control.
14. Implementation, guidance and control of the initial alternative chosen, as well as actions which may be dictated by those functions.
15. Updating the model.

Materials for this list were obtained especially from the following publications: Bross 1953; Churchman et al. 1963, p. 12—15, 105—154; Fishburn 1964, p. 1—6; Griem 1968; Gäfgen 1968, p. 101—102; Heinen 1968, p. 19—20; Hillier and Lieberman 1968, p. 12—20; Jääskeläinen 1971, p. 12—14; Kirsch 1970, p. 25—27, 76—96; Laukkanen 1968; Lehtovuori 1971, p. 7; Rantanen 1971, p. 11—18; Simon 1960; Särkisilta 1971, p. 14.

The economic decision making process, therefore, can be viewed as a dynamic series of events, with the next decision linked to the result of the former (Gäfgen 1968, p. 9). Every phase of the decision making process necessitates subdecisions which may yield important information, and hence contribute to the »success» of the larger decision (cf. Griem 1968, p.

22—26; Speidel 1970, p. 25—26). Each subdecision, in fact, requires its own process within the framework of the total decision process (Heinen 1968, p. 20). In addition, any choice taken gives rise to new decision situations.

As could be seen from Simon's (1960, p. 1) statement, the decision making process can with good reason be identified with the entire scope of management in operational unit. The decision model just presented can be applied to the concept of planning in an even broader sense. Varied versions of the factual contents of planning have been published in the literature (cf. Anthony 1965, p. 117—156; D. Schneider 1970, p. 24—25, and their bibliographies). Chapter 222 will outline the function of planning. If the alternative calculations are to be understood in their narrow sense, Items 9—11 of the model of decision making will cover them. It is obvious, however, that the building and solution of these models cannot be considered as a phase separate from the decision making process as a whole.

Wilson and Alexis (1969, p. 65—82), in their speculations on the theory of decision, divide the behaviour patterns in decision making into closed and open (cf. also Pulkkinen 1971). The decision making model is closed (not open) if it does not take into account (cf. Kirsch 1970, p. 25):

(a) how decision making problems arise
(b) how information is obtained
(c) interactions between the decision making process and its environment.

The premises of the closed systems of decision making are given, and known to the decision maker at the outset. Methods of formal logic, therefore, are peculiar to the use of the closed models (cf. Churchman and Eisenberg (1964, p. 49). The customary mathematic-statistical designs of the theory of decision making represent closed patterns.

The main characteristic of open patterns of decision behaviour is that they also contain an investigation of the origin of decision making problems and of the formulation of the decision making premises (Kirsch 1970, p. 26—76). The study of open patterns of decision making has led to skepticism concerning the realism of the assumption that decision makers search for optimum values, a frequent premise of closed models. It has been emphasized that often the decision maker in his bounded rationality (Simon 1957, p. 241—260) seeks only satisfactory decisions (those satisfying some minimum aspiration level). He searches a restricted number of alternatives and selects the one that meets the aspiration level, i.e. is satisfactory (March and Simon 1958, p. 140—141).

An open decision making process represents an open system. Interactions between the decision making process and the outside world must be taken

into account. In contrast, the closed model of decision making corresponds to a closed system (Kirsch 1970, p. 25) which contains, cut and dried, the problems and premises of the decision making.

The following chapters will set forth a detailed analysis of certain aspects of decision making theory which are particularly important for profitability calculations comparing alternatives. These fundamentals will then be applied to forestry.

22. Business economic models

221. *Model premises, and principal classes*

The economic decision maker, like anyone else, is a part of the »whole reality», of all that exists (cf. Pulliainen 1967, p. 27). With his decisions, he can influence only a part of this reality. In turn, he and his actions are influenced by only a part of the surrounding reality. Preparing his data, decision maker must as it were cut a »slice» of the whole reality, a slice relevant to his decision making during a certain time. This slice may be a given group of people, a certain section of the enterprise, a market area, a forest stand, etc. The part of reality from which the decision maker tries to obtain the observations he needs can be called his research object (cf. Pulliainen 1967, p. 27—28). The observer (decision maker) must try to understand the observations obtained to clarify the relations between the observations. Therefore he describes the research object (cf. Pulliainen 1967, p. 33). A complicated system cannot meaningfully be described in full detail; the most important elements must be selected (see Pulliainen 1967, p. 36—37). Hence any description of a given partial phenomenon of the real world, or of an imagined phenomenon, at a certain point in time is necessarily a simplification (cf. Malaska 1970, p. 248). In this way the observer defines a system, seen as a whole composed of elements and the relations between them. »The relations between elements make a system of a set of elements» (Pulliainen 1967, p. 20). The describer is often not interested in the research object in its entirety, but only a certain aspect of it, and this viewpoint determines the system he will construct. Depending on the aspect of interest, several different systems can be validly defined from the same research object (Pulliainen 1967, p. 34—35). Jahnukainen (1970, p. 15) also emphasizes the importance of the aspect of viewing the system.

Of course this kind of thinking has been characteristic of all specialized research »from time immemorial» (cf. Gäfgen 1968, p. 202; Vaivio 1962, p. 9—16). For example, a Scotch pine stand can be viewed as a system defined in terms of botany, forest mensuration, geography, microclimatology,

business economics etc. General systems theory is a kind of a universal language for these diverse disciplines, »present-day Latin» (see Lehtovuori 1969, p. 482—483). It can also be used quite practically in the solution of nonscientific problems as well.

In economic research or study, the research object and the period during which it is to be studied must be defined before any measurements are taken. »It is useful to see where the anchor shall be thrown and where it now is» Pulliainen (1967, p. 70—71). According to him the research objects can be placed into a two-dimensional system of coordinates, one dimension being time, the other the »research object». In general, an object of research can be defined in multidimensional space, if it is constrained separately in every dimension (cf. Jahnukainen 1970, p. 27). A research object constrained in a given way moves forward in time, from one state to another. In Chapter 24 this idea will be applied to the time-object-anchorage of investment alternatives (the term was coined by Pulliainen, 1967, for example p. 70—71).

Both the practical decision maker and the research worker should see in every situation only the most essential elements of the system, and the relations among them. Each must then build a model which describes the relevant characteristics of the system. The model is often intended also to predict the functioning of the true system (cf. Jääskeläinen 1971, p. 10). »Models are representations of systems that can be studied in rational ways» (Starr 1971, p. 21). »The model therefore is a tool for our attempts to control the world of tangible phenomena: by means of a picture simplifying reality, we try to see what in our observations is essential for our study, what is the structure of the phenomena and what are the causal connections among the phenomena» (Niitamo 1958, p. 194, cf. also Niitamo and Pulliainen 1960, p. 392—393). The model is usually so formulated that it makes quantitative investigation possible (Niitamo 1958, p. 195). This need not be scientific research: it could as well be the sort of study a business firm makes of its operations. According to Starr (1971, p. 27): »... management has turned to model-building because there is definite evidence that objective (»scientific») models can improve its performance». However: »Use of models for their own sake is an ever present danger. Like medicine, models can help if used as prescribed but can harm if used incorrectly». Bross (1953, p. 172) emphasizes that »... it is well to remember the following rule for working with models: A model is neither true nor false.... The standard for comparing models is utility, i.e., successful prediction. The evaluation of a model is therefore dependent on the situation in which it is to be used; ...»

Models can be divided into classes on many grounds (cf. Bross 1953, p. 162—169; Jääskeläinen 1971, p. 10—11, 1972, p. 13—14; Nii-

tamo and Pulliainen 1960, p. 394; Starr 1971, p. 47—60). An important criterion for business economic models is the degree of formality. On this basis, Starr (1971, p. 48—49), divides the models used by enterprises into subjective and objective. According to him, a lack of formal methods distinguishes the subjective from the objective models. Interaction of experience and intellectual ability is characteristic of the subjective models of management: »They all begin with intuition, and . . . even first-stage taxonomical models of the thinking process are difficult to develop» (Starr 1971, p. 48). The subjective models are the management's way of forming overall views and syntheses, of thinking subjectively about large systems. But according to Starr (1971, p. 49), the objective models are primarily analytic (»scientific») models. It is characteristic of objective models that even an outsider can explicitly verify them. On the other hand, little is known to date of how subjective models are constructed in the decision maker's thoughts or of the psychic events associated with his finding the solution (cf. Starr 1971, p. 48—49). Subjective models defined in this way are at an early development stage. Jääskeläinen (1972, p. 13), when considering the solution of a given problem by the marketing manager, said of his procedure: »The model exists only in his thoughts, and others cannot say anything about it». Many degrees of subjectivity doubtless are also associated with the explicitly expressed business-economic models, and therefore objectivity must necessarily be understood as a relative concept.

The majority of the objective (explicitly drafted) models used in business economics and by enterprises can be presented and solved by mathematical methods. Fig. 2 shows the construction of such a mathematical model, an artificially created expression simplifying the most essential features of a given part of reality (cf. Heinen 1968, p. 15).

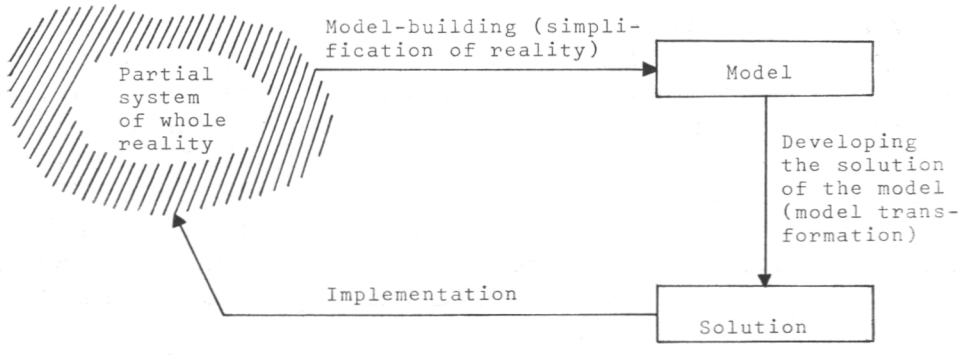


Fig. 2. Model as a simplified description of reality and a possible normative guideline for action. The tip of the arrow shows the end result of the phase represented by the arrow.

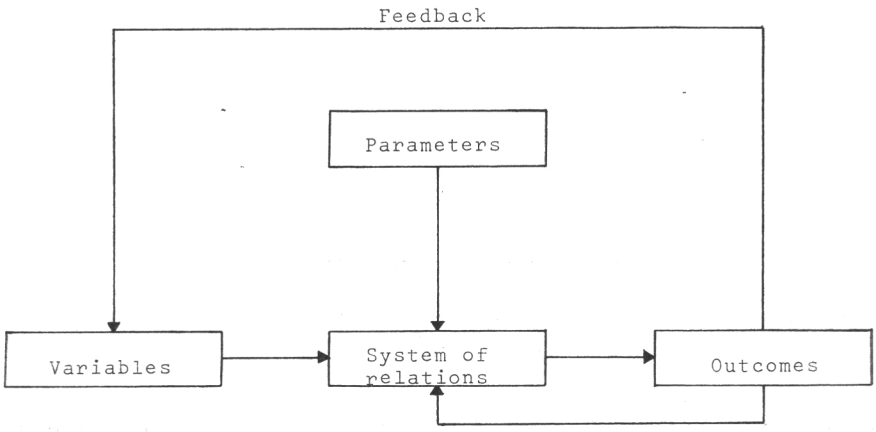


Fig. 3. Structure of the model, in principle[1]) (cf. Starr 1971, p. 37).

After the model is solved, the results can be applied to describe, explain and possibly to guide the system it presents. In practical management of an enterprise, for example, this means that the results obtained from solving a model can be reconverted into reality in the form of operational instructions (cf. Virkkunen 1961, p. 616). Of course this conversion may be accompanied by some difficulties (cf. Starr 1971, p. 96—98).

Fig. 3 shows the structural parts of the Fig. 2 model in greater detail, as a block diagram. This model expressed in mathematical symbols can be defined as a population of relations among the variables, specified by functions (Niitamo and Pulliainen 1960, p. 401). The elements of the model consist of variables and parameters, the latter showing the relations among the variables (cf. Niitamo and Pulliainen 1960, p. 402).

To define terms for the following text, the nature of the variables and parameters in mathematical models must be analysed, if only superficially. »The variables in economic models are quantities expressed in measurement units relevant for economics, quantities whose development and effects arouse interest» (Niitamo and Pulliainen 1960, p. 403). In calculation models for business economics, there are three main kinds of variables (Heinen 1968, p. 159—161, 223—224; Ijiri 1967, p. 151; Starr 1971, p. 122—124): (1) environmental variables, i.e. those not controlled by the decision maker, (2) decision, i.e. controlled variables, (3) outcomes. Environmental variables are not »perceptibly» affected by the decision maker, and often he does not even know the values they will acquire

[1]) Here the earlier result(s) affect the variables and outcomes (feedback) and complicate the situation. In compliance with the true situation, or only for the purpose of simplification, the model may lack the feedback.

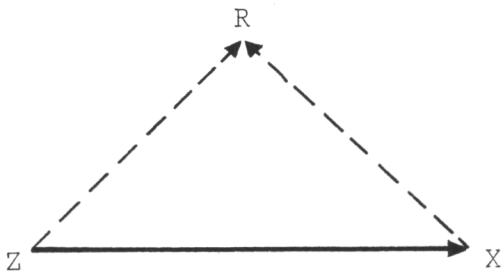


Fig. 4. Result or outcome (R) as a function of the state of environmental variables (Z) and decision variables (X).

(S t a r r 1971, p. 123). The decision maker considers the environmental variables as »given» (I j i r i 1967, p. 151). Some problems of handling environmental variables will be discussed in Chapters 222 and 352. The decision variables are those whose value the decision maker can substantially influence. He can form from these variables configurations of different kinds, which can be called his s t r a t e g i e s (S t a r r 1971, p. 122—123). The outcome is a result of interaction between a strategy and the set of environmental variables, collectively called an e n v i r o n m e n t a l c o n d i t i o n (see fig. 4). In normative models, the outcomes represent various types of goals (see Chapter 23), but in the descriptive models they are simply expected values (H e i n e n 1968, p. 159—160, 223—224).

An important basis for classification of business economic models is according to the main i n t e n d e d u s e and a n g l e o f v i e w i n g:

1. Descriptive models.
2. Prescriptive or normative models.
   (decision models in the broad sense).

D e s c r i p t i v e models are designed to help understand problems of the management (decision maker) and to predict various phenomena (cf. J ä ä s k e l ä i n e n 1972, p. 14; L a n g h o l m 1964, p. 29) by showing functional relations among essential variables. These models have thus two main purposes: to describe reality »purely» theoretically, or to describe the assumed decision makers' possible alternatives with their probable consequences in the sphere of applied business economics (cf. H e i n e n 1968, p. 22). The analyst must select a set of premises for his model and make certain assumptions concerning the structure and functioning of the economy (L a n g h o l m 1964, p. 31—32). As long as the decision maker has not accepted such things as the internal rate of return, calculable from Formula (1), p. 49, as the only criterion of his investment decisions, the model only describes or predicts the consequences of the investment. Thus the dependent

variables, goal variables, in the normative models are chosen by each decision maker himself. They are empirically true and not imagined. The same applies to the means available to obtain the goals. The model therefore gives a solution »suitable» for a given decision maker (Heinen 1968, p. 223; Starr 1971, p. 56). Decision models in a broad sense are normative. Normative models are created primarily to provide the decision maker with information, advice, helping him to achieve his goals. By some writers the decision model is considered normative only if the result it gives is the optimum solution (cf. Starr 1971, p. 56), in which case even decision models leading to other degrees of achievement would belong to the descriptive models.

Kosiol (1961, p. 322) divides mathematical calculation models into two groups, informative (Ermittlungsmodelle) and optimizing (Optimalmodelle). He includes in the former the traditional investment calculation methods (see Chapter 24 below) and the profit contribution and unit cost calculations, as well as comparison of their results with predetermined standards. The conceptual content of Starr's (1971, p. 58) descriptive models is close to that of Kosiol's informative model.

Drawing the line between descriptive and normative models, however, is often a matter of individual interpretation, because construction of normative models requires description of environmental variables and the predicted consequences of decision alternatives (cf. Heinen 1968, p. 159, 223).

The explanatory model seeks to explain a given empirical phenomenon or observation by means of other, that is independent variables. The model, therefore, is based on a causal sequence of the variables. Hempel and Oppenheim (see Cohen and Cyert 1965, p. 22—23) have presented highly demanding requirements concerning the logical conditions between the variables of an explanatory model, and the realism of the independent variables. We can try to explain by the explanatory model such things as why forest owners (as a statistical population) cut different volumes in different years. It is the problem of the microeconomic theory of economics. For an individual forest owner, that is from a business economic point of view, it is of secondary importance.

The division of the models into analytic and simulating is based on the method by which they are solved. The solution of analytic models is based on mathematical, deductive inference. Once a solution is found, the symbols can be replaced by numerical values (e.g. formula (1), p. 49, shows the present value of an investment). But many economic problems, and the mathematical models illustrating them, are so complicated that methods required for their analytic solution do not exist or the information needed for analytic solution is incomplete (Naylor and Vernon

1969, p. 330). Simulation models often are used to treat such situations. Simulation models differ from analytic models in that »simulation equations are like instructions, whereas analytic equations are intended to be reduced or solved» (Starr 1971, p. 53). Influences of independent variables and their relations on the expected variable (or vice versa) can be studied by giving the variables and parameters different values according to particular algorithms. Simulation then tries to reveal what happens if some action is taken, for example, on the different levels of output. Hence it may also facilitate the ultimate selection of goals. Simulation requires a large number of repeated calculations, and electronic computation is usually indispensable for this purpose. Consequently, the typical computer model often is a simulation model (Spencer 1968, p. 450).

Simulation models have been applied both in business economics and in enterprise practice, for example, for problems of marketing, investment, financing, production and storage (see Hansen and Waibel 1972, p. 30; Starr 1971, p. 56; Steiner 1969, p. 440). D. Schneider 1970, p. 76) criticizes indiscriminate use of simulation models for business economic problems. In his opinion, such things as random occurrences are involved in only unimportant business problems. In all important decisions, the reactions of a deliberately acting opposite number (client, competitor etc.) must be taken into account. This criticism is justified, but we cannot deny simulation its great importance as a method of solving complicated problems and detecting the consequences of alternative assumptions concerning the values of variables. Simulation has also been applied to the solution of forestry problems (see e.g. Gould, Jr. and O'Regan 1965; Kilkki 1968).

Another important basis for classifying models is the treatment of the time factor (Heinen 1968, p. 161—163; Starr 1971, p. 58—59). A model is static when all its variables refer to one point in time. In a dynamic model time is a fundamental variable. Following Frisch's (1935/1936, p. 100) train of thought, the model is dynamic if at least one of its variables refers to a time other than that of the other variables. A functional relationship must prevail between variables referring to different times or periods (cf. D. Schneider 1970, p. 41; Starr 1971, p. 58—59). Hicks (1946, p. 115) emphasizes in a somewhat imprecise way: (a) in dynamic consideration — unlike the static — attention is paid to »dating» the use of production factors and completion of products, and (b) »... we even pay special attention to the way changes in these dates affect the relations between factors and products». A model whose variables and parameters refer only to two different times or periods (there are two static states) is sometimes termed a comparative static model (see Heinen 1968, p. 163; Paakkanen 1962). On the other hand »kinetic» models

are sometimes considered a special subset of dynamic models; they contain time in the form of a continuous function (H e i n e n 1968, p. 163). The appearance of time in an economic model is shown in detail in Fig. 8 (p. 86).

Models can also be grouped according to the degree of certainty with which relationships among variables can be specified. When this is exact, the models can be called d e t e r m i n i s t i c (N i i t a m o and P u l l i a i n e n 1960, p. 408; H e i n e n 1968, p. 161). Even the goal variable (in descriptive models, the dependent or expected variable) obtains an exact value from the determinate values of environmental variables, decision variables and parameters. The information on the outcomes of every strategy is therefore complete (H e i n e n 1968, p. 161). In reality, of course, the relations between phenomena can usually be only approximately quantified. If the error factors of such an approximation are assumed to be random variables, a s t o c h a s t i c model is employed (N i i t a m o and P u l l i a i n e n 1960, p. 408). The values of the goal variable (or expected variable) are subject to a distribution which shows the probability of incidence of the various values (H e i n e n 1968, p. 161).

The division of business economic models into p a r t i a l and t o t a l is based on the scope of facts contained in the models, that is the constraints on the field of decision (H e i n e n 1968, p. 161). Constraints can comprise: a) the whole integrated enterprise or only its functional, organizational etc. sector; b) the research object of item (a) reviewed only during a certain time, or throughout its lifespan; c) the research object described in accordance with reality, or distinctly simplifying reality.

It is justified to give the name of a total model to such a thing as a model illustrating an enterprise entity even if only over a limited planning period and with purposeful simplification of reality.

222. *Calculation models serving decision making*

The principles and classifications of business economic models, described in Chapter 221, are also applicable to the more specialized profitability models for decision making. A particular problem in decision making often is the difficulty of predicting the environmental variables. Fig. 5 shows a way of classifying especially the models used in decision making, affording a possibility for analysing the choice of strategies and the associated uncertainty.

It is essential to distinguish between the character of the system viewed, i.e. the degree of stability of the environmental conditions and what the decision maker knows of it within the study period (S t a r r 1971, p. 144). Stability does not imply that only one set of environmental conditions can

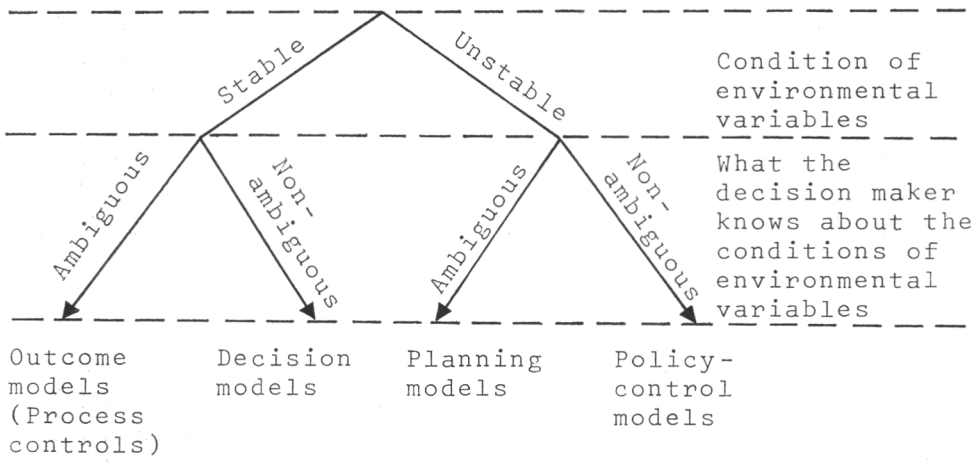


Fig. 5. Classification of models used in decision making according to how stable the condition of the environment (environmental variables) is and what the decision maker knows about it (cf. S t a r r 1971, p. 145).

be associated with the future but that the p o s s i b l e conditions in the period covered by the model are »given».

A characteristic of o u t c o m e m o d e l s is that the environmental variables contributing to each outcome are not known. However, the probabilities by which each alternative strategy can lead to the various outcomes are known. This indirectly justifies the conclusion that the environment, »the background», is relatively stable. This can be illustrated by a probability matrix (cf. F i s h b u r n 1964, p. 36—39; S t a r r 1971, p. 141):

$$
\begin{array}{c|cccc}
 & R_1 & R_2 \ldots & R_j \ldots & R_n \\
X_1 & p_{11} & p_{12} \cdots & p_{1j} \cdots & p_{1n} \\
X_2 & p_{21} & p_{22} \cdots & p_{2j} \cdots & p_{2n} \\
 & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot \\
X_i & p_{i1} & p_{i2} \cdots & p_{ij} \cdots & p_{in} \\
 & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot \\
X_k & p_{k1} & p_{k2} \cdots & p_{kj} \cdots & p_{kn}
\end{array}
\text{, where}
$$

$X_1, \ldots, X_k$ = the strategies available

$R_1, \ldots, R_n$ = all possible outcomes

$P_{11}, \ldots, p_{kn}$ = outcome probabilities with different strategies

$\sum_{j=1}^{n} p_{ij} = 1$ for each X_i, $i = 1, \ldots, k$ (the concept of probability will be discussed later in Chapter 352).

Decision models are characterized by the fact that the decision maker knows and identifies not only his own strategy alternatives but also all possible environmental conditions. Furthermore, the environment is stable in the sense explained above. The result can be expressed as a function of a given strategy and environment, i.e. $R_{ij} = f(X_i, Z_j)$ (Starr 1971, p. 124).

The following matrix of results illustrates a decision problem of this type:

Estimated probalities		p_1	$p_2 \ldots$	$p_j \ldots$	p_n	Expected values, by line [1]
Environmental conditions		Z_1	$Z_2 \ldots$	$Z_j \ldots$	Z_n	
Strategy	X_1	R_{11}	$R_{12} \ldots$	$R_{1j} \ldots$	R_{1n}	EV (R_1)
»	X_2	R_{21}	$R_{22} \ldots$	$R_{2j} \ldots$	R_{2n}	EV (R_2)
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
»	X_i	R_{i1}	$R_{i2} \ldots$	$R_{ij} \ldots$	R_{in}	EV (R_i)
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
»	X_k	R_{k1}	$R_{k2} \ldots$	$R_{kj} \ldots$	R_{kn}	EV (R_k)

[1] $EV(R_i) = \sum_{j=1}^{n} p_j R_{ij}$; $(i = 1, \ldots, k)$

In principle, probabilities can be added to show the incidence of environmental conditions known in advance. Determining these probabilities, however, is often impossible or incomplete. The decision models can be divided into subgroups according to what is known about the probabilities $p_1, \ldots, p_n$ (cf. Starr 1971, p. 127, 146—152). The various rules of mathematic-statistical decision making theory are based on this. Decision making based on information of varying degrees of reliability is systematized in Chapter 352.

Both planning and policy models are in general closer in their basic assumptions to the enterprises' everyday decision making situations than are the outcome and statistic-mathematical decision models. The basic components of policy and planning models are unit decisions. Their elements have many similarities with decision models. The unit decisions of both policy and planning models contain the following elements (Starr 1966, p. B-117, 1971, p. 306; cf. also Wilson and Alexis 1969, p. 64—65):

1. Minimum two strategy alternatives for controlled variables: X_i; $(i = 1, 2, \ldots, k)$.
2. One or more possible environments (conditions of environment): Z_j; $(j = 1, 2, \ldots, n)$. The environmental variables are non-controlled.
3. Each combination of a given strategy and environment yields one or more relevant outcomes which can be observed, i.e. $R_{ij} = f(X_i, Z_j)$.
4. The environments are distinctly individual and exclude each other. A probability (p_j) estimation per environment Z_j can be attempted (details in connection with planning and policy models later in this chapter).
5. Each unit decision can use, at a time, only one of the strategies belonging to the finite number of strategies.
6. Using a given decision criterion, one strategy is chosen from the total set of the available alternatives, e.g. one that maximizes the achievement of the decision maker's goals. For example, choose strategy X_i, which yields the result $\max \sum_{j=1}^{n} p_j R_{ij}$, if the p_j's can be estimated with »sufficient» reliability.

The environments of unit decisions are evolutionary in planning, they are in a condition of development and change as a function of time; whereas in policy models the environmental alternatives of unit decisions are repeated in identical form, that is they are stationary. Whenever unit decision problems of the same type occur repeatedly i.e. when the elements of the original unit decisions remain relevant, the model is a policy model (S t a r r 1966, p. B-118; 1971, p. 306—308). In a p o l i c y m o d e l, therefore, the same decision functions can be applied throughout the period under review (S t a r r 1966, p. B-118). In Fig. 5 (p. 26) however, the condition of the environmental variables in policy models has been found to be unstable. In the situation presupposed by these models the population of the environmental conditions possible in a unit decision is given. Nevertheless, each condition Z_j of the environment is expected to occur i n t u r n with great probability (preferably $p_j \approx 1$) (cf. S t a r r 1966, p. B-118, B-119; 1971, p. 306—309). In the statistical models discussed earlier the assumption was that only o n e of the separately specified environments is realized, and it remains throughout the period foreseen by the model. Probability coefficients show in this way how likely it is for each alternative of environmental conditions separately to prove true. It is common to both decision models and policy models, however, that the systems they illustrate are closed; the alternatives of the environmental conditions are given already in the decision making situation.

The more stable the population of possible environmental conditions is, and the closer to the value 1 the probability of occurrence in each environmental condition is, the more appropriate it is to make policy models in advance for a given period. The policies, therefore, are »strategy packages» made in advance, postponed decisions to be implemented when the expected very probable different environmental conditions are realized (cf. S t a r r 1966, p. B-118; 1971, p. 307). In order that policies can be committed to practice, a policy control unit must be established. It may be purely mechanical, purely human, or combined of these components. »The controller is instructed concerning what to observe, how to measure, how to respond to error, when to initiate operation and how and when to follow up on it» (S t a r r 1971, p. 307). Policy control can be applied to various steps in the maintenance and regulation of different technological processes (cf. S t a r r 1971, p. 307).

The more the environment changes from stationary, from one that recurs in identical form, into one that is changeable and each moment unique, the more reason there is to consider whether policy models provide a sufficient basis for successful decision making. Both the condition of the decision making environment and the attitudes of the management decide whether planning is preferable to the ready-made strategy stores of policy and control procedures (cf. S t a r r 1971, p. 315).

A characteristic of situations appropriate for p l a n n i n g m o d e l s is that among environmental conditions $Z_1, \ldots, Z_n$ continuously appear (and not merely because of occasional disturbances) new environmental conditions $Z_{n+1}, \ldots, Z_{n+s}$ etc. while former conditions disappear. Hence also the incidence probabilities of the conditions — if they can be determined — undergo changes (cf. S t a r r 1966, p. B-118; 1971, p. 304). It is therefore necessary to develop new strategies $X_{m+1}, \ldots, X_{m+r}$ etc. besides old ones or to compensate for them. Planning models are therefore characterized by consecutive unit decisions changing as a function of time. What the decision maker knows of these unit decisions necessarily declines faster than his knowledge of the facts of decision models. The decision model actually only contains one unit decision. However, if the developing environmental conditions of the planning models can be forecast with at least »some degree» of probability, predictions supply material for alternative plans. Of course planning means not only adaptation to new, more or less probable and given environmental conditions, but also an active effort to f o r m t h e f u t u r e of the decision unit. H o n k o (1969 a, p. 40) says: »Planning often means that something that otherwise would not happen is made to take place». R h e n m a n (1970b, p. 7—14) also emphasizes the importance of planning as a producer of change in the enterprise. Some of the possibilities that can be used here are: (a) a warning system by which undesirable events in the

environment can be evaded in time; (b) variables considered as non-controlled should be converted into controlled ones, by such means as research and development; (c) goals should be updated. Modification of traditions and expectations may be required also here in the course of time (cf. S t a r r 1971, p. 315). Furthermore: (d) an enterprise must be actively directed towards an environment (e.g. new sectors) in which its goals obviously can be better achieved, and new strategies suitable for this one must be sought. The ultimate purpose of planning, therefore, is to find means by which the decision maker can achieve his goal in spite of unstable environmental conditions, at least partly unknown in advance.

Planning models may in varying degrees be either deterministic or stochastic, formally or even as a result of the nature of the planning object. On this basis the planning models can be divided, for example into these three classes (cf. S t a r r 1966, p. B-121, B-122; 1971, p. 314):

1. fully constrained or deterministic planning models
2. partially constrained or stochastic planning models
3. threshold constrained planning models.

The starting point in d e t e r m i n i s t i c planning models — according to the general principles of determinism — is that the development of environmental conditions changing as a function of time, and the possible strategies for achievement of the goal(s) are definitely known (S t a r r 1966, p. B 121—122). This can be illustrated by the operational network used, for example, for project planning (Fig. 6).

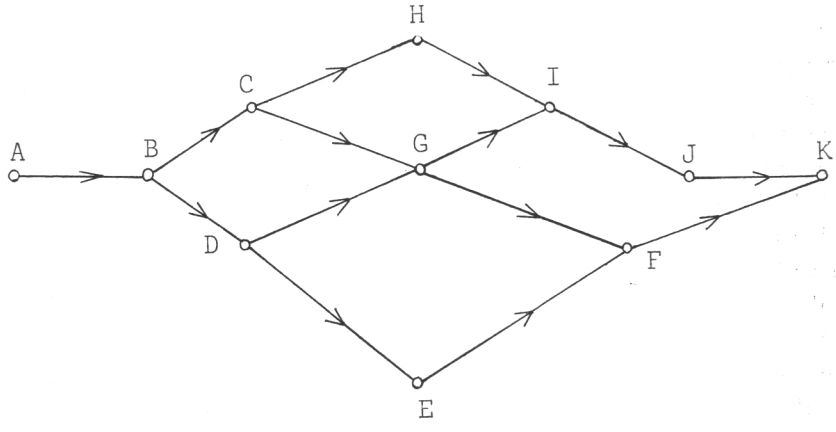


Fig. 6. Description of the different realizable alternatives for a certain project by means of an operational network.[1])

[1]) The arrows indicate each possible chain of strategy by which the project can be put into practice.

For example, chain of strategy ABCGIJK is one of the five alternative planning paths presented in Fig. 6. They are composed of the above-mentioned unit decisions, described by each node indicated by a letter. Certain unit decisions also result in certain outcomes for each planning path. They are easy to put into an order of priority (S t a r r 1966, p. B-122; 1971, p. 378). Evidently the deterministic model is at its most realistic when the time dimension of operational alternatives is small. In forestry, Fig. 6 might refer to alternative seedling growing strategies in a nursery, with a goal of minimizing the unit cost.

Till our day enterprises have based their plans mostly on the assumption that the system to be planned is deterministic, whether this is so or not. They apparently feel a need to simplify their planning methods, to cut the costs, to avoid the laborious inclusion of risk in calculations, etc. (see S t a r r 1971, p. 327).

When planning paths are numerous, techniques should be used which do not require separate formation and study of every alternative path when trying to find, for example, the optimum. The main methods to be used for this purpose are mathematical programming and simulation. The most important classes of mathematical programming are linear programming with its variants, integer programming, nonlinear programming (e.g. quadratic programming) and dynamic programming (N a y l o r and V e r n o n 1969, p. 146—167 and S t a r r 1971, p. 348—371).

S t o c h a s t i c planning models differ from the deterministic in the fact that the elements of the unit decisions on planning paths cannot be definitely determined in advance. Nor can any best path to achieve the goal be found in advance with certainty (S t a r r 1966, p. B-130; 1971, 379). Certain unit decisions (partially stochastic model) or every unit decision (fully stochastic model) are associated with more than one potential outcome. This is because on proceeding from the starting point to the final goal(s), the very next unit decision contains various potential realizations of environmental conditions. Each of these can still be reached alternatively by one or several strategy alternatives contained in the unit decision. Fig. 6 with very great simplification can be taken to show the initially (A → B) deterministic strategy path branches in some later phases, owing to stochastic environmental conditions. For example, in decision situation B, if strategy X_1 is used when the environmental condition is expected to be $Z_1(t)$ the system moves to condition C and if strategy X_2 is used it moves to condition D. Accordingly, by adding the number of branches from node B it is possible to describe the results of other possible mutually exclusive combinations of environmental conditions $[Z_2(t), \ldots, Z_n(t)]$ and strategy alternatives $[X_1, \ldots, X_k]$. When the number of alternative possible environmental conditions and strategies increases, the operational network

rapidly expands (also in timber growing, the alternatives are infinitely numerous in principle). Consecutive alternatives of environmental condition and the corresponding strategy alternatives can be shown in a graph commonly called a decision tree (see Fishburn 1964, p. 26—30; Luce and Raiffa 1958, p. 39—41).

The key question in stochastic planning models is prediction of the different environmental conditions including their probabilities. If probabilities can be attached to all strategy/environment combinations at every decision phase of the operational network, it is possible to calculate, for example, the expected value of the goal function of every planning path. One possibility then is to choose that alternative path for which the expected value of the criterion is biggest, and use the resources for this alone. »It has the advantage of requiring only one set of resources but the disadvantage of being unable to cope with the anticipated deviations from the expected value path» (Starr 1966, p. B-131). By this method, a plan of deterministic form is derived from the stochastic planning model (cf. Starr 1971, p. 382). A possibility for keeping the planning work at a moderate level is to include in the stochastic model, from the outset, only the most important strategy and environmental alternatives. One must then be prepared to consider other requirements of resources, etc., when the plans perhaps are being put to practice (cf. Starr 1966, p. B-122). It is evident that stochastic planning is more expensive than deterministic, both in the cost of planning and the cost required to prepare for changing situations. Some advantages are those afforded by the greater elasticity and speed of reaction (Starr 1971, p. 382). The so-called roll-back method is among those that can be used to find the most favourable of the numerous alternative paths suggested by the decision tree (see Magee 1964).

The threshold constrained planning models can be considered a subgroup of the stochastic models. However, these systems have the characteristic that some of their planning paths can lead to catastrophe. Evaluation of what is dangerous for the enterprise's existence naturally depends very much on the decision maker's readiness to accept risks (see Chapter 352). Such decisions which may jeopardize the existence of the enterprise obviously need special handling, and their desirability cannot be customarily measured, even by the utility function considering the readiness to accept risks (cf. D. Schneider 1970, p. 352, and the present Chapter 352). When it is to be suspected that such plans (or parts of plans) contain unit decisions or their combinations which may risk and bind a considerable proportion of enterprise assets, it is necessary to develop special procedures to eliminate them. This might be done e.g. by constraining the goal of maximizing profit so that no alternatives exceeding a »safe» probability of catastrophe can be considered or by minimizing the catastrophe (cf. Starr

1966, p. B-134; 1971, p. 404). Operational constraints are then defined from thresholds of acceptable risk. Threshold-constrained planning is closely related to extreme-value analysis (see Starr 1971, p. 405).

Of extreme importance in avoiding catastrophe (especially bankruptcy) is the liquidity of the enterprise. This is evident especially in planning at the highest organizational level of the enterprise. Various cash flow analyses are used to make sure that the liquidity of the enterprise during the planning period cannot fall below a certain threshold. On the other hand, for reasons of profitability a ceiling should also be defined on the liquid assets (especially ready cash) presupposed by each plan (see Asztély 1966, especially p. 26—32; Starr 1971, p. 407—408). Another important threshold is the permissible indebtedness of the enterprise (Rantanen 1971, p. 82).

Let us examine a threshold-constrained planning situation for an enterprise essentially dependent on revenues from forestry operations. One alternative strategy is to cut most of the growing stock — mainly old age groups — within a short period. Before this kind of strategy alternative can be accepted as a cutting plan, there must be a program for reinvesting a proportion of the funds so released from the forest. This proportion must be large enough to guarantee sufficient future revenue. A forest industry enterprise processing substantial amounts of timber from its own forests must make sure that, after these heavy cuttings, it will be able with a high degree of probability to augment the reduced fellings with increased timber purchases at a »reasonable» price.

It may be said that the need for applying essential principles of the planning models in group 2 and especially in group 3 to enterprise planning increases as the planning is carried on at higher levels on the organizational hierarchy. The overall planning in an enterprise is characterized by the longest possible time perspective, and an approximate estimation of the most essential decision elements. In the plan following overall planning these »fixed» element values then determine the framework within which the unit decisions take place. In this way, like enterprise's goals, plans also form a hierarchic system in which the higher-degree plan always determines the freedom of movement for a lower-degree, more detailed plan. Conventionally, there are long-term, medium and short-term plans (cf. Koch 1961, p. 34—44; von Malmborg 1967, p. 31; Speidel 1967, p. 159—161, and their bibliographies). Similarly plans from top to bottom serve decisions made at various levels of the enterprise. They are usually specified as follows (see Ansoff 1965, p. 3—11; Anthony 1965, p. 15—19):

1. Strategic decisions.
2. Administrative decisions.
3. Operative decisions.

23. Derivation of calculation models from the enterprise's objectives and goals

231. *Objectives and goals as the basis of calculation models*

The highest level objective of a firm type enterprise (for details see Chapter 232) is often called its mission (Honko 1969 b, p. 175; Särkisilta 1968, p. 112). »The mission or work is the bearing ground of the enterprise's action. It is the idea on which the firm's operations are permanently built. . . . The firm's objectives and goals represent the mission or work transformed into tangible form» (Honko 1969 b, p. 175—176). In brief, the mission expresses why the enterprise exists. The mission usually predominantly emphasizes the scope of the real process of the enterprise. Its mission might be, for example, to carry out forest industry based on available timber resources in order to satisfy market demand. But from the point of view of monetary process of the enterprise, the mission only indicates the main fields of work in which the enterprise intends to invest money and from which it expects to obtain revenue. The mission usually does not express the financial goals the enterprise tries to achieve.

The terminology concerning objectives and goals of decision making units is relatively heterogeneous. The term »objective», however, is considered to express an economic unit's intentions more on a level of principle than does the term »goal». Objectives are often considered to cover the whole enterprise and to refer to the state which the economic unit seeks to achieve in the long run (cf. Lehtovuori 1971, p. 9). In the formulation of goals, states of affairs reflecting the objectives are defined in detail according to kind, time of manifestation, and degree of achievement sought (cf. Colley 1962, p. 83; Granger 1964, p. 63).

Institutions ultimately have no objectives of their own but people use them to achieve their objectives (cf. Cyert and March 1963, p. 40—43; Riistama 1966, p. 183; Wright 1964, p. 35). An enterprise can be considered as an instrument with the aid of which all those interested, including the whole society try to realize their objectives (Chamberlain 1968, p. 126—147). Objectives may be economic or noneconomic (cf. Ansoff 1965, p. 59—74). »Note that the term 'noneconomic' means here 'not directly derivable from the firm's basic economic objective'. The impact of such an objective on a firm's profitseeking behaviour can be very far reaching indeed» (Ansoff 1965, p. 66).

Obviously the goals of people and groups of people interested in an enterprise will often conflict. A set of minimum interests of the society are represented by the regulations which set up a social framework, certain limitations and responsibilities for operations. The persons wielding power in enterprises must take into consideration not only public authority but

also the expectations and goals of creditors, business partners, workers and other interested groups (cf. Churchman et al., 1963, p. 114).

The formation process of objectives and goals (cf. D. Schneider 1970, p. 50—51) can be divided into many phases. The basis is the decision maker's motivation. The motive is an association of ideas which seem to the subject himself or to an observer to provide a good reason for some action (Weber 1951, p. 536; Schmidt-Sudhoff 1967, p. 30). Usually human actions are based on a range of motives, and their importance is differently weighted by the different schools of psychologic research (cf. Schmidt-Sudhoff 1967, p. 30—31, and the works in his bibliography). Some motives are a desire to satisfy the needs of everyday life, sense of duty, aspiration to authority and social appreciation, etc. (D. Schneider 1970, p. 52). Some motives derive from the person himself, while others come from the outside (cf. Schmidt-Sudhoff 1967, p. 30).

When economic goals are to be derived, the decision maker's motives should themselves be expressed in economic terms, insofar as this is possible. In this connection D. Schneider (1970, p. 50—56) speaks of goal variables (»Zielgrössen«). Of course there are many motives of economic action which cannot be transformed into quantitative economic goals, things such as philanthropy, personal ethics, etc. (cf. Ansoff 1965, p. 65). Nevertheless these things can affect the choice of goal variables. According to Griem (1968, p. 65—75), in the first phase of goal formation the personal interests of the interested parties are converted into the enterprise's economic objectives, formulated in general terms. More precise goal variables can then be derived from them. However, an exact conversion of motives and expectations into measures of benefit often is very difficult (cf. Heinen 1968, p. 43). There remain many objectives whose expression is only qualitative, and any measurement of the success of action must somehow take these into account (cf. Churchman et al. 1963, p. 118, 128—130 and 136—138). — The ends themselves often are means by which ultimate goals can be achieved (Simon 1961, p. 62). Economic goal variables are e.g. the economic result defined in different ways, the turnover, marketing share, and compensation for personal work input.

After the goal variables are named, the goal instruction (»Zielvorschrift«) is issued. It defines the level of the goal variable that should be achieved (D. Schneider 1970, p. 51). Not until this degree of achievement is shown are the goal variables really to be actively sought. The goal instruction can order such things as maximizing of the profit for planning period, keeping the former market share constant, making sure that the enterprise owner obtains a given compensation for personal work input, etc. (cf. Churchman et al. 1963, p. 109).

Griem (1968, p. 73—75) proposes a system of classifying objectives and goals according to their degrees of achievement.

1. Objectives and goals in terms of variables striven after.
   11. Restricted objectives and goals, i.e. »maximum» or »minimum» achievement degrees.
   12. Unrestricted objectives and goals, i.e. in general maximization and minimization of achievement degree.
2. Objectives and goals in terms of variables with predetermined values that must be achieved.

Restricted goals have the character of conditions: unless the action alternatives meet requirements expressed by these restricted goals, they cannot be considered. Examples of instructions for restricted goals are: investment expenditure must not exceed Fmk a, or the marketing share must not be less than p %. In calculating models restricted goals are given as inequalities.

For unrestricted goals, either maximum or minimum values of achievement are sought. In most cases realization preferably should be within the framework permitted by restricted goals, resource restrictions and various secondary conditions.

Unrestricted goals therefore have the character of a criterion for the choice of the most favourable alternative (Griem 1968, p. 75). Fixed goals differ from restricted goals in that the action alternative chosen must lead to the exact numerical value stated in this goal. For example, in year t the profit of the enterprise must be b Fmk, the turnover c Fmk, etc. One may ask whether such fixed goals agree with reality and are useful.

The restricted and fixed goals are alike in that any alternative failing to meet them cannot enter into the choice to be put to practice (Griem 1968, p. 74). But when the goal is unrestricted, the decision maker can try to achieve different degrees, although extreme values can be sought only for one goal at a time.

Depending on the classes of goals contained in the mathematical model, the following model types can be distinguished (cf. Heinen 1968, p. 225—226):

1. pure extreme value models
2. pure satisficing models
3. mixed models.

Pure extreme value models contain only the goal variable to be maximized or minimized. Pure satisficing models present all goals in restricted or fixed form. The mixed models contain elements from both of the other model

types. They can comprise such things as the goal of maximizing turnover with a given minimum profit, the goal of maximizing profit with a minimum liquidity, the goal of maximizing the future value of a forest unit with a given annual net revenue goal, etc.

These model types manifest the decision maker's and his environment's attitude to various goals. Resolving his goal conflicts in this way, the decision maker must either explicitly reduce some of his original component objectives or give them subjective emphasis. When the degrees of achievement of goal variables can be expressed with cardinal figures, resolution of the goal conflict, i.e. formation of a criterion for assigning priorities from multiple goal variables can involve the following main procedures (cf. D. Schneider 1970, p. 60—63): (1) disregarding all goal variables except one; (2) rejecting in advance all such alternatives which don't meet certain restrictions of fixed goals; (3) formulating a higher-order goal function (utility function) assigning weights to the conflicting goals to obtain replacement values; (4) choosing of the alternatives fulfilling the maximum or minimum value of the restricted goal chosen as the main goal the one which may be expected to give the biggest (smallest) value for the unrestricted secondary goal variable. This is a lexicographic preference sequence.

The issue is complicated by the uncertainty and risk associated with most decisions. A goal conflict can occur between high achievement degree usually with an even relatively great risk, and lower expected achievement with smaller risk. »Attitude toward risk is a major constraint which must be taken into account in formulating objectives and particularly in establishing their priorities» (Ansoff 1965, p. 65).

The decision procedures for a goal conflict under Items 1 and 3 lead to pure extreme value models, and that of Item 4 to a mixed model. The pre-elimination of alternatives involved in the procedure of Item 2 can result in either a pure satisficing model or a mixed model.

In the foregoing, the expression and achievement of goals have been reviewed only in principle. The formation of operational goals, however, requires the most precise possible definition of the goal variables in the form of definition equations, i.e. a goal definition (»Zieldefinition»). The goal variable is thus expressed as a function of the contributing variables. This phase of goal formation, therefore, is essentially a problem in economic science (cf. D. Schneider 1970, p. 55). One business goal definition is that profit for a period is equal to revenues less expenditures. At this stage the goals of all sectors of the enterprise must be brought into operational harmony (for further details, see Chapter 232). The goal instruction and goal definition together form the goal function, which can be concisely defined as the variable to be maximized or minimized (cf. Heinen 1968, p. 224). A broader definition can be used

in connection with restricted and fixed goals. Should a single goal function not express fully the influence of various decision variables on the goal variable, it must be expressed by separate explanation equations (»Erklärungsgleichungen») (see Heinen 1968, p. 224). These might e.g. express the components of profit, revenue and expenditure as functions of individual products. Before a model derived from the goals of an enterprise can be complete, equations and inequalities are often needed to indicate factors restricting the achievement of the goal function. Such limiting factors might be the amounts of various production factors, financial possibilities, etc. They are generally called constraints or secondary conditions, conceptually close to the restricted or fixed goals previously mentioned.

Special questions can be raised concerning the true goals in decision making of each economic unit. Even when working for economic gain, people do not always »feel like» acting as the pure profit-maximizing homo economicus of the classical economic theory. Various schools of ideas have been formed concerning the nature of the economic goal functions of individuals, enterprise management and other decision makers. Especially in the last twenty years the maximization of profit has been questioned as the relevant goal function of the enterprises. It has been claimed that entrepreneurs do not try to maximize their profit or any other financial variable nor could they do so operationally because of the uncertainty of the future (cf. D. Schneider 1970, p. 58). Unwillingness to accept the premise of maximization is the basis for the »satisficing» theory derived by Simon (1957, p. 241—260) from the psychological concept of satisfying the level of aspiration (Lewin — Dembo — Festinger — Sears 1944, p. 333—378). The decision maker, in his bounded rationality (see Simon 1957, p. 198—200) usually does not attempt an optimal choice but tries to find an alternative meeting his aspiration level (cf. March and Simon 1958, p. 140—141). According to Starbuck (1963, p. 135), from the angle of economic theory, »the conditions under which satisficing is more rational depend upon the specific assumptions which are made about the problem solver and his environment. However, two requirements seem clear: (1) the environment must be complex, and (2) the problem solver's perceptions must understate the complexity of the environment». And Starbuck (1963, p. 135) continues in his footnote 8: »These conditions are necessary if satisficing is to appear more rational to an omniscient observer. Satisficing will be more rational from the viewpoint of the problem solver only if he recognizes the existence of these conditions».

When matters are taken from the viewpoint of an individual enterprise and not as a phenomenon of national economics, the question of goals of the population of enterprises is not particularly relevant. Every enterprise has the goals its main decision makers decide to accept within the multi-

dimensional »elbow room» of the enterprise (cf. Lehtovuori 1971, p. 10; Rhenman 1970 b, p. 11—13). This might be the firm's latitude for profit achievement in the usually prevailing incomplete market (see Albach 1959, p. 17). Furthermore goals may be modified as the firm gets older, its size changes, its sector broadens and matures, the structure of the management or owners changes, and so on (cf. Ansoff 1965, p. 67—71). The true »elbow room» of an enterprise is therefore continually changing; both in external and internal factors (cf. viewpoints of the research object on a more general level in Chapter 221 above).

There are misconceptions concerning the maximization of goal variables which are common enough to require discussing here. Use of the profit maximizing goal, for example, is often rejected on the basis that maximizing is impossible since many of the possible action alternatives are always unknown. It is obvious, however, that any alternative maximally or otherwise satisfying the goal must be found only among the known alternatives. These are alternatives in which the values of the variables and parameters required for profitability calculation are known or can be found at »reasonable» cost (cf. D. Schneider, 1970, p. 58).

Therefore it may be considered that the operational usefulness of the goal function for an individual enterprise depends on the following factors: (a) the decision maker's desire to reach the goal (psychic factor); (b) the strategies (alternatives) available for the achievement of the goal function, and the relation of the decision maker's environment to this goal and to the steps its realization requires; (c) the possibilities for predicting future developments.

232. *Influence of the enterprise concept on goal formation*

The enterprise's decision making process and hence also its goal formation and model construction are perceptibly influenced by the definition of an »enterprise». The following classification of enterprises seems appropriate from the viewpoint of goal formation in economic decision making (cf. D. Schneider 1970, p. 19—22, 146—152):

1. Enterprises as juridical units (»firms»).
2. Enterprises as income sources for private persons (»personal enterprises»).

In general usage the enterprise concept more or less corresponds to the firm, although there are numerous definitions of varying nuance (cf. e.g. Artto 1968, p. 9—11; Bowen 1955, p. 2—4; Gutenberg 1965, p. 493; Lehtovuori 1966; Schäfer 1961, p. 103). Furthermore, the science of economics traditionally identifies enterprise and entrepreneur, the

entrepreneur referring to the owners of the enterprise (firm) (McGuire 1964, p. 20). In actual fact, the power of decision held by company owners and by shareholders in corporations is often very limited. On the other hand, there are numerous persons who simultaneously own shares in several enterprises, plus debentures and other securities, real estate and other income-yielding property. These persons are usually more interested in the management of their overall holdings in a way congruent with their own goals, than in the operation of any individual firm in which they own stock. The use of capital can therefore be reviewed from the point of view of (a) producing firms, (b) persons investing capital either in firms controlled by themselves or by others, or in bonds, bank accounts and other financial receivables. The analysis of assets in Fig. 7 illustrates some principles of the property relations between firms and personal enterprises. For the sake of simplicity, Fig. 7 disregards monetary institutions and other agencies responsible for outside financing of enterprises.

In addition to income-yielding assets, a personal enterprise involves the use of the person's work input, either in his own business or in the service of an employer. A personal enterprise, therefore, contains all actions

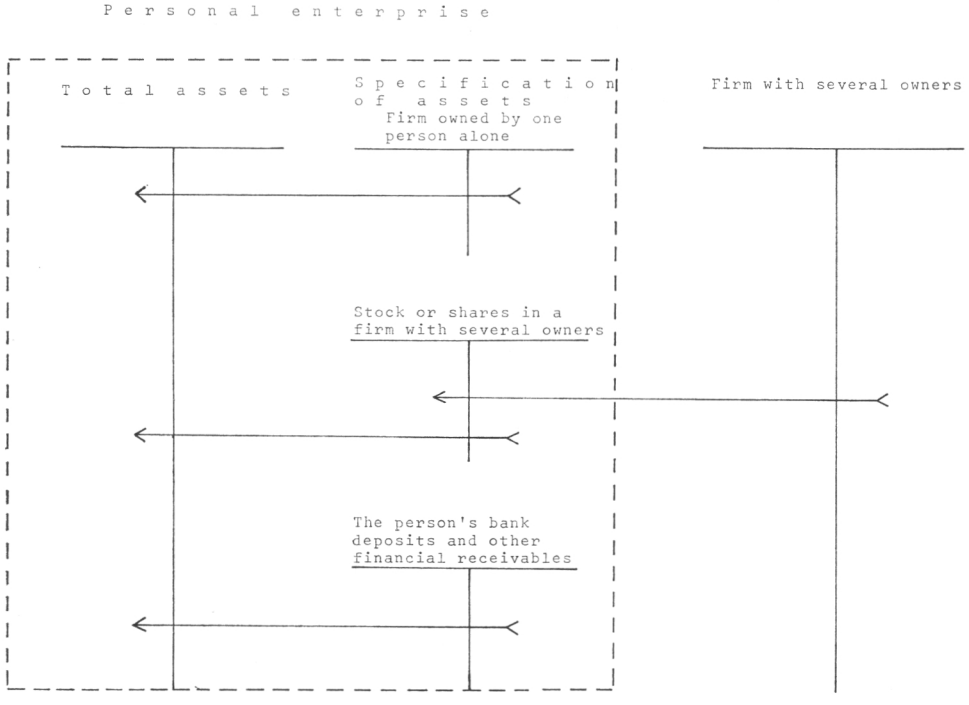


Fig. 7. Description of a personal enterprise solely from the viewpoint of the composition of its assets.

an individual takes in order to earn an income, all he »undertakes» (D. Schneider 1970, p. 19). Consumption decisions conceptually do not belong to the personal enterprise. However, these decisions determine the proportion of capital remaining at the enterprise's disposal. In fact, there is a distinct operational connection between the enterprise of a private individual (or family) and his consumption economy. One of the essential differences between a personal enterprise and a firm of several owners is that the person can regulate more elastically than the firm the money or commodities taken from his own enterprise. One person can decide to sell or buy securities and real estate, save or dispose of the growing stock of his forest unit, etc., whereas in corporations a small shareholder has practically no authority in the company's decisions concerning investment, disinvestment, finance, etc. The power of decision is mainly vested in the annual general meeting, board of directors, management board and other executives. Especially in firms with several owners, the entrepreneur is not the ownership but the management (Riistama 1966, p. 193; D. Schneider 1970, p. 150). Naturally shareholders or partners can contribute by voting to appointments of staff by the management, to decisions concerning the distribution of dividends, etc. A shareholder dissatisfied with some policy can of course sell his stock and invest in another firm. Of course the management's influence is great also in one-owner firms, when the person who has invested his capital does not take an active part in managing the enterprise.

A detailed discussion of the goals in these two groups of enterprises requires the definition of a few concepts relating to time (cf. D. Schneider 1970, p. 36—38):

1. In firms (with one or more owners):
   11. The planning period.
   12. The firm's life span.
2. In personal enterprises:
   11. The planning period.
   12. The activity period.

Both for firms and personal enterprises, the planning period covers the time which can be spanned by »adequately» detailed plans for the enterprise. It therefore refers to a period for which the influence of the enterprise's action alternatives on its goals can be measured. This expressly refers to a whole enterprise, and therefore primarily to the combined planning models of Chapter 242. Planning is not restricted to the use of the planning models defined in Chapter 222 but is understood more broadly. The deter-

mination of planning period length is discussed in greater detail in Chapter 353. In any case, an important factor limiting the length of the planning period is the uncertainty which increases as the period is extended (Chapter 352). The activity period of a personal enterprise again refers to the time during which the individual expects to make economic decisions (D. Schneider 1970, p. 36). When a 50-year old person makes his plans he may extend them perhaps to the age of 70 when, for natural reasons, he intends finally to end money-earning activity. This period of activity might be divided into two 10-year planning periods. He may feel that he can define his goal function and make specific plans for the first period, but perhaps only outline his actions for the following planning period. On the other hand, the firm's lifespan has no necessary limits (cf. Ansoff 1965, p. 44). Usually it is not bound to the ability and desire of a given person to continue the economic activity.

Ansoff (1965, p. 44—45), discussing firm-type enterprises, divides the time between the present moment and the »time horizon» into two parts: the »proximate period» extends from the present moment to the »planning horizon», and the »long term period» from there to the time horizon. The long term period, according to him, »may be very long indeed». The life span of a firm can be considered to correspond to the time from the present moment to the time horizon. According to Ansoff, the proximate period (perhaps 3—10 years) is determined by the length of time the firm is able to cover by forecasts with precision acceptable to its managers. He mentions an error term of $\pm$ 20 %.

When the planning period is shorter than the expected remaining life span of a firm or personal enterprise, we have a continuous enterprise (D. Schneider 1970, p. 36). In a personal enterprise, however, this continuity is confined to the length of the activity period of a person (or possibly family). In a firm, on the other hand, it usually refers to a period that cannot be determined in advance (name changes or other apparent »windups» of the enterprise are naturally disregarded). In some cases the planning period may be as long as the firm's life span or the activity period of a personal enterprise, although these are less common than continuous enterprises. We can call them fixed-term enterprises (D. Schneider 1970, p. 36—37).

As mentioned earlier, an enterprise can be given a quite varied range of objectives depending on the views and influence of those concerned, within the restrictions imposed by its resources and environment. Three financial objectives of the enterprise will be systematized here: (a) maximizing the money received, (b) maximizing the assets, and (c) a combination of (a) and (b). These financial objectives will be discussed first in the context of a personal enterprise; since the owner and manager are usually the same

person they are more clearly defined than especially in firms with several owners.

Let us make the simplifying assumptions that the activity period of a personal enterprise and the owner's labour input are given, i.e. independent of the alternatives to be compared. Then the entrepreneur has the following financial objectives (to be maximized) at his disposal (D. Schneider 1970, p. 147):

1. The value of the assets at the end of the activity period is maximized. Certain sums of »money received», often in varying amounts, are taken from the enterprise annually for consumption.
2. The desired value of the assets at the end of the activity period is pre-determined, and so is the relative distribution of money received in the different years. The annual money received from the enterprise is maximized.
3. The utility or wealth is maximized, in other words the entrepreneur seeks to reach during an operational period a maximum sum of money received and increase in value of assets.

Since all the person's money investment (also at zero interest) and earnings from work belong to his personal enterprise, according to the definition money received can be spent only on consumption and payment of taxes. If this thinking is accepted, the entrepreneur's »income» consists only of the money and commodities which he takes for his consumption purposes (cf. Honko 1959, p. 41; D. Schneider 1970, p. 148). This thinking is by no means new; it is based on the theories of capital and income published by Fisher early in the 20th century (Fisher 1923[1]), 1930). Recent developments in integrated planning calculations have shown that these ideas of Fisher's are particularly well applicable to an overall treatment of the investment, financial and consumer problems of individual persons, families and other similar »private» economic agents. The above objectives can be used expressly in the formation of goals for the combined (partial) models to be discussed further in Chapters 242 and 43.

Income and assets are interdependent. They cannot both be maximized simultaneously. Maximizing the utility in the way described (Item 3) is therefore possible only provided the terms of exchange between the units of money received and final assets are known (D. Schneider 1970, p. 149); in other words, how big an annual income the entrepreneur is pre-

[1]) The first edition was published as early as 1906.

pared to give up in order to increase his assets by one unit at the end of the operational period, and vice versa.

In a fixed-term personal enterprise the value of assets at the end of an operational period equals the assets at the end of the planning period. According to the definition, then, this quantity can be defined »sufficiently» precisely. On the other hand, the income yielding operations of a fixed-term enterprise cease at the end of the planning period. The entrepreneur then spends the funds obtained from the sale of the enterprise assets solely on consumption (D. Schneider 1970, p. 147). However, it could be assumed that funds obtained by sale of assets were »stored» in bank accounts yielding at least a nominal interest, to finance later consumer goods purchases (cf. Hämäläinen 1971, p. 417).

When a continuous personal enterprise is involved the intention is to use the assets existing at the end of the planning period, as well as the owners' mental and physical resources, for continuing income-yielding function until the end of the operational period. Even in a continuous enterprise, however, operations can be planned in »sufficient» detail only up to the end of the planning period. The maximizing goals are therefore operational only within the planning period. Care must be taken to ensure continuity of operations even after the planning period. At the end of the planning period, the assets, finance and other operational conditions must be structured so that they provide a base for the next planning period.

The objectives of firms are a compromise of the desires and requirements of various interested parties (cf. Wright 1964, p. 55—65; D. Schneider 1970, p. 149—152; Rhenman 1970 a, p. 71—85). However, it may be difficult for these parties to request any rapid change in the main activity sector of the enterprise. In this sense a firm is often an institution which can only gradually be changed.

At least in principle, the owners of a firm have their best chance of affecting the firm's objectives when a single person (personal enterprise) owns the whole firm. Irrespective of the degree of centralization of ownership, however, the most powerful of the parties interested in firms usually are their owners (often stockholders), the top executives, creditors, customers and suppliers, the local and central government and the employees. Even outside consultants may exert substantial pressure, although they are usually supposed to be neutral. Each of these and others strive to influence the determination of the firm's objectives in ways favourable to themselves. The influence they can bring to bear depends on legal standards, contracts, individual authority and executive power, and other sources of pressure (cf. Griem 1968, p. 66, footnote 39).

In firms the main objective of executives and other employees often is to secure their own position, with the highest possible and sufficiently safe

income. Converted into the firm's objective, this means primarily maximizing the assets, implying re-investment of profits into the firm (cf. D. Schneider 1970, p. 51). On the other hand, especially older executives may often think of securing the highest possible personal income at the expense of the firm's goals (Ansoff 1965, p. 62). The creditors' interests are apparently also best promoted by increasing the enterprise assets and seeing to it that the liquidity of the enterprise is not jeopardized, which naturally is a general expectation. It is usually not possible for the firm's goals to be formulated in such a way as to satisfy the personal-enterprise objectives of every shareholder. The higher the proportion of profit distributed as dividends, the larger the power of decision left to the shareholder as to whether he wishes to reinvest his dividends in the firm or to consume and/or invest them in other ways. Whenever the goal of the firm is the maximizing of its assets by adopting a policy of low dividends, the management in fact decides for the owners to reinvest profits. On the other hand, maximizing the assets is not viewed the same way by the ordinary shareholder as it is by the management (cf. D. Schneider 1970, p. 151—152). From the shareholders' viewpoint the firm's financial objective should be to maximize the average shareholder's dividends or the value of his shares. The expectations of the other interested parties are apparently best in agreement with the goal of maximizing the firm's real assets (the firm's value).

Especially in firms with an advanced functional division of labour, goals must be set by sections in order to realize the whole firm's objectives. At different organizational levels these goals must be expressed in terms of operational and verifiable variables associated with everyday work. These subgoals are in reality means of achieving the enterprise's overall goals. The subgoals naturally are also modified by changes in the objectives or organizational structure of the enterprise (Griem 1968, p. 69).

The operations of the whole enterprise may be planned in such detail that the values of financial goal variables could be calculated for the planning period only. A continuous enterprise, especially a firm, however, must link up its earlier operations with those following the end of a planning period as smoothly as possible. This must be ensured in the course of the planning period by specifying certain auxiliary goals; these auxiliary goals are correlated as closely as possible with the financial goal variables and support their achievement. The main kinds of auxiliary goals are: external competitive strength, internal efficiency, external and internal flexibility (Ansoff 1965, p. 49—59). In a continuous firm, adequate maintenance of these auxiliary goals becomes the best possible guarantee that the firm really is continuous and that its operations will not cease once the planning horizon is reached.

24. Principles underlying the planning models for investments and their financing

241. *General*

Usually some kind of financial goal is of central importance in an enterprise's goal system. For this reason the requirements and consequences of all actions are measured in monetary units whenever possible. Enterprise operations represent a continuous circulation following the rule: money → commodity → more money (cf. D. Schneider 1970, p. 134—136). In this context the entrepreneur sees his enterprise as an investment and financing object. This causes cash flows in the money process of the enterprise. Money must be provided to pay for the purchase of production factors, other implements of income earning, and the costs of financing. Financing can be defined as obtaining means of payment to the enterprise and investment as the use of these means to obtain either (a) commodities and services, or (b) various objects of financial investment (shares, bonds and other securities, etc.). Often the interval between sacrificing the expenditure (cash outlay) and obtaining the income (cash receipt) is short. On the other hand, enterprises also sacrifice expenditures against which income is earned only gradually, and which often are accompanied by costs sacrificed later. »These different outlay items, in a way their flows, make up the enterprise's investment process, briefly called investment» (Honko 1969 a, p. 13). Accordingly, we could speak of the financing process of investment.

Any discussion of investment must employ a multiperiodic or dynamic approach: the model is constructed to handle payments over a relatively long period of time. Mainly for practical reasons, this period is divided into subperiods of perhaps one year. If it is necessary to distinguish between the two aspects of financial planning, it may be done as Hållsten (1966, p. 17) says »... an investment project is defined as an act which in the firm's decision model is described by a cash flow starting with a disbursement; correspondingly a financing project is described by a cash flow starting with a receipt».

242. *The idea underlying combined planning models*

In principle, a total planning model should encompass a precise statement of all of the enterprise's decision alternatives. In a firm, this means all possibilities for investment, financing, purchases, sales, production, organization and cash flows until termination of the enterprise (D. Schneider 1970, p. 157). As stated before for various reasons, constructing

such a total model is not possible in practice and the cost of obtaining information for it would be prohibitive (see D. Schneider 1970, p. 157—158, p. 474). This maze must be properly simplified to supply data and models for an enterprise's multiperiodic planning calculations. Characteristics of the partial models of long-term enterprise planning, constructed on the grounds described in Chapter 221 are: a. Money planning is constrained to a period bounded by the planning horizon; b. Cash events are not dealt with individually but combined, for example, into yearly sums; the models can contain other assumptions concerning potential investments and/or financing (D. Schneider 1970, p. 150—160); c. Partial models often make summary statements of the average returns to be expected from the enterprise or from individual projects continuing after the planning horizon.

Partial models operating with monetary values can be divided into two main groups (D. Schneider 1970, p. 160):

1. Combined partial models.
2. Classical » »

Combined partial models are used to build an optimal combination of individual action alternatives. The principle of the optimal plan is that a number of alternative possibilities of production, investment, financing etc. are combined until the best degree of achievement of the objective is found. The goal variables of the model are always »genuine», that is at least the goals listed in Chapter 232 (p. 43) enter into question. Mathematical programming techniques are appropriate for solving combined models.[1]) Even the simplest of these, linear programming, can explicitly take into account the limits of financial sources, quantities of production factors, demand, and other basic conditions. Within the framework of these constraints, the model can indicate an optimum programme for the planning period. It gives for every year of the planning period a simultaneous solution for such things as the use of various financial sources, real investments to be made, production programmes, and the disposition of annual cash balances in a way that ensures liquidity. Essential to the success of this procedure is its recognition of the interdependence among different alternatives for the acquisition and use of money, materials, manpower and other factors of production (see Heinen 1968, p. 130).

Interdependences and combination possibilities can be distinguished (cf. Albach 1959, p. 49—72):

(a) during each year of the planning period
(b) between the years of the planning period.

[1]) Here and later, this briefer term is used for combined partial models.

Heinen (1968, p. 242) calls the former the chronologico-horizontal and the latter the chronologico-vertical interaction of investment objects. These latter interactions make the planning of investments dynamic. The programmes for interdependent years of the planning period are solved simultaneously from the model. This can be done by classical methods (Chapter 243) only in simple cases with certain assumptions (cf. Jääskeläinen 1964, p. 39).

The simplifications necessary in multiperiodic combined models are usually considerable. For instance, they may specify the external financing constraints with relatively detailed data on the availability and costs, while perhaps investment, production, marketing and other alternatives can be only coarsely approximated (cf. Jääskeläinen 1966; D. Schneider 1970, p. 160—161).

243. *The classical partial models for comparison of the profitability of investments*

This group of partial models includes the present value or discount method, the annuity method, the internal rate of return method as well as actual capital budgets compiled by these means (cf. Honko 1969 a, p. 80—88; D. Schneider 1970, p. 160).

The classical partial models employ profitability criteria for forecasting the economic consequences of investment projects. If the decision maker is willing to accept one of these standardized methods, he can use classical partial models to answer the following questions (cf. Asztély 1965, p. 17—42; Fog and Rasmussen 1961, p. 218—230; Heinen 1968, p. 236—247; Honko 1969 a, p. 89; Hållsten 1966, p. 51—60; Jääskeläinen 1964, p. 22—33; Jørgensen 1964, p. 389—394; D. Schneider 1970, p. 162—163; E. Schneider 1964, p. 22—57):

1. Is a certain investment possibility advantageous or not?
2. Which of two or more mutually exclusive investments is the most advantageous (best)?
3. How can an investment programme be compiled from several mutually independent projects so that its implementation maximizes the profitability criterion?

The classical methods of investment calculation are based on the assumption that expenditure and revenue can be determined for individual investment projects. In other words, the partial system of the enterprise described by the model is taken to be at least partly closed. This implies that the flow of outlays and revenues from each investment project is

independent of the other alternatives. In reality this condition may not often be satisfied, and this is one of the weaknesses of the classical methods (cf. Blumenrath 1969, p. 3—4). These shortcomings will be discussed in greater detail later in this chapter.

Classical investment theory relies on the methods of financial mathematics and differential calculus for making comparisons (see E. Schneider 1964). To facilitate discussion let us present the customary deterministic calculation formula for the present value or discount method:

$$(1) \qquad V_0 = \sum_{t=1}^{n} (R_t - P_t)(1+i)^{-t} - I_0,$$

where

V_0 = the present value or capital value of the independent investment project immediately before investment begins;
n = period of investment, e.g. years;
R_t = revenues obtainable from the investment during the t^{th} year (taken at the end of the year)[1]);
P_t = current expenditures for the investment during the t^{th} year (taken at the end of the year);
I_0 = the investment outlay at the beginning of the n-year period (immediately after calculation moment 0);
i = rate of interest used in calculations (calculation rate), a decimal figure.

Investment calculation is thus anchored to the investment project and to time (cf. p. 19 above). The capital value of the investment shows its ex ante value as a source of revenue (cf. Fisher 1930, p. 12). When $V_0 = 0$, the rate of return obtained (with reservations to be specified later) for the invested capital is exactly that equalling i, the calculation rate. If the decision maker considers this capital value as his only criterion of profitability, an individual investment or a combination of several investment projects is profitable according to the present value method whenever $V_0 \geqq 0$ (Honko 1955, p. 39; E. Schneider 1964, p. 24). The calculation rate is then considered as a minimum return required from the investment. Originally (Fisher 1930, p. 256—257), the calculation rate was considered to represent a known market rate of complete capital markets, a rate at which any amount of capital desired was available and could be re-invested (cf. also Albach 1959, p. 35—36; Hirshleifer 1958, p. 330). The economic rationale of the discount method is that of

[1]) The formula makes this customary simplification, giving up the calculation of continuous outlay and revenue flows which in practice is usually made impossible by lack of information. For suitable formulas, see e.g. Lutz and Lutz 1951, p. 13, Massé 1962, p. 16—17.

comparing a potential investment alternative with a »dummy» one whose internal rate of return equals the calculation rate (D. Schneider 1970, p. 167). Of two or more mutually exclusive investment projects, the most profitable is the one having the highest V_0 (Albach 1962, p. 27; Honko 1955, p. 43; E. Schneider 1964, p. 37—38, 43).

The annuity method is really only a modification of the discount method. The underlying idea is that the varying net revenue balances expected annually — including the basic investment I_0 (Formula 1) — are converted into equal amounts whose present value sum is equal to V_0 (cf. E. Schneider 1964, p. 25—27). The profitability is then assessed according to the principle used in the present value method.

The internal rate of return method can be formally presented using the formula of the discount method (1). The internal rate of return in the investment alternative refers to the rate of interest (i_a) with which $V_0 = 0$, i.e. the present values of revenue and expenditure discounted to the date of comparison are equal (e.g. Albach 1959, p. 22; Lutz and Lutz 1951, p. 13; Massé 1962, p. 20). When internal rate of return alone is the criterion an individual investment project is considered profitable if $i_a \geqq i_{min}$ (the entrepreneur's lowest acceptable rate of interest). If there are two or more mutually exclusive so-called genuine investments (for details see E. Schneider 1964, p. 12—13), the most profitable is that with the highest internal rate of return (Albach 1962, p. 27; Hållsten 1966, p. 53; Honko 1969 a, p. 97).

Use of the method of internal rate of return is hampered by the mathematical fact that an equation of n^{th} degree has n different roots, and these solutions may be either complex numbers or positive or negative real numbers (D. Schneider 1970, p. 178; cf. also Massé 1962, p. 21—22). Difficulties arise when there are more than one real solutions (Hirshleifer 1958, p. 349—350; Marty 1970, p. 277; Massé 1962, p. 21—23; D. Schneider 1970, p. 178), or when the equation is not satisfied by any real number (Hirshleifer 1958, p. 349; D. Schneider 1970, p. 178). The reason why more than one real solution (internal rate of return) can be obtained is attributed to the signs of the annual payment balances for the investment. In Formula (1), $(R_t - P_t)$ and I_0 may become positive or negative from year to year (1, . . ., n) (cf. Hirshleifer 1958, p. 349; Marty 1970, p. 277; D. Schneider 1970, p. 178). It is important, however, to note, that if the sign of the annual payment balances changes once, the equation has only one real solution (Hållsten 1966, p. 51; D. Schneider 1970, 178—179; Teichroew et al. 1965, p. 158). If the sign changes twice there can be at most two real solutions, but in certain cases there will be none (Hirshleifer 1958, p. 349; D. Schneider 1970, p. 179). If there are more than two

sign changes it is possible but not necessary that the equation can be satisfied by more than one real internal rate of return (i_a) (see Hållsten 1966; p. 52; Teichroew et al. 1965, p. 160). This complexity of possible mathematical results can render the internal rate of return method unpredictable and ambiguous. It is true, however, that many investment projects have series of annual payment balances in which the preceding sign of the balances changes only once in the period of investment, and the equation therefore has only one real root.

The use of classical investment comparison methods is based on certain assumptions. First it must be known that the decision maker finds these profitability criteria useful. Strictly speaking, capital value and annuity are suitable criteria of profitability only when the investment projects have separate income and outlay flows, and when unlimited funds can be obtained or invested at the same rate of interest at least during the same year, although the rate can vary between years (Asztély 1965, p. 40—41; D. Schneider 1970, p. 169; see also Honko 1969 a, p. 94; E. Schneider 1964, p. 34; Teichroew et al. 1965, p. 153). In reality many organizational and institutional factors, as well as scarcity of production factors, limit the funds which a firm can deploy in its investment program. In the present author's opinion it is not necessary to expect unlimited possibilities for financing and investment, although it is essential that adequate financing and investment are available for the alternatives actually compared (cf. Jääskeläinen 1966, p. 93). Accordingly, to employ the internal rate of return method, one must assume that the annual deficit of the series of investment payments can be financed and the surpluses invested at the internal rate (Asztély 1965, p. 40; D. Schneider 1970, p. 177, 181; Streyffert 1968, p. 450). The present author has not encountered in the literature any special mention that this demand of re-investment and financing should not apply to a case like the following: it must be investigated whether one separate investment of an investor operating with his own capital is profitable, provided the investor spends the income surpluses obtained from the investment on immediate consumption, that is uses up his capital. This represents a gradual liquidation of an enterprise consisting of one investment project.

The schematic financing and re-investment assumptions are intended to make each of the compared investment projects independent, by eliminating the following factors which might otherwise influence the comparison of profitability:

(a) the differences among the different alternatives in the cost of acquisition or investment
(b) the differences in the annual net payment balances under the different alternatives

(c) the differences in the durations of investment periods. This is in fact partial phenomenon of Item (b).

The schematic procedure is an attempt to constrain every investment project to a kind of miniature enterprise; an apparently complete profitability comparison is performed with heavy simplifications.

The internal rate of return is usually different for each investment alternative. It follows from this that the decision maker commits funds to each one of the compared investments at an individual rate of interest which is usually different from the other alternatives. It is therefore in reality incorrect to speak of the internal rate of a given investment project. The fact is that in practice the alternative cannot be isolated from its financing cost and from the expected returns yielded by the re-investment of the yearly surplus balances. Thus those expected returns are in fact external to the project (cf. Hirshleifer 1958, p. 350). The basic assumptions of internal rate of return method might have more meaning if the investor had investment projects of one type only, which he could either accept or reject, constantly investing released funds in a series of these projects. If the investor operated solely with his own capital, this criterion would perhaps also be realistic for comparing the profitability of two or more investments. The decision would mainly depend on the rate of interest the investor requires. But it is difficult to see how rational activity could satisfy the condition that released funds should be re-invested at the internal rate of return of the project whose profitability is being tested. To validate the calculation, our decision maker would be »obliged» to invest funds released from one alternative in another that happens to yield the same internal rate of return. This would produce a number of possible investment chains starting from the original investments. Each chain would have its own internal rate of return, remaining constant over time. Because of this condition, in most cases the present value method must be considered more realistic although even there the financing and investment assumptions are very schematic. More detailed discussion will follow in Chapter 354.

The internal rate of return obtained for a given alternative also depends on the outlays (or incomes) allocated to the alternative. The worst thing is that the ranking of the different alternatives often also depends on the kind of expenditure and revenue directed to each project (in partial calculations, this often is a matter of speculation). Alternative calculation methods usually adopt the idea that only the items differing among the alternatives are relevant (see for example Honko 1955, p. 154). If this procedure is employed in calculating internal rates of return, the resulting ranking of alternatives is often different from that obtained with the original, unabridged income and outlay flows. As shown by Hållsten (1966, p.

56—57), the disadvantageous effects of this phenomenon emerge concretely if the internal rate of return method is applied to a series composed of the differences between the annual cash flows of two alternatives (the so-called difference method; see Hållsten 1966, p. 57; E. Schneider 1964, p. 43—45; Vibe-Pedersen 1958, p. 147). A similar change in internal rates also follows when e.g. certain outlay items are »forgotten», knowingly or otherwise, even if those amounts are equal under the different alternatives (see Hållsten 1966, p. 54—56; D. Schneider 1970, p. 179). But in the present value method, the profitability ranking of the different alternatives is not changed by these transformations (see Hållsten 1966, p. 54).

D. Schneider (1970, p. 174—175) finds calculation of internal rates of return questionable for investments in which the capital input (»bound capital») is not the same throughout the period of investment. »Bound capital» means here that the only outlay is in the beginning of the investment period, and the investor draws out money only at the end of the period. A change in the amount of »bound capital» necessitates assuming that annual surplus balances can be invested and deficit balances financed at the internal rate of return. Calculating the internal rate of return is a correct and generally applicable method only when the investment is made for one period, e.g. one year (Hirshleifer 1958 p. 352; D. Schneider 1970, p. 181). In such a case the capital invested remains the same throughout the period under review, and its »internal» profitability can be calculated if only net revenue can be determined. According to D. Schneider (1970, p. 181), applying the internal rate of return method to a multiperiodic investment affords no advantage over the present value method, whereas its results often are so ambiguous as to be useless. Furthermore, calculations are more complicated than in the present value method. Only as long as an approximate, simplifying analysis is considered adequate is the internal rate of return applicable also in the multiperiodic models (D. Schneider 1970, p. 181). In the present writer's opinion, the financing and re-investment assumption of the internal rate of return method have their best validity when the investor operates only with his own capital. In this case the rate of interest initiates no cash flow (at least not in a personal enterprise) but the level of profitability requirements is subject to consideration. In spite of its methodological shortcomings, the internal rate of return method can be used to make approximations of the profitability of investments in categories »typical» to each sector of the economy. It is especially useful when the enterprise operates solely with its own capital. In such conditions, it is then assumed that (1) separate cash flows can be directed to the different investment projects, and (2) net revenue obtained is re-invested in similar projects.

The present value method is not accompanied by the same ambiguity of results as the internal rate of return method. However the proper use of the present value method does presuppose that in each year (1, . . ., n, Formula (1)), the expected surplus of the investment alternatives can be invested, or the deficit financed, at the same rate of interest (calculation rate). In reality, the rates for financing and re-investment often differ at least when outside capital is used, but if the difference is not very great the present value method can still be used for partial problems, and gives approximate results (cf. D. Schneider 1970, p. 169).

The internal rate of return method and the present value method often give different profitability rankings for mutually exclusive alternatives. This is due to differences in the basic assumptions which are used in each method to render the alternatives comparable to one another.

If it is desired to avoid the formal use of the calculation rate peculiar to the present value method, the alternatives must be formulated in detail. One must consider the returns from re-investment of funds as well as the cost of financing, with the result that every operational alternative shows as its payment balance only one of the »genuine» goal variables, with the underlying ideas described in Chapter 232 (cf. D. Schneider 1970, p. 156). This leads, in a way, to the simpliest combined models (D. Schneider 1970, p. 240). If the classical present value method and the annuity method are viewed in this light, they are found to be special cases of the combined model. They presuppose that, during the period of investment, no revenue is taken for consumption, and that all annual surpluses are re-invested at the calculating rate until the end of the investment period. The capital owner is paid the same rate of interest for the funds invested in the project. The difference between the cumulative revenue and expenditure balances (including re-payment of capital) accrued by the end of the investment period shows the investor's net funds at that moment. Such a prolongation of annual revenue and expenditure is a computational variant of the present value method. The corresponding situation under the internal rate of return method would be, for example, as follows: if the financier (subject who gives money to the enterprise, finances its functions) requires the return presupposed by the internal rate on the funds invested and the entrepreneur (user of capital) is able to re-invest the revenue obtained from his investment project at the internal rate, the entrepreneur's property does not increase at all through the investment. However, if the financier and the entrepreneur are the same subjects, then at these and only these re-investment terms the entrepreneur obtains each time the internal rate of return on the funds invested, and at the end of the investment period he obtains also the invested capital.

The classical investment theory also treats the problem set forth in

Item 3 cf. p. 48. Several investment projects which are independent but capable of parallel realization are combined into a capital budget intended to be realized in the nearest period (usually one year), that is an investment programme that maximizes the profitability criterion for the investments. The main tools in making this budget are the present value method and the internal rate of return method described above, when individual investments were compared.

The present value method gives a one-year (i.e., static) optimal capital budget by selecting for the program all investment projects with a present value $V_0 \geqq 0$ (Albach 1962, p. 27—28). One must make assumptions of complete capital markets, mentioned above in the profitability comparison of individual investment projects. Due to these basic assumptions, the financing of the investments will not restrict planning. Furthermore, all funds released from the investments are assumed to be re-invested at the calculating rate of interest and no revenue surpluses are distributed. The sole goal of the enterprise is to increase its capital with these presuppositions. The structure and extent of the capital budget therefore only depends on the potential profit available on the commodity market, since the financial investment yields only the cost of financing (Albach 1962, p. 31; D. Schneider 1970, p. 311). If the investor's financial conditions roughly meet the requirements of complete capital markets, the present value method gives a satisfactory solution for the static capital budget of the next period (e.g. a year). In reality, however, capital markets are incomplete (Albach 1962, p. 31). This means, firstly, that there is a ceiling limiting the acquisition of outside capital and also that owned by the enterprise. In addition, capital markets pay different compensations (prices) for capital. For example, the rate of interest on loans taken by enterprises depends firstly on political-economy factors, and for example on repayment and other terms, the intended use of the loans, the borrower's and lender's personal conditions, etc. This applies also to the capital (income surpluses) the enterprise may supply for the capital market.

The classical theory of investment, however, considers also a capital budget in certain plain cases of incomplete capital markets. With the present value method, it has limited itself mainly to the following cases (Albach 1962, p. 33):

1. Rate of interest changes as a function of time.
2. Rate of interest changes according to the total capital required.

In the first case it is assumed that complete capital markets prevail every single year, but the rate of interest changes from year to year and is assumed to be known in advance. The optimal investment budget, it is recommended, should be determined using the mean calculation rate, calcu-

lated by the compound interest principle for the investment period. This is used as the discount rate (L u t z and L u t z 1951, p. 156; A l b a c h 1962, p. 33). The computational method is the same as that used with the assumption of complete capital markets throughout the investment period. This simplification of the calculating interest rate, however, produces an error in the optimum budget in all but the exceptional case where the binding of capital in the investment budget is the same throughout its duration (planning period).

In Case (2) the supply of capital is also assumed to be unlimited. The factor limiting its use in reality is the increase in the interest rate as a function of the capital sum. The literature distinguishes, in principle, between two cases (A l b a c h 1962, p. 35—36):

(a) The enterprise obtains all its capital from only one economic subject. The average rate for the t o t a l capital relinquished is the higher the larger the capital sum made available to the entrepreneur. Re-payments of capital do not reduce the percentage rate on the capital that remains unpaid.

(b) The enterprise can obtain capital from several economic subjects, but only a certain amount from each. The rate demanded by each capital lender is higher, the greater the enterprise's indebtedness.

In both cases the volume and structure of the optimal investment budget determined by the present value method depend on what is done with the funds (net surpluses) released annually in the future (A l b a c h 1962, p. 36). If it is really assumed in the former case that capital re-payments do not affect the rate of interest on the remaining capital, it makes no difference whether net surplus is spent on re-payment of capital, or re-invested at the average rate of interest in question (disregarding the effects of taxation). The discount rate on the capital budget is then the mean rate percentage corresponding to the amount of capital at the relevant moment (cf. A l b a c h 1962, p. 36). The investment programme then still contains the possible investment project with the present value of zero, at the calculation rate.

In Case (b) it does make a difference whether the funds released from the investment projects included in the investment budget in their term of duration are spent on re-payment of the existing loans (capital), or whether they are re-invested in the capital market (A l b a c h 1962, p. 37). The classical investment theory is unable to provide a competent means of solving the problem of an optimal investment programme in such a case, although attempts have been made based on various assumptions (see A l b a c h 1962, p. 37).

The primary assumptions of the present value and annuity methods on unlimited possibilities for obtaining and investing capital, also make the factual use of the method impossible in a situation where it is known à priori

that only an exactly limited amount of capital is available in the budget year (cf. A l b a c h 1962, p. 39—40). A characteristic of this situation is that the supply of capital does not change, no matter how much the rate of interest is raised (a rather unrealistic assumption).

The use of the i n t e r n a l r a t e o f r e t u r n method for compilation of an optimal investment budget was originally discussed, above all, by B o u l d i n g (see A l b a c h 1962, and his literature references). According to him, the terms on which an annual investment budget can be optimized are that its average internal rate equals the marginal internal rate. It is naturally presumed that the above financial and other assumptions are valid for each individual investment of the budget.

D e a n especially developed the use of the internal rate of return method for the compilation of capital budgets assuming incomplete capital markets (see e.g. D e a n 1962; 1st ed. 1951). The basis is again a number of mutually independent investment projects for which the optimal budget of one period must be compiled. Internal rates are calculated for the investment projects, and on their basis the projects are placed into a ranking of profitability. The resulting capital demand can be illustrated graphically. If the ordinate shows the internal rate of the investment projects and the abscissa the amount of capital, the curve showing the demand for capital (fraction line) falls from the origin to the right. The supply of capital is discussed by D e a n (1962, p. 66—69) first in an enterprise using i n t e r n a l f i n a n c i n g (own financial resources). The supply of capital is assumed to be fixed regardless of the compensation percentage promised. The graph of capital supply is thus a line parallel with the vertical axis (the ordinate also describes the cost of capital as a percentage). The intersection of the lines for demand and supply shows the project still to be included in the budget, and its internal rate, provided the problem of the indivisibility of the objects can somehow be eliminated. If the investment projects really are (a) mutually independent, (b) the amount of internal financing (supply of capital) as a function of the rate of interest is absolutely fixed, and (c) there are no activity-limiting factors other than capital, the burdens remaining on the budgeting method described are »only» the basic assumptions, listed above, of the internal rate of return method.

In practice there are situations where the amount of internal financing is not fixed but increases according to the compensation (rate of interest) promised. In the absence of capital costs payable from the cash, the capital cost (per cent) curve must be based on alternative costs. If so, however, capital investment and cost curves are mutually dependent. This simultaneous solution is not possible by the classical methods (A l b a c h 1962, p. 46—47).

Assuming that the enterprise uses e x t e r n a l financing and that the

supply of capital increases as a function of the rate of interest, Dean finds that an optimal investment budget equals the amount of capital shown by the intersection between the capital supply curve and the capital demand curve, plotted according to the decreasing internal rate of return of the investment projects (see Dean 1962, p. 67, 69—70; Jørgensen 1964, p. 392). In reality, however, the marginal returns and costs of capital (hence also the capital supply and demand curves) are not mutually independent (Albach 1962, p. 47). Even if they were, the assumptions of the internal rate of return method are no longer valid individually for each object included in the budget. The rate paid for the capital to external creditors in reality is that shown by the curve, which is by no means the same as the internal rate of the projects.

Summarizing, the following can be said about the suitability of the classical partial calculations for the compilation of an investment budget for one period. The present value method is indisputably suitable only when the investment objects are independent, and when financing and re-investment possibilities at the calculation rate of interest are unlimited. The same, analogously, is valid for the internal rate of return method; the calculation rate is replaced by the internal rate. A classical one-period optimum budget can be compiled of independent investment objects by the internal rate of return method, even in conditions where a given amount of capital must be divided in the most profitable way between independent investment projects (Dean 1962). The true limitations in the use of the method are naturally the same for each investment object as when the profitability of individual investments is considered. In all these cases, naturally, the ultimate condition is that the decision maker accepts the capital value or the internal rate of return as his profitability criterion.

3. ANALYSIS OF THE CONCEPTS AND METHODS OF PROFITABILITY CALCULATIONS IN FORESTRY

31. The special features of forestry

The contents given to the concept of forestry depend on deliberation and on the purpose for which a definition is required. The main thing is that utilization of the forest (and other potential uses of the soil concerned), in each economic situation are seen from an angle wide enough to encompass all the necessary goals and potential uses. In many cases, this means that aspects other than timber growing must be considered in the treatment of forests.

Forestry, like any industry, has its special technological and economic characteristics. They may concern the various aspects of economic units on the line of business, and can be routinely classified as follows (H o n k o 1969 b, p. 94): (a) purchase of production factors, (b) combination of production factors in the production process and output of products; (c) sale of products; (d) financial process. Only the most essential characteristics of forestry can be considered here, those that affect the form and contents of its business economic calculations. To start with, such characteristics of traditional primary forestry as timber growing will be discussed within the subprocesses of the economic unit.

The most essential components of the production plant producing timber material, the forest, are the soil and the growing stock. Due to the lengthy production period of the forest, the amount (surface area) of soil often becomes the restricting factor. In Nordic conditions, for example, the soil is for decades the substrate of the same tree generation. The long production period also has the result that a large amount of capital is bound for lengthy periods in unfinished production (growing stock) (W o r r e l 1963, p. 7). The circulation of capital therefore is slow. Owing to the long production period and the relatively high degree of binding of the production capital the annual running expenses of a continuous forestry unit are relatively low. A production volume and structure favourable from the viewpoint of the goal are obtained mainly by adapting the tree species, as well as growing

stock volume and structure, to suit the sites of growth (natural conditions) and, as far as possible, the roundwood market demand. Producing the wood material itself is a biological growth process, but its purposeful regulation requires human work inputs of a high professional level (biological, technological and economic). Since in timber growing the finished products and the essential production factor are the same (trees), the emphasis in profitability calculations falls on dividing, in the different phases of production period, the growing stock to be kept in production from that to be removed (yield). This includes also the determination of production period, the rotation. Thus forest growing and financial investments have economic similarities, although the value increment of a forest stand, determinable in different ways as a function of age, has its special features. The economic units of forestry produce some commodities that can be estimated at market prices, and often also produce public goods difficult to assess in terms of money (recreation, water supplies, air protection etc.), which many sectors lack or have in negative form. Forestry in general must be classified among the industries most favourable to the environment of human life. Its biological production mechanism eliminates pollution and other environmental drawbacks produced by other industries and by consumers.

The special characteristics of the sale of the main product of forestry, roundwood, are connected with the subjective line drawn between the production factor (growing stock) and its output. Up to a certain limit, the growing stock is a nonperishable stock of goods, usually increasing in value. As a result, the roundwood supply from a forestry unit (apart from wood lots with sparse growing stock) is flexible in the short run and relatively easy to adapt to such things as cyclic variations in roundwood prices.

Timber growing is capital-oriented, and therefore requires financing which is large in view of the continuous turnover. This, in principle, is not obviated by the institutional factor, for example that in Finland a large proportion of forest holdings are transferred from one owner to another through inheritance, with payment of only inheritance tax and other public dues. It is true that the forest owner can sell his wood lot if required, to facilitate the financing of his other operations, for example the less capital-oriented (the alternative thinking or principle of lost benefit).

Cutting and short-distance transport of timber are today technically and economically closer to industry than timber growing. From the viewpoint of the profitability of forestry, however, it is important to see these two phases as a seamless whole, since the economic results from a forest holding greatly depend on an appropriate linkage between the two production phases. Unlike other industries, in timber harvesting the machines move and the raw material (standing trees) remains stationary, although large-scale timber harvesting today uses machine integrations comparable to industrial plants.

The increasing use of forests for purposes other than timber production attaches features to forestry that are peculiar to service trades. These are facts that often must be considered in the various calculations serving decision making in forestry.

32. Operational goals, and form of ownership

Here the concept of ownership form is not understood as a legal definition. The distribution into ownership groups which traditionally has been used in the discussion of Finnish forest ownership conditions has been adopted, with due modifications (see Uusvaara 1969, p. 3; Yearbook of forest statistics 1970, p. 57). No detailed study will be made of the names and contents of the organizations which make the decision concerning goals in the forestry units of the ownership groups (see Hermansen 1964, p. 302). The various interest groups have approximately the same influence on the goals of a forestry unit as stated in Chapter 231 relating to enterprise goals in general. However, special feature is that public authorities, owing to the great social importance of forestry, impose legislative restrictions — though often supportive measures also — on forestry unit operations more than on those of other sectors. Forestry units also have recreational, esthetic and other values difficult to measure, and aspiring to them may clash with the goals of timber production. Every enterprise, even one that owns forests, ultimately strives to achieve what its decision makers decide to achieve within the framework of the enterprise's multidimensional »elbow room». One determinant of this elbow room is forestry legislation. Hence the financial goals (possibly expressed by ownership forms, and partly hypothetical) which will be presented below are examples among many (mainly in Finnish conditions). For example, in combined planning models various subsidiary goals can be considered if necessary, either restricted as described in Chapter 231, or as fixed goals or constraints if quantifiable as operational units. They by no means need be expressed in terms of money.

Official forest policy and societies promoting private forestry, for example in Finland, seem to tend to maintain the growing stock volume in forests considered »eligible». In this way society tries to influence the forest owners, so that in their goal setting they will weigh chronologically more distant returns, i.e. the increase of property. The stipulation of the Private Forests Act in Finland has a parallel, indirect influence. No wonder that discrepancies arise between small farmer-forest owners' goals of maximizing cash revenues in a planning period, and the tendencies of increasing property, represented for example by advisory organizations.

In Finland, forest ownership at the beginning of 1965 was distributed among private persons (66.5 % of the total area); state (24.7 %); companies, mainly joint-stock forest industry companies (6.3 %); communes and federations of communes (1.5 %); church congregations (0.6 %); and co-operative societies, associations, foundations etc. (0.4 %) (Yearbook of forest statistics 1970, p. 57). The geographical location and the soil of state forests, however, are poorer than the average. Consequently their proportion of the growing stock volume of the country, and especially of the increment, is considerably smaller than the forest area would suggest.

Approximately four-fifths of the Finnish private forests are owned by farmers (Reunala 1970, p. 18). The integrated agricultural and forest holding belongs to a personal enterprise of its owner(s), e.g. a family, of the kind described before, often as their main source of income. The forest forms only a part of the personal enterprise's assets, and the goals for its use are modified according to those of the whole enterprise. Any of the three goals defined in Chapter 232 (p. 43) may represent the financial goal. Especially on small and medium holdings, the great importance of the work earnings of the holding to income and property formation should be emphasized. Private forest holdings not integrated with farming usually are parts of personal enterprises by various professionals. Urbanization is among the reasons why forest holdings have fallen into hands of persons engaged in trades other than farming. Some may have inherited such holdings; others have bought them to invest money, for recreation purposes, etc. These personal enterprises also may seek to achieve, for example, one of the three financial goals described. Especially with persons in high income brackets, maximizing the assets at the end of the planning period may be a frequent goal. However, the goal of maximizing the personal enterprise's overall assets may lead to heavy fellings and hence to low growing stock volumes (and forest values) at the end of the planning period, unless the model contains inhibitory constraints. One reason may be that, during the planning period, the owner finds investment projects which are more profitable than timber growing. He may still desire to hold his forest area, even though after the fellings it may be biologically and mensurationally »under-stocked». He may wish to keep it for recreation or to draw benefit from a continuous real price increase of the forest area, etc.

The vast majority of the forest land owned by the Finnish state is controlled by the National Board of Forestry (Usvaara 1969, p. 21). The other forest ownerships by the state will therefore be disregarded here. The Act on Forest Administration (No. 465/1966) stipulates that the National Board of Forestry shall »manage, protect and use the state-owned forests and land it controls with an increasing yield of timber and a favourable business-economic result as its objectives, while at the same time public

interests are to be borne in mind». Increasing yield of timber probably refers to constantly increasing physical outputs, i.e. felling volumes. Among the goals expressed in terms of money, this is apparently strongly correlated with the tendency to increase the value of assets, that is to increase future revenues. However, the goals set for the management of the forests controlled by the National Board of Forestry in Finland, and those in many other states, show a certain »looseness» and ambiguity (cf. G a n e 1969, p. 11—12). The main goal is often expressed as increasing yield and not in terms of money, etc. It is obvious that national economy viewpoints, for example a tendency towards economic growth, have greatly influenced the definition of the operational goals of the forests owned by Finland and by many other states.

Since the National Board of Forestry is by far the biggest single forest owner in Finland, the executives, officials and workers it employs constitute a powerful interest group compared to employees of the other individual forest owners. The official goals of the National Board of Forestry given above afford a fairly good basis also for the potential achievement of goals by its employees (cf. the general description of this interest group in Chapter 232).

The majority of company-owned forests in Finland are vertically integrated with forest industry units. These are usually firms with many owners, although a given family, for example, often may decisively affect the enterprise policy of the owners. The financial operational goals of company forests must be seen as part of the goals of a firm-type enterprise (cf. F e d k i w 1960, p. 3—4; H ä m ä l ä i n e n 1969, p. 145—152).The goal-setting of a forest industry enterprise is directly or indirectly influenced by all the interest groups of firms, mentioned in Chapter 232. If the decision makers of the firm primarily try to achieve the shareholders' financial goal to the maximal degree, the alternatives are maximizing the dividends of the average shareholder or maximizing the value of the shares (cf. Chapter 232).

The state has issued no legal stipulations concerned separately with forestry practiced by communes or federations of communes. They need a continuous income and must satisfy the timber requirements of their establishments, and especially the forests of urban communities have an important function as recreational areas for the people. These forests must often be used also to ensure employment, and it may be necessary to reduce the achievement degree of business economic goals.

The management of forests owned by the Evangelico-Lutheran congregations is covered by legal stipulations (Act 106/1966 and Statute 253/1966). These forests must be managed and used according to the plan accepted by the Chapter and instructions issued at forestry inspections. »Forestry on a farm constituting a part of the emoluments of a clerical office holder

must be organized purposefully in agreement with the prevailing conditions, and economically with a view to continuous prosperous forestry» (Statute 253/1966). In tangible cases, this statement can be interpreted in many ways. It is evident, however, that it presupposes a volume and composition of forest property at the end of the planning period which ensure that net receipts afterwards probably are not reduced.

Summarizing, instructive legislative stipulations exist in Finland only regarding the immediate goals for the use of forests controlled by the state (primarily the National Board of Forestry) and the Evangelico-Lutheran Congregations. For the Forestry Board, the law seems to propose an increase in the yield of the growing stock, which »converted» into a financial goal variable primarily refers to an increase in property. The majority of the privately owned forests are integrated in other sectors. Integration is mainly horizontal (farms), but also vertical, in forest industries. Forestry in these conditions seeks to achieve the goals of the entire enterprise (farms are usually a part of the owner's personal enterprise). The balance of the private forest holdings belong to personal enterprises which often have no other production. The financial goals depend largely on such things as the owner's other revenues, readiness to consume, his chances and readiness to invest. Each of these, in turn, depends very much on the social and economic structure of society and its change (cf. Quinney 1962).

The goals of forest owners discussed above are mainly financial on the enterprise level. But in the economic units of forestry, the variables affecting the goal function must also be expressed at practical working levels, in terms that the responsible persons understand and can influence, often in physical measurement units, such as cubic metres, cross section area of the growing stock at D 1.3 m, kilometres of road ,etc. (cf. Chapter 232 above, p. 45; Johnston, Grayson and Bradley 1967, p. 110).

33. The traditional profitability models in forestry

The traditional profitability models here refer to those calculation models for determination of profitability and its components in forestry, which have been developed in the sphere of forestry and forest science even before the generalization of the methods of operations research.

The profitability calculations of forestry were created in Central Europe, especially the German language area. Since the 1750's, the basic idea of the cameralistic doctrine was the social and economic objective of forestry, manifested in a continuity principle which considered the benefit of future generations (Speidel 1967, p. 18). Since the early 19th century, liberalistic economic theories contributed to a change. Before 1850, Central

European forestry theory made maximizing private economic profit the goal of forestry (S p e i d e l 1967, p. 18). The result was a forest land rent theory; the best known among its calculation models is the »formula of the value of (bare) forest land» formulated by F a u s t m a n n in 1849 (Faustman's original article, translated into English, is published in a collection of articles edited by G a n e (1968, p. 27—55), who also wrote an extensive introduction). In actual fact, this model is the formula of the classical present value method used in profitability comparisons of single investment projects. It was originally intended to aid the calculation of the expected value of bare land used for afforestation. F a u s t m a n n also developed formulas for the calculation of the expected value of a whole stand and, separately, its growing stock (see the above article edited by G a n e). These formulas and their variants have later been discussed by various authors (see e.g. E n d r e s 1911, p. 52—55; S p e i d e l 1967, p. 177; S t r e y f f e r t 1938, p. 11). The idea underlying the formula for the value of bare forest land is to calculate the present value sum of afforestation investment with the following premises: the time horizon is eternity, the cost of the bare land making the starting point is disregarded, in other words it is considered to have zero value, and rotations are chosen optimally from the viewpoint of the present value sum. To avoid very short rotations, a so-called »forestry rate of interest», lower than the »general» rate, was later introduced in the calculations. H i l e y (1930, p. 101) translated this into English as »the forest per cent» (for details, see Chapter 354). The formula for the expected value of bare forest land has later been used also to determine the rotation, the »maximum land rent rotation» (see e.g. D a v i s 1966, p. 238—242; N y y s s ö n e n 1958, p. 11; S p e i d e l 1967, p. 177).

According to B e n t l e y and T e e g u a r d e n (1965, p. 83): »The assumption peculiar to the Faustmann model is that there is no access to land markets; that is, land is a fixed factor of production, and consequently all economic surplus accrues to land». The article by F a u s t m a n n may lead to this idea. However, the fact is, that although it would be neither possible nor necessary to determine any market value for land in the calculation situation, this does not refute the fact that the capital value of the investment (the s o - c a l l e d land value) indicates the ex ante profitability of the t o t a l investment project (including all production factors). Only it must be borne in mind that it c o n t a i n s also a compensation, indeterminable in detail, for the use of land for timber growing (for details, see Chapter 42).

Used as a tool to plan the management of an (at least apparently) independent forest unit, or one integrated with businesstechnical units of other sectors, the formulas for the expected values of land and of a stand with

growing stock share the weaknesses of the classical partial model with the present value method of the general investment theory. If, in addition to the formula for the bare land expected value, one considers the models also developed by Faustmann for the calculation of the value of a land currently carrying a stand (and their later derivatives, see e.g. Bentley and Teeguarden 1965), it cannot be denied that Faustmann's models substantially also affected the planning of timber growing in a whole forest unit. The principles expressed by the models have been used, not only to determine the maximum land rent rotation and age of maturity, but also for partial comparison of the profitability of various thinning methods, reforestation and other silvicultural measures. Added emphasis is given by the fact that calculations of rotation (period of long-term investment) and maturity (date of replacement of long-term means of production) in forestry are exceptionally important in regulating the economy of the whole unit. This is because the means of production and output are identical, and because forestry is capital-oriented. It is worth noting that the classical partial models for investment calculations in general business economics, discussed previously, were developed decades after the expected value formulas presented by Faustmann (Speidel 1967, p. 18; Gane 1968, p. 5).

Practical foresters used to suspect the results of forest land value obtained from formulas, e.g. the short rotations. As a counterweight, scientists developed a so-called forest rent theory (Speidel 1967, p. 19). Its economic objective is the highest possible continuous annual net revenue from the whole forest unit. Income and expenditure are not discounted to a base year (the rate requirement is not specified). The maximum revenue goal is obtained by certain policies of regeneration, silviculture, thinning and administration, so that the rotation is extended to an age at which the annual increase in the cutting value of growing stock (marginal returns) equals the annual running expenditure (without interest on capital). The forest rent principle presupposes, therefore, that the forest unit is financed either entirely with internal capital, or with external capital at no cost, or that the amount of interest and other expenses for foreign capital are considered irrelevant from the viewpoint of the forest policy choice, as long as the expenses can be paid from the cash of the forest unit. The possibility that cutting revenues were invested outside the forest unit is completely disregarded. When the forest rent principle is applied to the whole forest holding, the profitability calculations must be bound to the normal forest, »the going concern». Otherwise the net revenue is not the same from one year to the next. In reality, however, the forest holdings and their environment (roundwood market etc.) are usually in an »abnormal» state. The forest rent theory is unable to take into account

the cost and loss of income during transition to the constant maximum of forest rent, when the decision must be made while the true forest holding still is in an abnormal state. According to static economic theory (B o u l d i n g 1955, p. 706—707; H i c k s 1946, p. 115; H o n k o 1955, p. 13), the time factor is simply disregarded. Forest rent theory represents an extreme case of the decision models discussed in Chapter 222: there is only one strategy alternative and one environmental condition. This strategy and environmental condition reflect the state reached, a kind of goal achieved. Planning, however, is directed into the future and cannot be confined to outlining the state at the end of the planning period. The goal function must contain, expressly, the events producing cash flows during the planning period, and their effects on the degree of achievement of the goal variable(s) (this is tangibly manifested by the combined model in Chapter 43). This is one of the facts the forest rent theory disregards.

Another classical doctrine worth mentioning among the profitability calculations in forestry is the theory of m a x i m u m p r o f i t a b i l i t y o f a f o r e s t. It tries to calculate the profitability of continuous forestry as the ratio of the annual net revenue from the wood lot and the sum of the separate values of asset components (land and growing stock) of the wood lot (see S t r e y f f e r t 1938, p. 15—18). However, the methods of calculating the value of the asset components are highly disputable and easily lead to irrelevant results. Furthermore, application of this static procedure to true decision making situations is subject to the same difficulties as the forest rent theory.

Considerable progress was implied by the introduction of various budgeting methods into planning of the operations of a true forestry unit in its entirety. Their predecessors in the forestry sector were the forestry plans according to which fellings, silvicultural measures, road construction etc. were planned for the next 10 or 20 years, mainly in terms of physical measurement units. The development of planning budgets operating with monetary values has doubtless been affected by those forest utilization plans (E n d r e s 1911, p. 150: »Abnutzungsplan»), which were and are made to serve as bases for calculating the discounting value of a forest area. The methods developed by O s t w a l d (1931, particularly p. 264—301) and by K r i e g e r (1929, 1956, 1960) on the basis of Ostwald's ideas, were intended for use especially on large and fairly large forest holdings. Their emphasis was placed on the regulation of annual monetary revenues and calculation of results rather than on the selection of the most profitable forest utilization alternatives. Broadly speaking, O s t w a l d 's method calculates a gross forest rent, or to use current terminology, cutting return annuity for 120 years on the basis of the cutting returns estimated by periods of 10—20 years. The true annual cutting returns differ from

this computed average return. As a result, Ostwald founds a reserve fund by which the forest owner's annual money takings can be smoothed, to make them independent of the irregular cutting returns. Consequently, in the re-investment of released funds, he takes a step toward the models termed in the foregoing as combined partial models. The »Ostwald test», developed by K r i e g e r, is also based on the calculation of a forest holding's even cutting revenue annuities (»Messziffer») from the present value sum, »dynamic sum» of periodic cutting returns (K r i e g e r 1956, 1960). By modifying the final cutting dates of the stands in the forest holding (the recommended rotations), on which the calculations are based, the values obtained for cutting return annuities vary. On the other hand, a more or less uniform distribution of true cutting returns among the periods is obtained.

The models of classical forest economics belong to the group of descriptive models described above in Chapter 221. As already mentioned, when deriving these models the analyst (scientist) himself has to define the premises of his model, including the goals of the imagined economic entrepreneur. However, the representatives of classical forest economics were not satisfied with descriptions of the consequences, and profitability ranking of the operational alternatives based on alternative assumed goals. Instead, they began fruitless disputes of the mutual preferences of the goal contents in different models. Similar features were noticeable also in general business economics, especially in the early decades of the 20th century (K o s i o l 1966, p. 240).

In the 1950s and 1960s, different (and differently named) procedures to build economic plans for forest holdings, or investment and other budgets have been developed in several countries (e.g. B a r r a c l o u g h and G o u l d 1955; B j o r å and D y r i n g 1966; F e d k i w 1960; J ø r g e n s e n 1964, 1969; v o n M a l m b o r g 1965 a; N e r s t e n 1965). A general characteristic of these methods is that the number of alternatives compared is relatively small in order that the cost of calculation be kept reasonable. In addition to the main criterion, they often try to take into account such things as use of the labour force on the farm (work earnings), liquidity etc. J ø r g e n s e n (1964, 1969) drafts the investment budget for a private forest owner at a given date, making both the various investment projects (investment preference) and consumption (consumption preference) compete for the forest owner's liquid funds. The consumption, investment and financing budgets are determined on the basis of a liquidity diagram (J ø r g e n s e n 1964, p. 390, 1969, p. 46). The principle is the same as D e a n (1962) used when he made solely an investment and financing budget as a function of capital supply with rising cost of capital (Chapter 243). F e d k i w (1960) also, in planning the use of forests and

investments for a forest industry enterprise, based his work on Dean's principles of capital budgeting. The special character of growing stock, which is both a production factor of fixed assets type and a marketable product, in the short run doubtless facilitates the possibilities of internal financing. On the other hand, it emphatically brings forth the weakness of the static budget (spanning one period only).

The budget alternative, which is compiled with the aid of traditional planning methods and is to be realized, is by no means an optimum. A satisfactory solution has been achieved with due consideration of various activities and restrictions. But a formal optimum at least can be reached by the planning methods of operational analysis (e.g. linear programming and dynamic programming) which have been used in different parts of the world in comparisons of the profitability of separate and integrated forestry units (see Schöpfer and Höfle 1970).

34. Suitability of general profitability models in forestry

Here as well, profitability models refer to the model types used especially in planning the use of capital, and therefore with a time dimension, described in Chapter 24. When the possibilities of applying them for profitability calculations of forestry are considered, the special features of forestry units must naturally be taken into account. This is necessary even when calculation procedures, common in themselves, are applied to economic units of any sector. Things to be considered include their technological, institutional etc. structure and the society in which the units operate. In every sector, the calculation models of different types, their variables and parameters assume different forms, contents and weighting.

The classical partial models of Chapter 243 (in the first place, the internal rate of return method and the present value method) are applicable to profitability comparisons of the stands in the forest holding with the same conditions and restrictions, in principle, as to other partial profitability studies in enterprises. The preceding Chapter (33, p. 68) revealed that traditional principles of making an investment budget have been applied to planning the economy of a forest owner. The difficulties in applying the combined planning models based on the most modern methods are not really due to the principles, but rather to incomplete information (data material). This is a result of such things as the vast variabilities in the production function of the forest. Research into the forest yield, forest biology and technology today can supply only a limited amount of quantitative material on this function.

35. Essential problems relating to the variables and parameters in the ex ante profitability models of timber growing

351. *General*

The treatment of the model element problems in forestry (Chapters 351—354) will be held on a relatively general level. The methods by which the problems were solved in the empirical part of the present study are broadly described. The details for each variable and parameter can be found in the subchapters of Chapter 4.

In a decision making situation of real life the decision field is usually very complicated, for at least the following reasons (cf. G ä f g e n 1968, p. 199):

1. A large number of operational alternatives (strategies) is usually available for choice.
2. Single actions can be combined differently into alternatives both successively and in parallel. This was seen above in the discussion of classical partial models and combined models.
3. Every alternative has numerous consequences of different quality, which can be evaluated by different criteria. These consequences also have both (a) a chronological and (b) a factual dimension. The consequences affect the interests of many outside subjects. Furthermore it could be added that:
4. The decision maker often has the possibility, at least partially, to choose the environment of his operations and decision making (e.g. when he chooses the location of a new mill, buys a forest lot, etc.).

When a model is abstracted from this complicated whole, the multidimensional decision field represented by the model must be constrained, both for factual dimensions and the time dimension. The borderlines of the area described by the model can be called its h o r i z o n s. The contents of the following Chapters 352—354 are essentially concerned with these horizon problems. To start with, it is useful fo define the following concepts of horizon (cf. G ä f g e n 1968, p. 201):

1. Value horizon, i.e. the factual or temporal limit beyond which the consequences possibly produced by the alternatives are irrelevant if measured by the goal variables (value criteria). For example, when the profitability of a single investment object is determined, the present value of chronologically distant net revenues can be negligible.
2. The constancy horizon of the value system, i.e. the time limit within which the value system of the enterprise is constant.

3. The objective technological horizon, i.e. the factual or temporal limit beyond which the alternative, according to the model, has only infinitely small factual consequences, or none at all. The consequences of the alternative in question cease. It is known, for example, that after five years the whole forest area must be sold and becomes an airfield. Cuttings can be carried out until the date of relinquishment, and the last business entry is the sale of the area.
4. Information horizon, i.e. the subjective technological horizon. The limit beyond which information on consequences, »adequate» for the construction of a model, is no longer available. In the present author's opinion, the limit can be both factual and chronological. It is factual in that information incomplete in varying degrees, and the heavy expenses of finding information and of the computational process, etc., make it necessary to eliminate variables and parameters of the model from the outset. This is one cause of the differences between the classical partial models and combined models, and between the latter and the total models. For the elements excluded at the outset, the chronological information horizon = 0, whereas that for the variables and parameters really contained in the model is due to the fact that information generally becomes less complete, the farther in the future are the phenomena concerned.

Especially on the basis of Chapter 31, it can be said that all the foregoing is valid both for the profitability models in forestry in general and for timber growing models separately. In the profitability models of timber growing the chronological horizons and the time factor also otherwise (Chapter 353) have a particularly great emphasis. Since the production factor and production output are physically identical, the number of production alternatives, and hence also technological consequences, is infinite in principle even in one stand. In a forest holding their number still increases owing to the biological, technical and economic connections between the stands [G ä f g e n (1968, p. 201) in general terms: the technological connections].

Forecasting the technological consequences of timber growing lies on a relatively firm basis in that the main product, at least in the true roundwood production districts, with fair certainty will be the same, that is roundwood, until a distant future. How varied the available production functions describing the production alternatives are depends on the intensity of research into forest yield in each country.

The problems of timber growing models discussed in Chapters 352 and 353 concern both the classical partial models and the combined models. The calculation rate (Chapter 354), on the other hand, is mainly a problem of the classical partial models.

352. *Incompleteness in the information and how to allow for it in the model*

Model construction needs information on its variables and the relations between them. This information mostly is incomplete. From the decision maker's point of view, at least the following aspects can be distinguished in the incompleteness of information (cf. Kosiol 1966, p. 198—200): (1) shortage, i.e. information important from the point of view of the problem is absent — there are gaps in the information; (2) inaccuracy, i.e. the information is summary. The information given says, for example, that the current volume growth of a stand is 3—4 solid cu.m./ha. The more inaccurate the form of information given, the more reliable the information (Kosiol 1966, p. 199). An example is provided by the reliability ranges of statistical tests compared, for example, with the mean value alone; (3) uncertainty, i.e. information corresponds more or less incompletely to the empirical reality; (4) doubtfulness, i.e. the decision maker believes that information is incomplete in the ways mentioned under Items (1) — (3) above.

Shortage of information is a relative concept. The part played by one and the same shortage depends greatly on the purpose for which information is used, and by whom. The more advanced the theory of some economic sector, the easier it is to »patch» information gaps and use even relatively inaccurate empirical material. Empirical shortages can be replaced with the aid of a good theory. In decision models directed to the future, the uncertainty of information means incomplete information of future developments (cf. D. Schneider 1970, p. 63). The future is ahead, and therefore no empirical information concerning exactly it is available. Despite uncertainty, decisions must be made and also calculations to serve as their basis. It can be said that uncertainty of varying degree does make deliberated decision necessary; the decision can no longer be derived automatically from an exact criterion outcome value of a deterministic calculation. The amount of information usually can be increased and its quality improved by paying more for data collection. In other words, the information shortages described can be eliminated. The time available for decision making, and the cost benefit ratio in the collection of information set a limit to appropriate steps.

In the mathematic-statistical decision making theory, the decision situations are classified on the basis of the degree of certainty the decision maker attributes to information at his disposal. The classification often used in the literature is the following (cf. Menges 1969, p. 176—178; Naylor and Vernon 1969, p. 296—297; Ruuhela 1965, p. 67; D. Schneider 1970, p. 66—67):

1. Decision making when certainty prevails; only one environmental condition Z_j (see Chapter 222) is considered possible. With each of the strategy alternatives, only one outcome can be obtained ($p_j = 1$).

2. Decision making in risk situations:
   21. The decision maker knows a finite number of possible environmental conditions $Z_1, \ldots, Z_n$. From empirical material, he can determine the incidence probability of each environmental condition, termed objective probabilities (for the concepts of probability and procedures for probability determination in risk situations of decision making, see Fishburn 1964, p. 131—201; Manninen 1963, p. 62—63; Menges 1969, p. 21—27, 191—194; Schneeweiss 1967, p. 27—29; D. Schneider 1970, p. 72—82). The decision maker knows the probability distribution of the different environmental conditions, P: $(p_1, \ldots, p_n)$, where $\sum_{j=1}^{n} p_j = 1$ and $p_j \geq 0$; $j = 1, \ldots, n$.
   22. On the basis of such things as his expertise and intuition the decision maker can determine at least approximately the so-called subjective probability of every environmental condition $Z_1, \ldots, Z_n$.
3. Decision making when uncertainty prevails.
   The alternative conditions of environment, $Z_1, \ldots, Z_n$ are known but not even subjective probabilities can be formed for them. All these environmental conditions are equally possible. Schneeweiss (1967, p. 12) writes of uncertainty in a narrower sense, a concept in which he — referring to Knight (1921) — also includes the decision situation of Item 22. In the following, uncertainty in a decision making situation refers to a situation in which the possible environmental conditions are known but their (subjective) incidence probabilities have not been determined, or cannot be. Schneeweiss (1967, p. 12) specifies yet another type of decision making situation, the game situation, in which environmental conditions are strategies of rational adversaries.

It is generally considered that decision making situations in enterprises, for example, because of continuous change in environmental conditions are largely unique, and personal factors are of importance for the decision. For this reason, objective probabilities based on empirical observations usually cannot be determined for the different environmental conditions, and therefore not even for the possible outcomes (see Naylor and Vernon 1969, p. 298—300; D. Schneider 1970, p. 68). This is valid especially for investment and financial decisions extending far into the future. Of risk situations, only a version determined by subjective

probabilities usually enters into question in an enterprise. The degree of uncertainty is even higher in cases in which the decision maker is unable, even subjectively, to weigh the potential outcomes of the alternatives.

When the field of action of decision making theory is defined, it is important to bear in mind that the theory is unable to eliminate the uncertainty of decision making. In decision making theory, therefore, it is not a question of searching and making such a decision which afterwards proves to be the most correct possible, although naturally even in this sense a decision as »good» as possible is sought. However, the main thing is to find a decision which, on the basis of information available, in advance seems the most rational and which therefore can be defended on these grounds even afterwards (D. Schneider 1970, p. 65). Before rationality can be assessed, the available strategies, the possible environmental conditions, their incidence probabilities, the corresponding outcomes, and the decision maker's attitude to risk must all be known. These provide a basis for determinations of the risk accompanying the decision. In economics and decision making theory, risk has meant many different things at different times and in different connections. In connection with decision making, risk can be defined for example as divergence between the true (ex post) outcome from the expected value of the possible outcomes (cf. D. Schneider 1970, p. 128). Since the true outcome is not known in advance, the decision maker's attitude to risk, especially in unique problems, becomes the central problem in decision making. These attitudes can be grouped approximately as follows: (1) Risk attraction, that is the decision maker prefers the risk-laden alternative (a) to the »certainty equivalent» (e) or its expected value (see result matrix in Chapter 222, p. 27), that is $(a \succ e)$. It may be recalled that the expected value in this situation is:

$$EV(R_i) = \sum_{j=1}^{n} p_j R_{ij}; \quad (i = 1, \ldots, k);$$ (2) Risk neutrality, i.e. $a \backsim e$; (3) Risk aversion, that is the decision maker prefers the certainty equivalent to carrying out the alternative $(a \prec e)$.

Sciences studying decision making (including business economics) have developed axioms with which the decision maker could confine his subjective attitude to the risk (risk preparedness) only to that part of decision making where the objective means are exhausted. Axioms help to check whether various rules and criteria developed to support decision making under the prevalence of uncertainty (in the narrow sense) and risk correspond to certain logical standards (see Laukkanen 1968, p. 161—162; Luce and Raiffa 1958, p. 286—298; D. Schneider 1970, p. 90—104).

Generally, solution of a decision problem in a risk situation (Items 21 and 22 above) can be said to presuppose:

(1) that the possible outcomes from the different alternatives, and their probabilities, are known;

(2) that the risk utility indicating the »value» of an alternative for the decision maker can be determined for every alternative on the basis of the probabilities of the various outcomes and the decision maker's risk preparedness.

A remarkable field of study in which efforts have been made to approach the decision maker's choices in a risk situation is the so-called utility theory, often mentioned in connection with the names von Neumann and Morgenstern. The utility of the risk alternatives cannot be measured unless the decision maker's utility function can be determined (for the determination techniques in simple cases, see Naylor and Vernon 1969, p. 310; D. Schneider 1970, p. 104—108). If this is so, the von Neumann—Morgenstern utility of the risk alternatives, i.e. the expected value of the utility, can be determined from the following formula (cf. Naylor and Vernon 1969, p. 311):

$$(2) \quad U_i = \sum_{j=1}^{n} U(R_{ij})\, p_j, \text{ where}$$

U_i = the expected value of the utility of the i^{th} risk alternative for the decision maker;

$(j = 1, \ldots, n)$;

$U(R_{ij})$ = the utility of the result R_{ij} $(i = 1, \ldots, k;\ j = 1, \ldots, n)$;

$p_1, \ldots, p_j, \ldots, p_n$ = the (subjective) probabilities corresponding to the environmental conditions $Z_1, \ldots, Z_j, \ldots, Z_n$.

The recommendation for the decision maker to choose that alternative giving the maximum expected utility, if he wishes to act logically, is based on the preferences shown by the utility function he expressed in advance. The financial maximizing goals of Chapter 232, in a risk situation, become maximizing goals of the corresponding utilities. The use of the expected value of utility as a criterion of selection in a risk situation is based on the very fact that the decision maker first, with his utility function, expresses the surely obtainable sum of money which to him is »equal in value» to the probability distribution of the outcomes of the alternative. The decision maker's attitude toward risk is manifested by the expected value of utility as related to the expected value of the outcomes.

It is evident from the above that the use of only the expected value of the outcomes as a criterion of selection indicates risk neutrality in the decision maker's behaviour. When acting in this way, the decision maker gives equal value, for example, to investment alternatives with expected values of the present value in Alternative $A = 0.1 \times (-100) + 0.9 \times 200 = 170$ and in Alternative $B = 0.5 \times 150 + 0.5 \times 190 = 170$. According to the expected value criterion, the best of several alternatives is the one the

expected value of which is at its maximum or at its minimum. The latter enters into question at such times as when the goal is to minimize certain costs. The best among combinations of several independent projects is the one in which the sum of the expected values of the projects is at its maximum or minimum. Using only the expected value as a criterion of selection, in the often unique decisions of an enterprise, can with good reason be criticized (Naylor and Vernon 1969, p. 306). Originally, the criterion began to be applied in circumstances in which environmental conditions recurred randomly on numerous occasions (gambling, insurance etc.). According to the Law of Large Numbers, the mean value of the true outcomes then approaches the expected value of outcomes as time goes on (so-called quasi certainty; cf. Gäfgen 1968, p. 108). On the other hand, applying the Law of Large Numbers presupposes that the successive actions (measures of »the same kind», projects, etc.) are mutually independent, which seldom is the case in enterprises.

Attempts have also been made to express the risk inherent in action alternatives by using as choice criterion the expected value plus some measure of dispersion, for example, variance or standard deviation (see D. Schneider 1970, p. 128 and his literature references). This method therefore condenses information available to the decision maker on the risk situation. The parameters must be interpreted so that all alternatives with the same expected value of outcomes and the same dispersion are equally good (their utility to the decision maker is the same). When the decision maker is a risk-avoider, it is true that, other things being equal, utility grows as the expected value increases and diminishes as the standard deviation increases. The utility function, which corresponds to the decision making rule based on expected value and standard deviation, is a quadratic function of the income (cf. Hax 1970, p. 132; Schneeweiss 1967, p. 113; D. Schneider 1970, p. 129). The decrease in (risk) marginal utility in relation to the income is constant, which naturally cannot be considered a generally applicable form of behaviour in risk aversion (D. Schneider 1970, p. 129, and his literature references).

Hillier (1963) states, initially, that although in practice the investment calculations of individual projects are usually carried out using single-valued estimates of the relevant variables, subjective probabilities, though incompletely defined, are often used as auxiliaries in the estimation. However, since the calculations are carried out as single valued estimates, some information is lost. Therefore Hillier's logical conclusion is that investment calculations should be carried out using the subjective probability distributions of the relevant variables, and the profitability criterion should accordingly be expressed in terms of a probability distribution. Hillier calculates the expected value and variance for this

probability distribution. Calculations give the decision maker additional information on the risk, beyond that provided, for example, by the present value of the single-valued discount method or the internal rate of return method, if among other things, the variables are normally distributed.

The model developed by Hertz (1964) for analysing the risk of a single investment project is formally of the same type as that of Hillier. However, Hertz uses the technique of computer simulation in risk analysis of the most uncertain variables and those that most essentially affect the value of the criterion of the investment model. The (subjective) probability distributions of the variables most essentially influencing, for example, the present value of the investment model are determined first; they may have an arbitrary form. The computer then generates a random variable from the distribution of every crucial variable, and on the basis of these figures calculates the present value of the investment. This is continued and repeated until there is the necessary number of outputs to clarify the distribution of the present value (Naylor and Vernon 1969, p. 416). The decision maker's evaluation of the probability distributions of the different alternatives depends on his attitude toward risk. Hertz's simulation model can also allow for the interdependence of the variables.

To find decision making rules in which risk is considered for individual decision problems requiring investment calculations with classical partial models, it is useful first to define these situations. The following main situations can be distinguished: (a) recurrently emerging problems which cannot have been considered in the enterprise's traditional investment budget or its combined model, or (b) profitability comparisons of the detailed method of implementing a project that has been accepted in large-scale planning (for example, afforestation has been decided, and the method must be chosen). Only in exceptional cases there is a question of such decisions, which can jeopardize the existence of the enterprise (Chapter 222 above). Simple decision making rules can be used for individual decisions of relatively small importance. If the necessary information on outcomes and their probabilities is available at reasonable cost, the expected value of the outcomes should be considered. The decision maker here shows — especially owing to the relatively small importance of the decision — a risk neutrality in his decision making.

In reality there are many enterprises with no overall planning as yet. Calculations concerning individual decisions then receive much more weight than under (a) and (b) above. If a quantitative idea is desired of the risk involved at least in the most essential decisions, some yardstick of the risk must be used (D. Schneider 1970, p. 132). A means is afforded by the expected value of the outcome distribution and standard deviation with the implicit utility function assumptions outlined above.

A simple and practicable method for approximate investigation of the risk connected with alternatives is sensitivity analysis. According to Morris (1964, p. 323): ... »it is used primarily as a supplement to judgments about risky decisions». When it is applied to such things as investment calculations, the criterion values of the alternatives are first calculated by means of deterministic partial models. The next question studied is the range within which the parameters and environmental variables of the calculation may vary without the best alternative being displaced. The variables and parameters are given different numerical values, and the influence of these changes on the profitability criterion of the alternatives is ascertained. The procedure has long been known, for example, in investment theory under the name of critical value calculation (see E. Schneider 1964, p. 62—66). With other things equal, every variable or parameter is allowed to change in turn, and its »critical» value is recorded, the value above or below which the ranking of profitability of the alternatives perhaps changes. Among the most common variables are the calculation rate of interest, life span of a property (for example machine), or more generally, the time horizon of the investment, the price of the product or the quantity produced, its various costs, etc. Sensitivity analysis naturally need not necessarily be extended to ascertaining the critical points of every variable and parameter. For instance, with classical partial models, it suffices that the present value sum or internal rate of return of the alternatives is calculated with only a few possible values of variables and parameters. This gives an idea of the intensity and trend of the influence of these factors on the criterion value of the different alternatives. If possible, trials can be continued, for example, to find the critical values of the most essential factors. A thorough sensitivity analysis is highly reminiscent of the simulation procedure and therefore narrows the gap between analytically solved investment models and simulation models (cf. Starr 1971, p. 57). Sensitivity analysis can lead to the result that a given alternative is optimal with any combination of environmental variables and parameters that can be considered possible. Often, however, the analysis gives a negative result. In other words, it has been found that there are combinations of environmental variables and parameters, which lead to an optimum alternative different from that obtained from calculations with the original single-valued variables and parameters. Sensitivity analysis cannot help to solve this decision problem (Hax 1970, p. 131).

In practice, incomplete advance knowledge of investment calculations and the resulting risk are often taken into consideration by including in the calculation, separately, the income-outlay consequences of each alternative only up to a certain date (Naylor and Vernon 1969, p. 408). This is an attempt to reduce the impression of the project's profitability.

The procedure seems to be based on the following assumptions:

(1) Some kind of an approximate utility is determined for each alternative.
(2) The attitude to risk is that of the risk-avoider.
(3) The amount of risk throughout the lifespan of the project is considered to be the value of net revenues remaining beyond an »artificial» time horizon, in single-valued units of the criterion (for example, the present value sum in monetary units).

However, it is very difficult to determine the point of time from which onwards the criterion value of the net revenue to be excluded equals the risk deduction resulting from the decision maker's desire to avoid risk. Interpretation of the results of the calculation goes astray if it is forgotten that they represent a desire to calculate the utility of the risk-avoider, and not the risk-neutral criterion value obtained by the deterministic investment models. Using this procedure naturally requires the lifespans of the several investment alternatives to be abbreviated by different amounts. The proportion of this shortening to the total lifespan usually is different for each alternative. This leads readily to a contradiction, for example with the basic premises of the classical partial models given in Chapter 243. Restricting the movement of the model in one dimension easily causes confusion and disproportions in the whole system the model represents, and in its bases. Externally the same, the problem of time will be discussed again in Chapter 353. However, that chapter concerns the influence of other factors as well as insufficient advance knowledge on the time horizon of the model.

Yet another method for taking into account the risk of individual investment projects in practical calculations is to allow for the risk of an alternative by means of r i s k d i s c o u n t i n g. The shortening of the time horizon, described above, in a way is a summary method of this type. But here the risk discounts are produced by changes other than that of the time variable. In classical partial models, for example, the following methods are used: (a) systematic discounts in components affecting the revenue flows, or corresponding additions to those affecting the expenditure flows; (b) raising the calculation rate by a »risk factor». A risk discounting according to Item (a) can be considered a useful method, in principle, when the decision maker is a risk-avoider and can determine the probability distribution of the variable or parameter. However, the method does not guarantee that the risk discounting were applied from one decision to another in any consistent manner, since the (risk) utility function is not explicitly expressed (cf. N a y l o r and V e r n o n 1969, p. 304—305). The method of Item (b), raising the calculation rate by a risk factor is one of the most common ways used in practice when trying to make sure that the alternative should not seem »too» profitable. When this method is applied, rate of interest i in the dis-

counting formula (1) of p. 49 is replaced by the sum i + δ, in which δ = risk factor as a decimal (see Baumol 1965, p. 454). Depending on the relative size of the risk factor, its use is a symptom of the decision maker's weaker or stronger desire to avoid risk. In most cases the risk factor is determined summarily without an analysis like that of the utility function. When applied to partial investment models the method presupposes, furthermore, that the risk grows, for example, as a function of the lifespan of the investment project according to the compound interest principle, an assumption which is far from being always valid. For example, in forest planting in North Finland perhaps the worst cause of risk is the failure of planting. Therefore, if the calculation situation of a partial calculation model refers to the bare land phase of the stand, the risk discount apparently is mainly applied to incorrect cash flows. The use of a risk factor coupled to the calculation rate in classical partial models, as a measure of risk aversion, is therefore a very schematic procedure. At its best, it requires careful study of the chronological distribution of the cash flows attending the investment project.

Markowitz (1952, 1959) developed a model for the selection of an optimal security portfolio. This model, at least in principle, has a certain importance from the viewpoint of drafting real investment programs. Among other things it explicitly takes into account how the risk of a whole investment programme is determined with the use of the risks of individual investment projects (Hax 1970, p. 133). The stochastic dependences between investment projects of different »kinds» are considered in the co-variances of their returns. The important viewpoint of a diversification of the projects of an investment budget is herewith introduced into the selection (Hax 1970, p. 133; Naylor and Vernon 1969, p. 418—419). As is known, diversification means distribution of resources to several independent lines of action. However, according to Manninen (1965, p. 293), Markowitz's model and other selection models built on the corresponding principle have so many weaknesses that they are hardly suited to serve as general selection models at the practical level in a risk situation.

A linear programming model solves an optimal investment budget, at the beginning of the planning period, simultaneously for the different subperiods (e.g. years). Multiperiodic models of linear programming applied in practice are usually deterministic in form. The variables and parameters of the model appear as certain or nearly certain, or quasi certain. The deterministic model is solved, and a sensitivity analysis is used to study whether the solution is sensitive to parameter changes (Jääskeläinen 1971, p. 29—33; Lindgren and Näslund 1968, p. 35—45; Hillier and Lieberman 1968, p. 164—166). In the sensitivity analysis of linear programming, an essential part is played by the concept of shadow prices or dual variables. The concept of shadow price is connected with the resource constraints of

the model. It indicates how much the value of the goal function of the original task changes if the constant on the righthand side of the constraint equation or inequality changes by one unit. Shadow price analyses, however, are only possible when the parameter change is so small that the optimum programme after the change still contains in positive form the same decision variables (such as stands to be cut, products to be made, securities to be bought, etc.) as the original solution did. But the mutual quantitative ratios of the decision variables in the optimum programme usually change if the value of the constraint is modified. Systematic methods of sensitivity analysis have also been developed, for example for linear programming (the so-called parametric linear programming; see Hillier and Lieberman 1968, p. 499—504). »Sensitivity analysis can be conducted, for example, by suitable parametrization techniques which have been developed to provide efficient ways of studying program responses to variations in the data» (Jääskeläinen 1966, p. 155). Hax (1970, p. 130—131) has expressed doubts concerning the appropriateness of using sensitivity analysis when an optimal multiperiodic investment budget must be compiled with the aid of a linear programming model of deterministic form. The criticism mainly claims that deterministic planning, complemented with sensitivity analysis, does not take into account (fails to plan) the way in which the investment programme is adapted to changing circumstances. In the course of the planning period some values may become different from those estimated at its beginning.

It is more difficult to use a stochastic model than a deterministic one, for example, in linear programming. Firstly, because the goal function is stochastic, the above mentioned decision maker's utility function must be determined. The goal function therefore tends to become non-linear, which complicates the solution of the model (Jääskeläinen 1971, p. 164). In addition, determination of even the subjective probability distributions of the variables and parameters can be difficult.

The best known methods of linear programming, with structures of the model taking the risk factor into account, are: (a) stochastic linear programming; (b) so-called linear programming under uncertainty (in reality, this means the risk situation); (c) two-stage optimizing, and (d) risk-constrained programming. Here reference is made to the relevant literature (for example Jääskeläinen 1966, p. 154—182; 1971, p. 162—182; Lindgren and Näslund 1968, p. 67—71; Näslund 1967, and their bibliographies).

The literature has also presented many criteria for decision making in conditions of uncertainty, that is in situations where the probabilities connected with outcomes are not known. These criteria of decision making in conditions of uncertainty are based on the decision maker's attitude of

principle toward uncertainty. They are therefore »criteria of criteria» (of outcomes) (cf. Radner and Marschak 1954, p. 61). The following is a brief list of choice criteria (principles) proposed for a situation of uncertainty (see for example Manninen 1965, p. 282—284; Morris 1964, p. 382—395; Naylor and Vernon 1969, p. 314—318; Ruuhela 1965, p. 66—71; D. Schneider 1970, p. 68, 121—124):

(a) The criterion of Laplace, or of insufficient reason; the alternative is chosen which has the highest mean of the possible outcomes.

(b) The maximin (profit) or minimax (cost), Wald's criterion (the pessimist's criterion); the alternative chosen is the one with which the worst possible outcome is better than that with the other alternatives.

(c) The maximax criterion (the optimist's criterion); the alternative is chosen with which the best (maximum) possible outcome is better than that with the other alternatives.

(d) Hurwicz's criterion; the weighted mean of the best and worst outcome is calculated for every alternative, and the one is chosen for which this mean is highest. The decision maker's attitude often affects the final choice and is manifested in the weight figures of the outcomes. On the basis of its principle, this criterion remains between the criteria represented by Items (b) and (c).

(e) Savage's or minimax regret criterion; the alternative for which the biggest possible loss (regret) is smaller than for the other alternatives is chosen. The regret is the loss (outcome lost) resulting from failure to choose the alternative which, had a particular state of affairs materialized, would have produced the most profitable outcome.

The selection criteria of decision making in conditions of uncertainty are based on a subjective and usually one-sided appraisal of the possible outcomes. D. Schneider (1970, p. 121—124) is one of those who have discussed the weaknesses and contradictions of these selection criteria in the light of various axioms of decision making. It can be said, however, that the decision maker has the chance in conditions of uncertainty to test what choices the different choice criteria would bring. The most objective of these selection criteria is perhaps Laplace's criterion, which is to be considered a special case of the expected value criterion in risk situations. On the other hand, it is obvious that the decision maker mostly has to deliberate upon whether determination of the subjective probabilities of the different outcomes is possible, that is to say, whether decision making in conditions of uncertainty or a risk situation is at hand.

Forestry usually involves no decision possibilities of the type discussed in Chapter 222, with consequences that might jeopardize the entire enterprise. For example, catastrophic consequences of nature can be compensated for by insurance. However, the special character of the growing stock can lead the forestry entrepreneur »insidiously» into difficulties. A person, largely dependent on forest earnings, may cut a large proportion of the growing stock of his forest holding and spend the money on consumption. He may as a result, face difficulties very soon since the later cutting revenues are small, while silvicultural works following cuttings are largely not performed and thus the corresponding disbursements unpaid. In Finnish conditions, furthermore, he must also continuously pay the forest tax, which is independent of the returns from the forest holding. On the other hand, when forestry is only a relatively modest part of the economy of a personal enterprise or firm, the alternatives of timber growing usually cannot lead the enterprise to catastrophe. Nevertheless, for individual stands incorrect or inadequate consideration of such things as biological factors can cause losses or increased expenses, compared with the revenue and expenditure consequences which are considered »normal».

Timber growing takes a long time. As a result, f o r e c a s t s of the future development of environmental variables are required to measure the influence of alternative cutting and silvicultural measures using the achievement degrees of the profitability calculation model. From the viewpoint of the forest owner's decision making, variables associated with phenomena outside the forest area are usually environmental variables whose development he cannot appreciably affect. When he plans the cutting and silvicultural measures for his forest land he must take into consideration how nature responds or reacts to his various strategies. The various forestry variables or combinations of variables which, according to their basic character, are e n v i r o n m e n t a l v a r i a b l e s, can be grouped, for example, as follows:

1. Component factors of the forestry production function, or the so-called quantity components of profitability calculations.
   (a) Growth and other factors of the forest, that is n a t u r e.
   (b) The t e c h n o l o g i e s of timber growing and harvesting, and of forest holding management, and their development.

2. Variables influencing evaluation of the quantity components of profitability calculations in forestry.
   (a) P r i c e l e v e l of roundwood and its development.
   (b) P r i c e l e v e l s of production factors for timber growing and harvesting, and for the quantity components in forest holding management (human work, machines, etc.), and their development.

(c) The general economic, social and legislative development of society, and its influence on the forest owner's personal freedom of movement, social obligations and the relative profitability of the use of different production factors (including social security costs).

The uncertainty associated with the environmental variables of Item 1a can be reduced by silvicultural and yield studies, converting environmental variables increasingly into the decision maker's strategic variables. If the statistical premises for the application of a given production function to each tangible problem do exist, the yield forecast approaches stochastic quasi certainty (see G ä f g e n 1968, p. 108). This becomes more probable as it is applied to larger numbers of stands (e.g. larger holdings). Technological development is composed of several variables. In constructing a particular profitability model, it is important that the forestry entrepreneur chooses the most favourable technical combinations for the achievement of the goal, and that he is able to forecast them as well as possible within the time perspective of the model. From various technological elements he compiles alternative solutions of timber harvesting, silviculture and administration, which best help him to achieve the goal when priced with value components.

What was said above in this chapter about considering the risk and uncertainty in business economic (especially multiperiodic) calculations is valid in the main also for the profitability calculations of timber growing. The long production period in timber growing, however, brings all the above aspects of incomplete information in calculation models to the fore. It will depend on the decision maker's subjective deliberation, perhaps even more than »usual», whether and in which form he finds it reasonable to carry out multiperiodic calculations for timber growing. A factor in favour of such calculations is that their most essential purpose often is not the absolute value of the goal variable in itself, but the determination of the p r o f i t a b i l i t y r a n k i n g of the mutually exclusive alternatives of forest growing and utilization. This is not sufficient when the forest holding is seen only as part of the whole enterprise or other economic unit. In such a case, relatively detailed deliberation can cover only a short planning period. The alternatives of environmental conditions which the decision maker constructs from the various environmental variables also depend on the decision maker's deliberation, and he must furthermore consider whether he can estimate probabilities of their realization.

The s e n s i t i v i t y a n a l y s i s, discussed above, is the procedure especially applicable in practice to the profitability calculations of timber growing based on the classical partial models. It suits the timber growing calculations fairly well, since the number of essential variables affecting

the degree of achievement of the goal variable is not great. In the profitability calculations of the present study, based on classical partial models, the calculations using the different stumpage price levels of the various parts of the Lake District of Finland, in a way represent sensitivity analysis. The mean stumpage prices of the Lake District of Finland, its minimum stumpage prices by subregions, and the corresponding maximum stumpage prices were then separately applied to the calculation models (see Table 5, p. 119). Relatively thorough studies of the main trends and cycles in stumpage prices and costs were made. After this, in the framework of the mean price and cost levels of the Lake District of Finland, trials were made of the influence of the environmental condition alternatives of Table 5 on the profitability ranking of the cutting, management and silvicultural strategies.

The example of empirical application of the combined model in this study is the deterministic multiperiodic model of linear programming. In the planning situation of this case, for example, it is no doubt possible to apply some procedures allowing for the risk. The procedures described in the literature quoted above might be appropriate, although it is not always easy to obtain the necessary data material.

353. *The time problem*

The role of time in profitability calculations, and its particular importance in those concerned with forestry, has already been pointed out in earlier chapters. It can be seen from Fig. 8, modified on the basis of H e i n e n 's (1968, p. 162) report, how time can be present and be taken into account in the economic model. First, a variable of the model can be expressed in time units, for example the rotation of a stand in years. This presence of time in the model can be expressed with Part I of the diagram; the arrows indicate the alternative possibilities of combining, in the model, aspects shown vertically and horizontally on different levels (1—5). Second, the variables of the model (including the goal or expectation variable) can be expressed in units other than time, but as a function of time (the network of alternatives, Part II). The broken line — — — indicates how the chronological aspects corresponding to levels 1—5 were solved for the present profitability calculations per stand, as far as the cutting volumes per year of rotation are concerned. For example, a certain number of piled cu.m. volumes (quantity units) of pulpwood are cut in predetermined years of the stand's life (in time units, periods equalling a year). The annual removals, however, are expressed in the model in terms of annual sums, for example at the end of the year (a given date). There is, therefore, a function discontinuous with regard to time, in which the studied variable

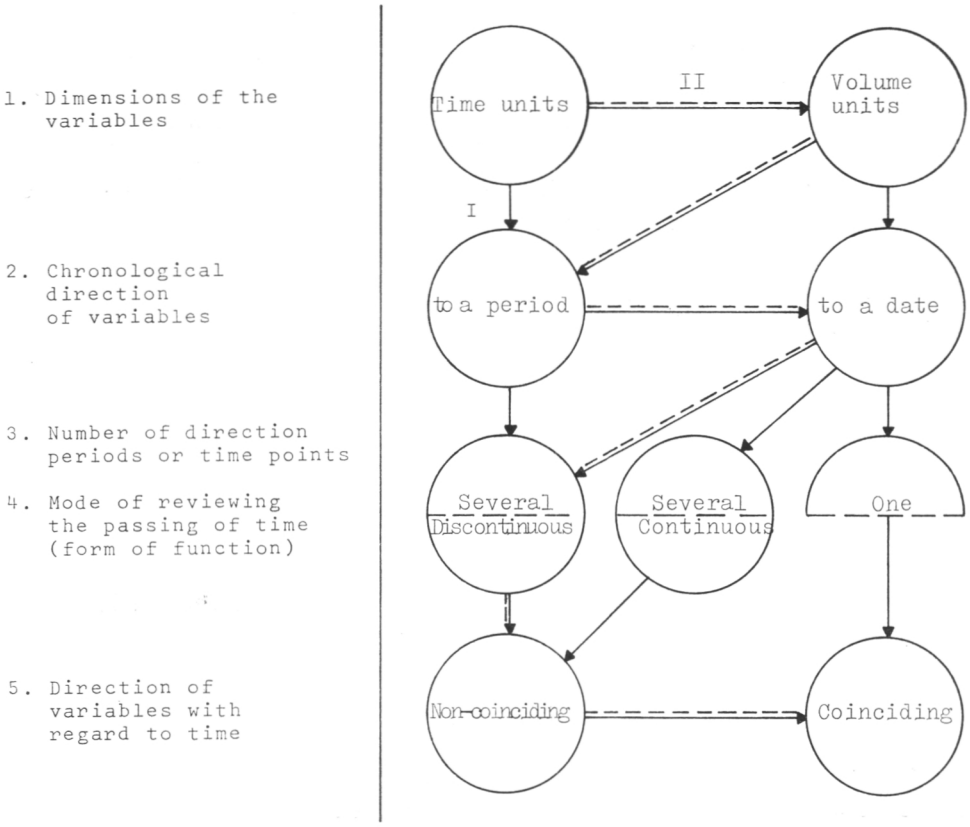


Fig. 8. The time factor in (business) economic models (essential explanations are in the text).

(removal) is directed to certain dates of the rotation. In the classical partial models, the non-coinciding values of the variables can be made to coincide by discounting or prolongation (the horizontal link at the bottom of the diagram).

Let us now discuss the total length of the period of time (and component factors), the consequences of which the decision maker takes into account in his alternative calculations. Let us call this period by the general name of t i m e d i m e n s i o n o r t i m e p e r s p e c t i v e of the model. The date, the time limit, to which extend the consequences of the strategies included in the model, may be generally called the t i m e h o r i z o n. The factors affecting the distance from the moment of decision making to the entrepreneur's (decision maker's) time horizon can be classified, for example, as follows:

I. T h e o b j e c t i v e f a c t o r; the time limit is known beyond which the alternative has no or negligible technological consequences (the

objective technological horizon). The alternative can then refer both to a separate operational alternative (classical partial models) and to a combination of the various activities and functions of the enterprise (combined models).

II. The subjective factors

1. The estimated length of the enterprise's activity period or life span (cf. D. Schneider 1970, p. 38).
2. Importance of the decision problem to the enterprise (D. Schneider 1970, p. 38).
3. The length of the period during which the enterprise's goals and value criteria (value system) remain approximately constant (the chronological constancy horizon of the value system).
4. Availability of information to the enterprise (decision maker); (the chronological information horizon).
5. The decision maker's views concerning the influence of the application of time perspectives of different lengths on consequences measurable in the value system (the chronological value horizon).
6. The decision maker's attitude to the degree of simplification which is potentially possible for the model applicable to each decision problem.

Owing to the long production period of timber growing, its objective technological consequences (due to the ever increasing growing stock and/or removals) extend unusually far into the future. Since these consequences can be valueless in very few circumstances (irrespective of whether the growing stock is industrial raw material or makes an essential component of a recreation area), this therefore also applies to technological consequences measurable expressly in value quantities. This fact must be accepted as an important starting point for determination of the time horizon for timber growing. The problem of time horizon will be discussed in the following, separately for classical partial models and for combined models.

In the classical partial models, how can the decision maker's subjective conditions and views affect the length of the time perspective in timber growing which objectively extends far into the future? As pointed out before, a certain personal enterprise especially has a limited period of activity. But the person can often be expected to pay attention to his children's interests also, and if so the personal enterprise's period of activity in principle becomes indefinitely long. Whenever the enterprise's period of activity will apparently be limited, it would seem natural that in his profitability calculations the entrepreneur would consider only the consequences of the alternatives »covered» by the planning period, or at the most the

period of activity. Depending on the tangible decision making situations, this attitude can naturally also be defended. However, a grave mistake is committed both in principle and in practice if the value of the stand at the end of the planning or activity period is not taken into account as a positive item (revenue). Apparently the majority of decision makers would share this opinion (Item II 5 above). For example, there are few who would seed or plant a bare soil, knowing that after 20 years they would have to give up the stand to an outside economic agent without compensation. On the other hand, the value of the stand at the time horizon usually must be assessed by one or other variant of the discounting or present value method. With regard to classical partial models it is therefore not quite natural to use a special planning period including asset values in the planning horizon. It is more logical to continue the time perspective of calculation immediately to the time horizon.

It was mentioned earlier that, owing to the relatively great homogeneity of the means of production (the main means of production are stands), classical partial models can be applied in forestry, with better reason than usual, to the selection of operational strategies for the whole enterprise. This also tends to extend the time horizon of the classical partial models of timber growing (cf. Item II 2 above). The classical methods of investment calculations start from the relatively coarse generalizations described above, in order to make the investment projects factually independent. Logically, these simplifications (Item II 6 above) are also permissible in relation to the time horizon. On the other hand, necessary information is usually more easily available for simple than for complex phenomena, and therefore simplifications of classical partial models, irrespective of the sector concerned, tend to extend the time perspective.

A problem may develop, in particular, in the classical partial models spanning a long period: the entrepreneur's value system (value criteria) may change as a function of time. The decision maker, at different times, may desire to achieve different goal variables and their achievement degrees. The classical partial models are strictly bound to their own criterion variables. This, however, is true regardless of the length of the time perspective applied. The profitability criteria of classical partial models must be either accepted or rejected, regardless of whether they measure consequences arising from alternatives now, or for example after 20 years.

Far-reaching technological consequences are not peculiar to timber growing. Products can be produced, for example, by means of various buildings, structures, machines, vehicles and other fixed assets. They can, accordingly, cause an ongoing use of production factors during many decades, up to between 50 and 100 years. For the time problem in timber growing, it is useful to consider certain aspects concerned with the deter-

mination of the time perspective in the profitability calculations of these mutually exclusive independent investment projects, based on classical partial models:

1. The cash flows of the compensators after the first »generation» of the fixed asset must be considered in the investment calculations, at least in principle, since these cash flows can be shown to affect the profitability, the optimal lifespan etc. of the first investment (see Honko 1955, p. 66—67; D. Schneider 1970, p. 258; E. Schneider 1964, p. 51—62).
2. Information on the future is so incomplete that as a rule it is not known, at least not which certainty, whether the original investment project will be compensated some time, and if so, how it will be done and what the cash flows of the compensators are in the lifespan of the investment. In the absence of better information, D. Schneider (1970, p. 258) finds it rational to assume that the conditions of the first generation of the fixed asset are repeated as far as cash flows are concerned. This by no means implies that the consequences of the current and subsequent generations of the investments were identical physically, but only in terms of value units. The starting point is that the capital remains and subsequently yields in the same way as the investment project of the first generation.
3. As a result of discounting, the influence of the cash flows attending the later compensation investments on the value of the profitability criteria of the classical partial models is heavily reduced, compared with their undiscounted value at each date. Uncertainty in the cash flows of the later compensation investments, therefore, seldom produces great errors in the value of profitability criteria. With this procedure, the error is more likely to be randomly distributed than if the cash flows are artificially interrupted at a certain date, disregarding even the estimated sale income obtainable from the asset.
4. The basic assumptions of the classical partial models must be taken into consideration: if the calculation periods of the independent alternatives compared are not equally long, it may be assumed that the alternative with a shorter effect gives a yield, during the difference period, which agrees with the calculation rate. It is difficult to present an argument why this procedure should lead to a smaller bias in the value of the profitability criterion than, for example, the assumption that cash flows after the first generation of asset holding are repeated at an identical rate. By extending the time horizon to eternity, the time perspectives of the alternatives are aptly given

equal lengths. This solution can hardly be claimed to be inferior to any other solution (cf. E. Schneider 1964, p. 129, footnote 2).

There is no doubt that determination of the time horizon of classical partial models must allow for the incompleteness of information (especially its uncertainty) available on future conditions. This does not imply, however, that the time horizon in comparing individual investments is schematically placed at the distance of a given finite number of years from the date of decision making, without studying the character of the income and outlay flows of the investment projects, especially their chronological distribution.

In Finland and many other countries, certain institutional factors characterize the time perspective of timber growing within the whole forestry unit: various forest legislation obliges the forest owner to carry out »reasonable» forest regeneration measures, as long as he cannot prove that he uses the land for other purposes. Society, therefore, decides, in a way, on the forest owner's behalf that the enterprise is continuous. Furthermore, for example in Finland, society defines, at least indirectly, a certain minimum limit for the length of the production period in timber growing.

On the basis of the foregoing, the following views, for example, can be advanced concerning the time perspective in classical partial models used in the profitability calculations of timber growing:

1. The decision maker must first decide whether he considers his information on the future so unbroken, precise and reliable that results obtained by classical partial models are useful for his decision making. He must consider the length of the production period in timber growing, and especially in the profitability calculations of an investment starting from bare soil, the accumulation of both technological and positive value consequences (revenues) for the latter half of the production period. When judging the suitability of these partial models for profitability calculations of timber growing, the decision maker, in principle, must review a period not shorter than one production period (rotation). Alternatively, he must intend to sell the forest holding of which the stand is a part, at a certain date.

2. On the other hand, the rotation is one of the essential variables affecting the value of the profitability criteria in profitability calculations concerned with one stand. For this reason, the time perspective of the classical partial model should be able to span receipts and disbursements for rotations of varying lengths. This requirement cannot be fulfilled when the length of the time perspective is pre-determined, finite and the value of the stand at the time horizon is nevertheless disregarded. With this procedure, the revenue of the first final cutting in some rotation alternatives

would fall beyond the horizon. With some other rotation alternatives, the silvicultural expenditures in the early phases of the next tree generation (rotation) would be sacrificed within the time perspective, whereas the revenues of the same rotation would fall outside the calculation. But the procedure by which a fixed, finite time perspective is defined in a classical partial model and by which the property values of the alternatives at the horizon are indicated, usually only means, for the reasons given above, that the discounting calculation is chronologically split into two parts. Classical partial models, however, do not benefit from this splitting as do the combined models (see Chapter 43).

3. In order that a profitability calculation with classical partial models could consider equitably the consequences of the different methods of treating the stand, the time perspective must necessarily become long. A conflict situation due to incomplete information arises easily. The above viewpoints can, however, serve as an argument especially for two methods of constraining the length of the time perspective: (a) the time horizon is extended to eternity, and (b) the time perspective in each compared alternative is defined as equal to one rotation. It is assumed that the funds released from the stand are invested during the period by which the longest rotation alternative exceeds each of the other alternatives, at the calculation rate or, under the internal rate of return method, at the internal rate of interest for each of the methods.

The eternal perspective was used in the present profitability calculations with classical partial models. When the present value method was used the influence on the value of the profitability criterion of revenues and expenditures, at different distances from the base year of calculation, was analyzed, both cumulatively and separately for the most important revenue and expenditure items falling on the various points of age of the stand.

When the decision maker reviews the alternatives of his economic activity as an entity, he admits that the different component actions are interdependent. This is theoretically a total model which must be abstracted into a combined partial model when applied to practice (Chapter 242 above). The combined partial model is usually more complicated than the classical partial model, because of its interdependences and various constraints. To make the more complex treatment useful, the time horizon of the model must be so selected that the functions between variables can be estimated. This refers in the first place to the subjective information horizon of Chapter 351. Chapter 232 discussed the main characteristics of the time horizon of an enterprise entity. Both factually and for calculation techniques, in a model examining enterprise entity it is natural that the time horizon is

made the same for all actions (or component plans) (cf. Orth 1961, p. 55). This is appropriate even though the subjective information horizon of actions clearly distinguishable from the whole might be extended further than that of its other actions. But as was evident from Chapter 232, this does not mean that the assets the enterprise has at the end of the planning period should be disregarded.

The chronological limit of the monetary calculations in the combined model is the previously defined planning horizon. It coincides with the future date beyond which the entrepreneur no longer finds it meaningful to plan in the relatively great detail required by the combined model, since information is increasingly incomplete (cf. D. Schneider 1970, p. 40, and the views by Ansoff in Chapter 232 above, on the permissible error limits in predictions). The activity of the so-called continuous enterprise is assumed to continue beyond the planning period up to the time horizon (see Chapter 232), but the level of simultaneous planning of different functions, presupposed by the combined model, is out of reach. For the measures ensuring continuity of actions beyond the planning horizon, reference is also made to Chapter 232. A fixed-term enterprise can have either an independent planning horizon, or one defined, for example, according to the achievement degree of the goal function (cf. Lutz and Lutz 1951, p. 25—32).

The planning horizon can usually be extended by allocating more funds for obtaining and processing information. At least in principle, therefore, there is an information optimum. Formally, the information optimum is reached when the increase in the goal variable obtainable by additional information (»marginal return») equals the marginal cost of obtaining the information. The optimal planning period (and planning horizon) of an enterprise would theoretically exactly coincide with the point of time where the marginal return equals marginal cost. The greatest difficulty apparently is how to determine the marginal returns from information (cf. D. Schneider 1970, p. 40—41).

When a combined model also contains forestry alternatives, their planning period necessarily must be the same as in the enterprise generally. Determination of the value of assets at the limit of the planning horizon, or definition of constraints that guarantee continuous production, may involve special features.

354. *The calculation rate*

Combined models estimate both the cash flows according to the alternative potential activities per year of the planning period, and the flows to and from potential financial sources. As a result, these models also contain

the cost of the financial sources available, and the alternative investment possibilities for released funds, with predicted returns. Therefore, the combined models which simultaneously solve the investment and financing problems need no schematic calculation rate of interest during the planning period. The substantial importance of this rate for classical partial models was already seen in several contexts in Chapter 243. This does not mean that the estimation of the costs of the potential financial sources and the estimation of the return percentages of the possible re-investment projects of the released funds have also to be approximate in the multiperiodic combined models (see D. Schneider 1970, p. 160). The difference from the classical partial models lies in the method. In combined models the influence of different investment and financing alternatives is visible immediately and, as far as possible, agreeing with the true conditions, in the degree of achievement of the goal function.

There is no doubt that the development of theoretical total models and combined partial models in investment and financing theory has facilitated understanding of the limitations in use of the classical partial models, and their basic simplifying assumptions. In this simplification the calculation rate plays an essential role. As could be seen from Chapter 243, simplified combined models of each different investment project to be compared according to the present value method are made using this rate. An essential characteristic of classical partial models is that the calculation rate must be assumed to have been decided before the beginning of profitability calculations. Determination of the calculation rate of interest has been based in the literature, for example, on:

1. The uniform, so-called market rate of complete capital markets (Albach 1959, p. 35—36; Hirshleifer 1958, p. 330; Honko 1955, p. 43).
2. The market rate plus a subjective premium for risk etc. (Albach 1959, p. 37; Davis 1966, p. 328—331; E. Schneider 1964, p. 66—67).
3. The mean rate of interest the enterprise pays on loaned capital (including the cost of acquiring the capital) (Albach 1959, p. 37—38);
4. The mean rate of return on the sector, with possible corrections (Albach 1959, p. 38).
5. The rate of return of the enterprise in the last few years (Albach 1959, p. 38).
6. The mean dividend percentage of the sector, modified in different ways (Schmalenbach 1954, p. 53—54), or the expected rate of return on the sale price of the enterprise's new shares (Dean 1962, p. 43).

7. The marginal rate of return of the enterprise's investment budget (Albach 1959, p. 38; Jaensch 1966, p. 26—32) or generally the rate of return of the rejected alternative (cf. Terborgh 1949, p. 166).
8. The minimum rate of return the investor requires in spite of economic arguments (D. Schneider 1970, p. 243).
9. The mean, weighted with the amounts of capital, of the yield rate of an alternative investment of own capital and the cost of loaned capital (Honko 1955, p. 195; E. Schneider 1964, p. 67).

It is not possible here to give the detailed argument for these views. A general feature is that all try to approach the true financing and investment conditions either from the angle of the explicit cost of capital (Items 1—3 and 6) or from that of the potential yield rate of the capital (Items 4, 5, 7 and 8). The truth is that the calculation rate of interest for classical partial models can be solved indisputably only with prevailing complete capital markets (Item 1), which in reality never exist (Modigliani and Miller 1958, p. 273). On the contrary, the chances for an enterprise to obtain and invest capital are limited, and the other functions of the enterprise also have their constraining factors. In such conditions, the problems of production, marketing, investment, financing etc. must be solved simultaneously. In theory this is done using total models, but in reality by using combined partial models. If financial sources are the only limits, when linear programming is applied the shadow prices connected with periodic liquidity restrictions indicate the calculation rate per period (Jääskeläinen 1964, p. 179—184; 1966, p. 89—93). Broadly speaking, this principle has been adopted also in traditional investment theory when the calculation rate is determined as an expected rate of return obtainable on alternative use of the money (Item 7 above). It is often said that the calculation rate should equal the rate of return, or opportunity cost, of the best project discarded from the investment budget (cf. D. Schneider 1970, and his literature references). Purely technically, this determination of the calculation rate presumes that the internal rates of return of the investment alternatives chosen and the best rejected alternative are known. It therefore implies acceptance of Dean's proposals quoted in Chapter 243. If the problem of choice among investment alternatives is solved in this way, no calculation rate is required. On the other hand, for comparison's sake, profitability calculations can also be carried out with the present value method. But the present value method cannot be used to draft an investment budget without violating its basic assumptions, if the amount of capital is limited (Chapter 243 and its literature references). In these conditions, a calculation rate must be known before profitability calculations are

started. The use of calculation rate is meaningful only in profitability calculations concerned with individual, independent investment projects (either with the present value method or the internal rate of return method). From the viewpoint of the total enterprise, it would be preferable naturally to take into account all possible alternatives while compiling the investment and financing budget. However, organizational practices, continually changing conditions etc., require that comparisons must be made outside the budget proper to serve as bases for rapid individual decisions. On the other hand, there is no particular reason why the calculation rate should be made equal to the marginal rate of return of the investment budget. If this percentage is known, it naturally provides a fixed point for the determination of the calculation rate. Other bases are the rates of return of the available investment projects, and the cost of external capital involving cash outlays (cf. Honko 1955, p. 41—42, 194—197; D. Schneider 1970, p. 241—242). An approximate general rule is that the internal rate of the compared alternatives must not be less than the percentage cost for capital acquisition. This cost of acquisition forms the lower limit of the rate of interest required for external capital within the enterprise (Honko 1969 a, p. 65). In this case, and generally when the calculation rate of interest is determined, the effect of taxation on the cost of financing must be taken into account (see Asztély 1965, p. 54—65; Jørgensen 1969, p. 44—47; Saario 1958; D. Schneider 1970, p. 261—265). A different matter is that the profitability of external capital in an enterprise usually cannot be determined separately. Neither capital obtained by internal financing nor that invested by a private person into his enterprise has this lower limit of a rate of return based on cash outlays. If the enterprise uses loaned capital, in certain situations it is possible to repay it, and in such a case the relevant cost of the capital is the rate on loans. The calculation rate for individual investment projects may, with good reason, equal the effective rate of return on long-term credits (D. Schneider 1970, p. 241). Especially if an enterprise uses mainly internal financing it may be useful to ascertain the internal rates of interest for at least a few such potential investment projects on which substantial capital sums can be invested if necessary. One of them is selected, or the mean values of some are selected as the target rate of return or calculation rates. The more numerous the investment and financing alternatives studied, the closer we come to the above investment-financing budget of Dean.

In forest economic studies the calculation rate of interest, especially the level of the rate, has of old been much disputed. The subject has mostly been discussed in times when investment and financing budgets in general, and the potential uses of combined models in particular, were not yet known. The forest soil rent theory was closely connected with the concept of the

so-called forestry rate of interest. It was considered that this rate should be lower than the »general rate of interest» indicated by long term risk-free security investments, because the industries based on land utilization were less profitable than the average and because forestry operations involved special benefits which were difficult to measure (see Endres 1911, p. 14, 20—24; Dieterich 1942, p. 73—75; Hiley 1930, p. 102—104; Krieger 1960, p. 251—252). Endres (1911, p. 14—18) linked the forestry rate of interest with the average profitability of privately managed forestry units (the objective forestry rate of interest, $\approx$ 3 %), or with the profitability percentage of a certain forest owner's holdings (subjective rate of interest). In principle, the links with the concepts of the average rate of return of the sector and the recent years' yield percentage of the enterprise are obvious. Endres and many of the researchers whose work he mentions base their ideas on an independent nonintegrated forestry unit. The calculation rate of interest cannot be affected by the alternative investment possibilities outside forestry, and by no means by the »normal» loan rate. According to Streyffert (1938, p. 102, 105—106), the private forest owner's calculation rate is affected both by the loan rate and the rate of return obtainable from alternative investments. Many forest economists in the United States, when they discuss the interest rate of forest economic calculations, use a general risk-free rate (»pure rate»), represented by such things as goverment bonds, which are in fact long term, relatively risk-free loans. The »ordinary» loan rate is obtained by adding premiums to this pure rate for the lender's risk, the cost of loan management, loan period, and the lender's profit (cf. Chapman and Meyer 1947, p. 26—28; Davis 1966, p. 328—335; Duerr and Vaux 1953, p. 87, 271; Worrell 1963, p. 262—268). This procedure is especially helpful for determination of the cost of external financing of a forestry unit. Worrell (1963, p. 268) says that, in operations with own capital, the interest cost equals the rate of return (including risk) which this capital can fetch in the best alternative investment. Duerr (1960, p. 144) feels that the guiding rate of interest can be determined on the basis of either the return from the alternative investment possibilities for the forest owner's funds, or his consumption preferences.

A basic assumption in the present study is that calculations in any enterprise, including forest holdings, need a calculation rate mainly for the partial models used in comparison of individual investments. A calculation rate may also be required in combined models to determine the value of assets at the planning horizon. In reality, timber harvesting and growing are seamlessly interconnected, technologically and economically, especially when timber is sold on delivery. However, it is useful to discuss the calculation rate in classical partial models applied to forestry, separately for

the investment calculations of forest growing and timber harvesting, administration and other actions (cf. von Malmborg 1965 b, p. 215—216).

Classical partial models can be used to calculate e.g. the thinning and regeneration methods and rotations most profitable in timber growing. The calculation rate of interest affects the choice of these decision variables. Ultimately this rate regulates the amount of capital tied to timber growing. Particularly if no thinnings are made the amount of capital committed to the growing stock of the stand increases as the stock grows (in manufacturing and other industries the value of fixed assets usually decreases as a function of their age). The calculation rate, therefore, is exceptionally important in forestry for regulation of the amount of capital committed to the existing production machinery. Since the production factor and the product are identical this also provides a chronological and quantitative regulation of (cutting) revenues.

The site of growth is decisive for the economic result of timber growing. Hence the yield of the forest growing on certain sites, and often the production techniques and structure of the yield can only be modified within relatively narrow limits. The average profitability of timber growing on a certain site within one rotation period can therefore be only rather slightly affected by modifying the production function. If the forest owner chooses such a high calculation rate that no production technique can ensure the average profitability (internal rate of interest) during the rotation, it presupposes that if he wishes to be rational, he must: (a) reduce his required rate of interest; (b) depending on the rate of interest, liquidate existing growing stock to a greater or lesser extent; or (c) give up forest ownership. The last two conclusions have better ground in forestry than in general economic life, even on the basis of the results of partial models actually intended for comparison of separate investments (Chapter 33). This by no means suggests that the planning of a forest holding could be based, in principle, only on partial profitability calculations per stand. In practice, however, the conditions on a small forest holding and the expenditures involved often do not make it possible or appropriate to use combined planning models. The values of profitability criteria calculated by site class and by tree species provide relatively good grounds for decision making.

In a partial study the private forest owner operating entirely with his own capital can, of course, »be satisfied» with the internal rate of interest which is estimated (perhaps optimally) to be achievable at each site of growth in his forestry holding. He then accepts the internal rate of return method with its re-investment and financing assumptions, and reviews forestry as a closed economic unit, »pure forestry». If the calculation rate of interest exceeds the internal rate for every site type, the above conclusions of partial liquidation or abandonment of the forest holding are appropriate. In partial

liquidation the final cuttings involve stands even younger than those with a rotation indicated by the optimal internal rate of interest, the thinning cuttings become extremely heavy, and so on.

The alternative investment projects for private forest owners (personal enterprises) include in particular bank deposits and various securities. Both the taxation and the protection against inflation of the alternative investments must be considered. Forest ownership may be regarded as comparatively safe against inflation. In contrast the present author (Hämäläinen, 1971) has found that a deposit made in Finland on January 1, 1950, for 20 years, on an ordinary savings or deposit account gave a real rate of internal return, adjusted by the wholesale price index, of —0.16 per cent. The return percentage deflated by the cost of living index was —0.41 per cent. With corresponding deflations, the real internal rates of interest on the high-interest deposit accounts during the time this form of deposit existed, from April 1, 1959 to December 31, 1970 were +1.55 and +0.94 per cent. The Finnish goverment bond loan, issued on April 1, 1955 and repaid 6-monthly by April 1, 1970, measured with the same indices, gave the real rates of internal return of 5.2 and 3.0 per cent. The return percentages of the »A» index accounts, almost completely protected against inflation, were somewhat lower during the time that this form of account existed (for details, see Hämäläinen 1971).

The high-interest deposit accounts and the long-term goverment bond loan, which are real financial investment projects, thus gave the investor a relatively modest real return percentage (both were tax-free, for example for private persons). The capital and interest of this government bond loan were protected against approximately half of the deterioration of the value of money (so-called half index terms). The currently issued bond loans of the Finnish state lack this protection. Provided inflation continues at the same rate as during the period April 1, 1955 to April 1, 1970, and the nominal annual rate of interest on the bond loan is 8 per cent, the real interest return for tax-free bonds will remain within the range of 3.3—2.0 per cent, depending on the index used to measure the price level (Hämäläinen 1971, p. 417—419). It can be estimated that the »general rate of interest» in the near future in Finland, in real terms, will be of the order of 2.0 to 3.5 per cent.

The common rate on bank loans in Finland is of the order of 9 per cent. If the value of money is assumed to deteriorate by an average of 5 per cent a year (Hämäläinen 1971, p. 417, 424), and the forest owner's (marginal) tax percentage is 40, the real cost of loaned capital, after taxes, is $9 \times 0.95 - 5.0 - 0.4 \times 9 = -0.05$ per cent. There is thus no real interest charge. If the forest owner is able to raise loan capital, forestry can bear the charge of the loan rate provided the forest owner manages to pay the nominal-value amortizations and interest on the loan (cf., for ex-

ample, the internal rates of return obtainable after tax payment on the various sites in South Finland: Report of the Committee on the Costs of Forest Planting and Seeding, p. 76). If the calculation rate used by forest owner in his classical partial model is the real loan rate after taxes, or the rate of return on government bonds which is available to everybody, it remains below the internal rates of return obtainable on the various site types, with due allowance for taxation (see the Report of the Committee on the Costs of Forest Planting and Seeding, p. 76). When a forest holding in this way, with the aid of the calculation rate of interest, is connected to the financing and investment markets, it is usually not necessary to reduce the growing stock capital below that presupposed by the optimal rates of return. A different question is whether the loan re-payment programme agrees with the optimal growing of the stands.

Investments in machines, road construction, office buildings etc. required for timber harvesting and administration of a forest holding are usually considered a better economic proposition than investments in timber growing. It may here be justifiable to use a higher calculation rate of interest than in the profitability calculations of timber growing. On the other hand, it was seen above that, in an economy with inflation and high taxation, financing with loan capital causes hardly any real incremental costs. The problem is whether the forest owner can raise a loan and whether he can manage the disbursements it involves.

In conclusion, the main lines of A l b a c h 's (1962, p. 50) opinion can be accepted, viz. that classical partial models have been particularly created for profitability calculation. It is too much to require that the rate of interest should consider numerous mutually heterogeneous factors such as the various utilization periods and amounts of capital, the type of pledges, various terms of loan re-payment and payment of interest, details of share and stock financing, and so on. The calculation rate is a once-and-for-all assumption, condensed into one figure, of the possibilities of financing and re-investment (cf. D. S c h n e i d e r 1970, p. 240). If the entrepreneur wishes to carry on continuous forestry, he must consider the internal rates of interest obtainable, for example by site types, as an approximate ceiling level when he determines the rate of interest for profitability calculations of timber growing. The forest owner can also apply the calculation rate at a higher level than the (optimal) internal rate of return of timber growing, that is, the t a r g e t r a t e o f r e t u r n. This, as pointed out above, leads to the partial liquidation of the growing stock, perhaps restricted by forestry legislation in the different countries. If, on the other hand, the calculation rate of interest is lower than the (optimal) internal rate of interest of each site type, the volume and value of the growing stock bound in production are accordingly higher than when the internal rate of return method is used.

4. EMPIRICAL APPLICATION OF PROFITABILITY MODELS

41. Activity alternatives of the economic unit

411. *Aspects of integrated economy, forest management unit and stand*

The following disposition in principle outlines, on the basis of Chapters 232 and 32, the integration of the basic forestry units i.e., the forest holdings, into enterprises, and into administrative units in public economy.

1. In personal enterprises.
   11. A forest holding as a part of the earning and consumption economy of a farm owned by a private person (or partnership).
   12. A forest holding as a part of the earning and consumption economy of a private person or partnership (no farming).
2. In firms (impersonal juridical economic units).
   21. A forest holding as a part of a company engaged mainly in forest industry.
   22. A forest holding as a part of a company mainly engaged in a sector other than forest industry.
3. In state economy and other administrative units of public economy.

Forestry, without exception, is integrated in one of the higher-grade economic units under Items 1—3 above. There are no forest holdings with an independent economy »outside» the enterprise entities defined above. The concept of f o r e s t h o l d i n g presupposes some knowledge of its integration and ownership relations, the goals of the controlling economy, the arrangements for the financing of the economic unit, its taxation and other relations to social institutions, financiers, clients and others interested. The biological-technological production, the supply, sales and other mechanisms of a forest holding, and its utilization for achieving the goals of the enterprise constitute the f o r e s t m a n a g e m e n t (in German,»Forstbetrieb»). The essential means of production are the f o r e s t s t a n d s, in addition to which the forest management unit can comprise roads, buildings, machines, trained and skilled personnel and other long-term production

factors. In reality, the smallest treatment unit in a forest management unit — because of, for example, the mechanization of timber harvesting — is usually an area composed of several forest stands.

In the present study, profitability calculations of forest growing (a pine stand on the Vaccinium site type) were carried out both for the stand (classical partial model) and within an integrated economy (combined partial model). In the latter case the forest holding was a part of a personal enterprise as in Item 12 above.

412. *Main assumptions concerning the sectors of the economic unit*

Profitability calculations for the stand cannot be made without knowing the type of forest holding to which it belongs. The forest holding as a whole affects both the formulation, and the mutual profitability, of the alternative stand treatments. The affecting factors are not only the mensurational, topographical and other business-technological aspects, but also the geographical location and surface area of the forest lot, and the organization of the forest holding operations as a function of these and numerous other factors.

In reality, all forest holdings are different. As mentioned in Chapters 22 and 33, the scientist comparing the consequences of different alternatives by means of descriptive models must define the premises of his model himself. The study must be simplified and the conditions of profitability calculations determined. The profitability of growing a stand is reviewed in the present study within a normal pine forest of 37 ha. This according to the Agricultural Census of 1959, is the mean area of private forest holdings in the Lake District of Finland. The assumption of a normal forest, however, does not essentially weaken the possibilities of applying stand calculations to true forest holdings. The majority of the expenditures of forest holding—with the organization of forest holding operations as assumed in the present study—are either incremental stand costs or divisible among the stands proportionately to their surface areas.

The economy of a forest holding can be organized in many ways. There are two main alternatives for the extent of the traditional sector: timber growing alone or timber growing combined with timber harvesting. The present study presumes that the total annual roundwood output of the normal forest, corresponding to each series of stands, is sold by delivery contracts. The presumption diversifies the analysis of profitability calculations and takes explicitly into account the interaction of timber growing and harvesting with the profitability of forestry. The techniques of timber harvesting were standardized to agree with the collective labour agreements in forestry valid at the time of the study.

The way in which the owner himself, a permanently hired manager, or a consultant employed when required take responsibility for the forest holding affects the possibilities of specifying the cost per stand and the numerical value of the cost. The present study accepted the solution which is apparently the most common in privately owned forest holdings in Finland: the forest owner employs an expert (the adviser of the organizations for the promotion of private forestry) for the more demanding jobs in planning, management and sales techniques.

The forest holding of the personal enterprise (combined model) was assumed to be exclusively pine on the Vaccinium site type, with an area of 37 ha. It was divided into six stands of different surface areas, including two which were in demand for recreational dwellings. The stand compartments and their activity alternatives are described in Chapter 4134. The other details of enterprise activity and the owner's annual consumption goals are reported in Chapters 43 and 443. However, it may be said here that the entrepeneur, at the beginning of the planning period, was assumed to own a certain number of shares, government bonds and shares in a jointstock housing company from which he rented an apartment; their annual rate of return during the planning period was estimated. He also had the possibility of selling and buying these assets. Furthermore, he had a bank deposit. He was estimated to have a certain annual income from salary during the 10-year planning period. On the other hand, he wished to spend annually estimated sums of money on consumption (money received). The consumer durables he owned at the beginning of the planning period were excluded from the model, and the possibility that they might be realized during the planning period was disregarded. To ensure liquidity, the person was to have a certain minimum sum of money on his bank account. The maximum of his bank loan commitments annually during the planning period was half of the total assets at the beginning of the year. The goal was to organize the activity of the personal enterprise so that the value of assets at the end of the 10-year planning period was maximized, taking into account the annual money received and various constraints.

413. *Production alternatives for growing a Vaccinium site type pine stand*

4131. General presentation of the treatment alternatives per stand, and their silvicultural assumptions

The alternative yield series of a stand and the silvicultural measures they require form an essential basis for monetary calculations per stand

Table 1. Alternative treatments of Vaccinium type pine stand

Thinning methods and intensities		Maturities applied, and discrepancy between them and rotation [1]											
		Natural regeneration by the seed-tree method			The other three regeneration methods, maturities applied separately to each [2]								
Thinning from below	Slight	..	..	..	95 4	89 4	83 5	77 5	71 6	65 6	59 6	53 6	47 6
	Slight/ medium ...	95 5	83 4	65 3	95 4	89 4	83 5	77 5	71 6	65 6	59 6	53 6	..
	Medium	95 5	81 4	67 3	95 4	88 4	81 5	74 5	67 6	60 6	53 6	46 6	..
	Heavy	89 6	81 5	65 4	..	89 3	81 4	73 4	65 5	57 6	49 6	..	..
	Radical	..	..	..	93 3	..	..	73 4	..	..	53 6	..	..
Selection thinning from above low intensity	Slight/ medium ...	95 5	83 4	65 3	95 4	89 4	83 5	77 5	71 6	65 6	59 6	53 6	..
	Medium	95 5	81 4	67 3	95 4	88 4	81 5	74 5	67 6	60 6	53 6	..	..
	Heavy	89 6	81 5	65 4	..	89 3	81 4	73 4	65 5	57 6	..	..	..
Selection thinning from above high intensity	Slight/ medium ...	95 5	83 4	65 3	95 4	89 4	83 5	77 5	71 6	65 6	59 6	53 6	..
	Medium	95 5	81 4	67 3	95 4	88 4	81 5	74 5	67 6	60 6	53 6	..	..
	Heavy	89 6	81 5	65 4	..	89 3	81 4	73 4	65 5	57 6	..	..	..

[1]) Maturity is indicated at the top of the squares. The figures refer here to stand age in accordance with yield series (yield tables). The bottom figure of the squares, under regeneration with the seed tree method, refers to the age of the undergrowth at the time the seed trees were removed. When it is subtracted from the age of maturity, the result is the rotation, or the interval between final cuttings (cf. Lönnroth 1930, p. 754; Nyyssönen 1958, p. 10—14). Under the heading »the other three regeneration methods ...» the bottom figures of the squares indicate the assumed duration of the bare soil phase, in years, between the removal of the shelterwood (= final cutting) and the development of the full-density seedling stand through natural regeneration by means of shelterwood and border stand seeding. In this case the rotation exceeds by this number of years the age of maturity. In regeneration by seeding, the bare soil stage equals 0 years, whereas in a planted forest the rotation, under all treatment alternatives, is considered to be 2 years shorter than the age of maturity.

[2]) The maturity alternatives of this part of the table were applied separately to three alternative methods of regeneration: (a) natural regeneration with the aid of the shelterwood and border stand seeding; (b) seeding; (c) planting.

and also for the treatment alternatives of an integrated forest holding. Table 1 lists the treatment alternatives for profitability calculations per stand. The corresponding yield series are based on the methods developed by Vuokila (1965, 1967, 1970 a) and on his material. In collaboration with Vuokila, minor modifications by timber assortments were made in these series; they are specified in Chapter 4132. The yield series presupposing seed tree regeneration were worked out under Vuokila's surveillance expressly for the present study. The present writer took part in planning the treatment of the growing stock as the stand was being regenerated.

The series compared involved four regeneration methods: 1. Natural regeneration (a) with the seed tree method, (b) by shelterwood and border stand seeding, 2. artificial regeneration (a) by seeding, (b) by planting. Vuokila's growth and yield series, however, presuppose in actual fact the natural regeneration of a stand (mainly in accordance with Item 1b above and the corresponding development of the seedling stage (Vuokila 1967, p. 23, 1970 a, p. 22). Little information is available on the growth and yield of seeded and planted stands in Finland. Kallio (1960) admittedly studied the structure and development of artificially seeded pine stands in South Finland. The methods of study, however, are not comparable with those of Vuokila's, and the study does not give yield volumes according to alternative thinning methods and intensities. For this reason, yield series of the shelterwood and border stand regeneration were used in the present study for seeded and planted pine stands. Financial calculations took into account the possible differences between rotation and maturity which vary according to the method of regeneration, as is explained in footnote 1 of Table 1.

In given natural conditions, the kind, amount and chronological distribution of the silvicultural measures required by the stand in its regeneration and seedling stages depend mainly on the method of regeneration. In theory, at least, the same stem frequency distribution series can be arrived at by different combinations of measures. Table 2 lists the necessary silvicultural measures by methods of regeneration. In shelterwood and border stand regeneration, (mechanical) preparation of the ground can encounter technical difficulties if rotations are short and the growing stock is still relatively dense (maximum, 1,743 stems/ha) at the time when it is necessary to prepare the ground. In reality, the second silvicultural treatment of the seedling stand should perhaps be carried out at about the age of 14 years. The growth and yield series of Vuokila's Vaccinium type pine stand are based on the assumption, however, that the number of stems in the stand is brought to correspond to the initial growing stock of each thinning intensity degree at the average age of 18 years (Vuokila 1967, p. 24).

Table 2. Measures of regeneration and seedling stand management by regeneration methods[1])

Silvicultural measure / Method of regeneration	Clearing and site preparation	Seeding and planting incl. preliminary work (clearing etc.)	Blanking	First	Second
				Weeding and spacing	
1. Seed tree method	—12	—	—	9—a	18—a
2. Shelterwood and border stand seeding	— 6	—	—	9+a	18+a
3. Seeding	—	0	4	9	18
4. Planting	—	0	4	7	16

Three different thinning methods were applied in the treatment of the stands regenerated by these four main methods:

1. Thinning from below (Vuokila 1967, esp. p. 19).
2. Selection thinning from above, with a relatively low selection intensity.
3. Selection thinning from above, with a selection intensity higher than under Item 2.

»Selection from above, as understood in the present study, is a method of treating stands at a more advanced age, based on the high timber capital obtained after thinnings from below in the young phases of the growing stock. The earliest date possible for the application of the method is when most of the growing stock has reached saw timber tree dimensions» (Vuokila 1970 a, p. 11).

Thinning intensities were determined as the removal percentage of the D1.3 basal area of the growing stock (Vuokila 1967, p. 18), and they were the same with every intensity of all thinning methods (Vuokila 1970 a, p. 23). Irrespective of the intensity of thinning and maturity age, the following numbers of stems per hectare were left standing in the preparatory cutting which preceded the final cutting under the seed tree method:

[1]) Each silvicultural measure is carried out only for the regeneration methods for which figures are given. The figures indicate how many years before (—) or after (+) the final cutting the measure is carried out. a means, for the seed tree method, the age of the undercrop seedlings at the time seed trees are removed, and for shelterwood and border stand seeding, the life span of the bare soil phase between the final cutting and seedling stand of full density (both obtainable from Table 1).

Series	Number of standing stems
Thinning from below	200 [1])
Selection from above, lower intensity	250
Selection from above, higher intensity	300

The stem numbers, in the pine stand, correspond to the saw-timber stand (cf. Kalela 1961, p. 331). Especially in silviculturally treated pine stands, an »adequate» stock of seedlings develops naturally in the saw-timber stage, and this timber can be removed 5—10 years after the shelterwood had been partially removed leaving the saw-timber stand (Kalela 1961, p. 331, 333).

4132. Timber crops or yields

In his studies, by the temporary sample plot method and on the basis of a material collected from the Lake District of Finland, Vuokila (1965, 1967, 1970 a) developed increment, volume and timber assortment functions per tree. On this basis, he prepared growth and yield tables for pine stands (including the Vaccinium type) treated with thinnings from below of varying intensity (Vuokila 1967) and the corresponding tables for pine stands treated with selections from above (Vuokila 1970 a). The yield series of the present study have been calculated according to the methodical principles of Vuokila's studies (1967, 1970 a), using his material. In the absence of full empirical yield material, the yields of the so-called radical thinning (for this term, see Vuokila 1970 b, p. 118) are less reliable than those of the other thinning intensities. Vuokila, however, worked out this yield series in order to obtain at least an approximate idea of the influence of relatively infrequently repeated thinnings on the profitability of stand growing. In the radical treatment alternative the first thinning is carried out at the age of 33 years and the following thinnings at 20-year intervals (Table 1), unless the final cutting of the stand coincides with these dates.

The special problems of the yield research theory do not belong to the sphere of the present study. Therefore the yield series were accepted as they were available as described above. These yield series were deterministic in form, although in reality the development of the stands after various cuttings is stochastic in character. In principle, it would be pos-

[1]) In the series of high-intensity thinning from below, however, with a maturity age of 89 years, the number was 240 stems, i.e. the same as with the other three regeneration methods.

sible to take this into account when yield functions are developed. However, the number of the yield alternatives corresponding to each treatment strategy of the stands would then become extremely high (cf., generally, Chapter 222 above). This is the case especially when interference with stand development, by silvicultural measures or cuttings, takes place several times during one rotation. The higher the number of stands in which a certain cutting and silvicultural strategy is applied, the smaller the influence of random factors is on the yield consequences. We approach the definite advance knowledge presupposed by the deterministic models.

The discrepancies between the yield series of the present study and those quoted in V u o k i l a 's papers (1967, 1970 a) are mainly due to the following factors. In the present study, according to prevailing custom, small sized wood was not supposed to be removed at all, the minimum top diameter (excluding bark) of pulpwood was reduced, for the same reason, from 8 to 6 cm, and the volumes were indicated as 2-metre timber, unbarked. The minimum top diameter of sawlogs in V u o k i l a 's studies was about $5^1/_4''$ (V u o k i l a 1967, p. 29). In the yield calculations made for the present study it was fixed at exactly 5″. Since the minimum dimensions per timber assortment were modified, the size of the minimum stem of the two timber assortments had to be re-determined, and the volume cubing equations for timber assortments obtainable from the stems had to be re-constructed.

4133. P r o f i t a b i l i t y c a l c u l a t i o n s i t u a t i o n s p e r s t a n d

Two main situations can be distinguished in the profitability calculations per stand if the purposes of the present study are taken as the basis:

1. Profitability information is to be obtained on mutually exclusive cutting and silvicultural alternatives for a c e r t a i n s t a n d.

2. Profitability information is to be obtained, at the time of determining the profitability, on mutually d i f f e r e n t stands. This category also covers the determination of the value of different stands and their assets (e.g. by the present value method), and the comparison of these values.

Most important for the present study are the calculation situations under Item 1. Profitability comparisons by the present value method and the internal rate of return method were carried out at the following ages of the stand:

1. 0 years (the bare soil phase)
2. 21 »
3. 39 »

In each of the three calculation situations, the group of mutually exclusive alternatives, in question, differs on the following points:

1. At the age of 0 years, the alternatives of seed tree regeneration cannot be possible since they have no bare soil phase. The shelterwood and border stand regeneration, according to assumptions, contains the bare soil phase (in reality, apparently a phase of a seedling stand with clearings). To make this regeneration method comparable with the planting and seeding alternatives, the cost of clearing the cutting area and preparing the ground 6 years before the final cutting was prolonged to date 0 (see Chapter 42). It was considered that these silvicultural measures do not change the yield of the shelterwood during this 6-year period compared to the planting and seeding alternatives. At age 0, the mutually exclusive alternatives totalled 222.

2. At a stand age of 21 years the cost of its regeneration and silviculture has already been paid. The topical question is that of choosing the intensity of thinning. The Table 1 series of slight, slight/medium and medium thinnings presuppose that the first thinning is made at the age of 22 years. In the series of heavy thinnings the stand age is 23 years and radical thinnings 33 years. The treatment alternatives of Table 1 if used as mutually exclusive alternatives for a certain stand contain, however, a slight approximation. In reality, the stem distributions of the alternatives with thinnings of different intensities were differentiated before the stand age of 21 years (see Chapter 4131). This was because Vuokila (1967, p. 23—25) — on the basis of Pettersson's (1955) study results — considered that the heavier the thinnings of the series, the smaller was the stem number of his initial growing stock at the age of 18 years. There is no doubt that an initial growing stock of a certain stem number and of certain dimensions, which nevertheless makes possible thinnings of varying intensity and date, would be the best starting point for profitability calculations just before the thinning phase begins. However, even the lowest stem number of the treatment alternatives, that of heavy thinning (3 000 stems/ha) at the age of 18 years provides the necessary initial stock for a yield series of even a slight thinning; in this series the stem number of the stand is greatest at all times of the rotation. The stem number differences between the thinning intensities at the age of 18 years are mainly due to the stem numbers of the $D_{1,3}$ diameter classes of 1—5 cm (see Vuokila 1967, p. 25). — At the age of 21 years, the profitability comparisons thus covered all the mutually exclusive 249 alternatives listed in Table 1.

3. From stand age of 21 years onwards, according to the yield series, it is no longer possible to move from one thinning intensity to another. For profitability calculations for a stand older than 21 years, the treatment series must first be grouped by thinning intensities. The treatment alternatives so grouped can, however, still differ in the thinning method, regeneration method, and age of maturity. A stand age of 39 years is a suitable time in the present study for profitability comparison of a stand which by then has been treated with a certain thinning intensity and in the future also will be so treated, for the following reasons:

(a) With heavy thinning, the yield series of selection given by the above methods differ from those of thinning from below at the age of 41 years.

(b) With shelterwood and border stand regeneration, when the lowest maturity age of 46 years is applied, clearing and preparation of the ground must be undertaken at the age of 40 years.

(c) With the lowest maturity age (65 years) alternatives of seed tree regeneration, the yields from the age of 41 years onwards differ from those of the alternatives presupposing any of the other regeneration methods (although the same thinning methods and intensities are presupposed).

The total numbers of future alternatives in stands previously treated, and to be treated in the future, with thinnings of different intensities, grouped according to the method of thinning, method of regeneration, and rotation, are the following:

Intensity of thinning	Total of treatment alternatives
Slight	27
Slight/medium	81
Medium	75
Heavy	57
Radical	9
Total	*249*

4134. Forest treatment alternatives of an integrated economic unit (combined model)

The 37 ha forest holding represented by the combined model of a personal enterprise was supposed to have, at the beginning of the 10-year

planning period, the six stands specified in Columns 1—4 of Table 3. The mutually exclusive treatment alternatives (cutting and silvicultural strategies) possible in these stands during the 10-year period were determined by the initial state of the stand, the treatment alternatives of Table 1, and the resulting silvicultural measures (Table 2). A limitation was, however, that the alternatives based on shelterwood and border stand regeneration were disregarded. On the other hand, the sphere of the independent treatment alternatives of Table 1 was widened as follows: The assumption was made that stand 5 (see Table 3) could be clear-cut alternatively in any year of the planning period. The final cutting revenue for cutting ages other than those presupposed by treatment series 34 . . . was derived with the aid of the growing stock value after the preceding intermediate cutting and the corresponding value increment percentage. The same principle was applied to Stand 6 where the value increment percentage, in the absence of the material described, had to be extrapolated for the ages of 96—100 years. The mutually exclusive timber growing alternatives, by the stand, can be seen from Column 6 of Table 3, and from Fig. 9.

The combined model presupposes that the stand values at the planning horizon (Chapter 43) are determined as maximal discounting values (in the empirical application, using the 4 per cent calculation rate). This value was sought for stand by stand (1—6). First, all possible future treatment alternatives determined by thinning intensity, thinning and regeneration methods, and length of rotation, until the alternative end points of the then current rotation, were ascertained according to Table 1. If measures determining thinning intensity, thinning and/or regeneration method, or rotation had been undertaken in the stand before the planning horizon, the number of alternatives during the remaining rotation of the stand was accordingly reduced. After the remaining part of each alternative rotation, the stand was assumed to be treated according to the optimum alternative (with a 4 per cent calculation rate). In Stand 2, however, in order to facilitate calculation work, the treatment required by the optimum alternative was not adopted until the succeeding stand had reached the age of 21 years.

One of the assumptions of the combined model was that in any year of the 10-year planning period, the entrepreneur could sell either a part or the whole of the lake-shore stands 2 and 4, for recreational, building or other purposes. These stands, or their arbitrary parts, therefore had these independent operational strategies, in addition to the timber growing strategies shown in Table 3 and Fig. 9. The land sale strategies presupposed that growing stock was not treated at all during the planning period before the possible date of sale of the lots.

Table 3. Timber growing alternatives by stand, for a forest holding, according to the combined model

Stand No.	Area, ha	Age of stand at beginning of planning period	Treatment of stand prior to the planning period	No. of alternatives	Mutually exclusive timber growing alternatives in the 10-year period [1]
					Alternatives defined by codes
1	2	3	4	5	6
1	5.16	3	Sown young growth	1	Future silvicultural measures for the stand only
2	7.27	19	Stand one year after first treatment	4	11 ..., 12 ..., 13 ..., 15 ...
3	4.51	39	11 X [2]	9	141 (65 yrs.), 241 (65 yrs.), 341 (65 yrs.), 112 (47 yrs.), 113 (47 yrs.), 11 ... (> 47 yrs.) [3], 14 ... (> 47 yrs.) [3], 24 ... (> 47 yrs.) [3] and 34 ... (> 47 yrs.) [3]
4	5.90	62	342 or = 343	6	341 (83 yrs.), 342 (65 yrs.), 343 (65 yrs.), 342 (71 yrs.), 343 (71 yrs.), 34 ... (≥ 77 yrs.)
5	7.34	75	342 or = 343	21	34 ... (95 yrs.) and 342 (76 yrs.), 342 (77 yrs.) etc. → 342 (84 yrs.), 342 (85 yrs.) and 343 (76 yrs.), 343 (77 yrs.) etc. → 343 (84 yrs.), 343 (85 yrs.)
6	6.82	90	242 or = 243	20	242 (91 yrs.), 242 (92 yrs.) etc. → 242 (99 yrs.), 242 (100 yrs.), and 243 (91 yrs.), 343 (92 yrs.) etc. → 343 (99 yrs.), 343 (100 yrs.)

[1]) Explanation of three-number codes (e.g. 141):

1 st code number = thinning method during planning period		2 nd code number = thinning intensity during planning period		3 rd code number = future regeneration method determining the removals and silvicultural measures of the planning period	
Code number	Meaning	Code number	Meaning	Code number	Meaning
1	Thinning from below	1	Slight	1	Seed tree method
2	Selection from above, slighter selection cutting	2	Medium	2	Seeding
		3	Heavy	3	Planting
3	Thinning from above, heavier selection cutting	4	Slight/medium	...	Stand treatment and silviculture are the same during the planning period, regardless of the future regeneration method (exception: see footnote [3])
		5	Radical		

[2]) X = for reasons given in Chapter 4131, the growing stock of the initial stand is the same, regardless of the way in which it started (regeneration method).

[3]) Here, the Code 3 entry ... should be interpreted as follows: measures towards applying any of the three regeneration methods, apart from the previously mentioned treatment alternatives 141 (65 yrs.), 241 (65 yrs.), and 341 (65 yrs.), will lead to the same treatment during the planning period. The figures in brackets (65 yrs.) etc. indicate the age of maturity of the alternative(s) in question. Whenever the age of maturity is mentioned separately, it means that age is a factor affecting the treatment of the stand (cuttings, silvicultural measures) during the 10-year period.

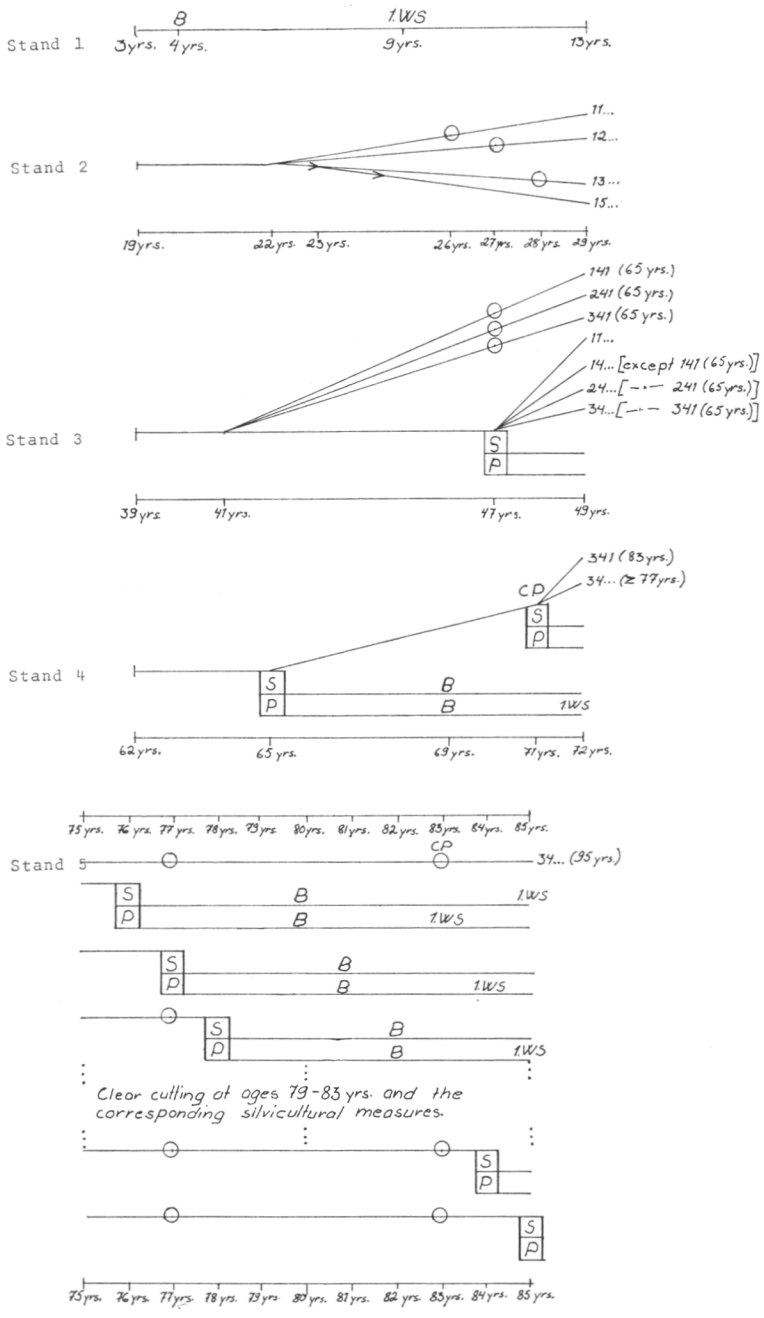
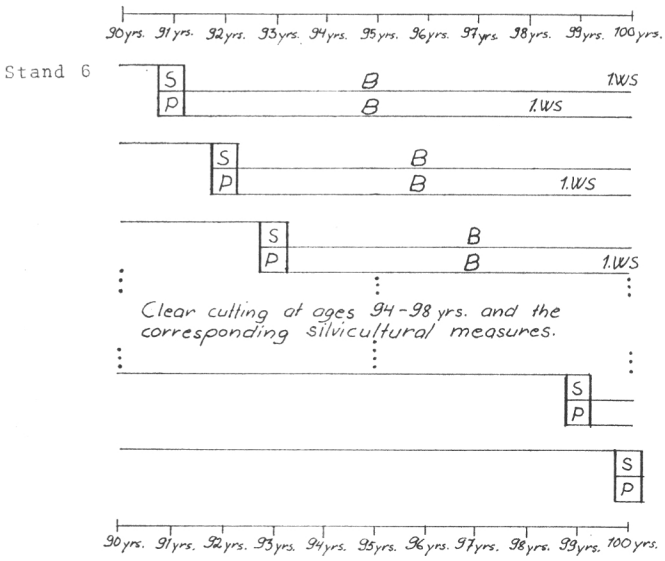


Fig. 9. Timber growing alternatives per stand for



Explanation of symbols:

t_1 yrs. = Potential choice at age t_1 yrs, concerning the intensity and/or method of stand thinning. ⟶ means that the stand is not thinned at age t_1 yrs.

t_2 yrs. = The thinning removal (intermediate cutting) presupposed by the alternative chosen (here, slight thinning from below) is carried out at stand age t_2 yrs. (there are no alternative treatment strategies).

S, t_3 yrs. = The stand is clear-cut at age t_3 yrs. and immediately regenerated by seeding.

P, t_3 yrs. = The stand is clear-cut at age t_3 yrs. and immediately regenerated by planting.

B = Blanking

1.WS = 1. weeding and spacing of the seedling stand.

CP = Clearing of cutting area and preparation of ground for seed tree regeneration.

Code numbers (to the right of some of the drawings) = After the available stand treatment alternatives (Tables 1 and 2), the stand itself (but not the later tree generations) must be treated, after the planning period, as indicated by the code numbers (for explanation of code numbers, see footnotes 1 and 3 of Table 3).

Only some of the alternatives of stands 5 and 6 are shown graphically. To facilitate presentation, the different alternatives of the stand have not been started at the same decision making juncture, although in reality the stand 5, at the beginning of the 10-year period, has 21 mutually exclusive treatment alternatives, and the corresponding number for stand 6 is 20.

a forest holding, according to the combined model.

42. The classical partial models of timber growing

The yield-theoretical and silvicultural premises of the profitability comparisons for raising the stands which form integral parts of the 37 ha normal forest described in Chapter 412, were presented in Chapters 4131, 4132 and 4133. The profitability was compared using the present value method and the internal rate of return method. The argument for the selection of the base years at which profitabilities were compared (stand ages of 0, 21 and 39 years) was presented in Chapter 4133. It was based especially on the available yield material and the relevant silvicultural and other assumptions. The main features of the calculation of present value sums and internal rates of interest per stand can be seen from formulas 3 and 4. As can be seen from the formulas, the values of the profitability criterion were calculated according to two main principles:

1. The forest owner only wishes to have the ownership revenue (capital returns).
2. In addition to the former, the forest owner also wishes to have earnings by doing the work of harvesting the roundwood in his own forest.

The procedures by which prices and costs are determined are described in Chapters 442 and 443. Table 5 shows, in main features, the alternative premises according to which the profitability calculations per stand were made. The present value sums of the flows of outlays and revenues for the stand, per hectare, obtained from formulas 3 and 4, received in the output the form of the present value of contribution profits. They show how the expected income from delivery sales from each stand age group (0, 21 or 39 years) in the future to infinity, is distributed between the present values of the various types of outlay (or alternative costs) and the present values of the contribution profits succeeding them. The contribution profit schedule, based on the principle of ownership revenue shows, to take an example, the present values, discounted from infinity, at stand age of 21 years (radical thinning from below, maturity age of 93 years, and future regeneration of stand by seeding). This is the alternative which, with the present value method, using the »constant mean prices» of the Lake District of Finland (see Table 5, Column 5) and a 3 per cent calculation rate of interest, proved to be the best. It is evident that the shares of the present values of different outlay categories, and thus also of the contribution profits of varying degree, in the present value of sales income vary, depending on the age at which the comparisons are made. The other contribution profit schedule shows an analysis of exactly the same alternative

$$(3)\quad V_n^{(o)} = \left[\sum_{t=1}^{u'} \frac{R_t - H_t^{(o)} - M_t - G_t - T_t^{(o)}}{(1+i)^t} - \sum_{s=1}^{4} DS_s^{(n)}\right] Ca_{u'} - V_{P(n)}^{(o)} \quad ;$$

(n = 0, 21 or 39 years)

$$(4)\quad V_n^{(o+w)} = \left[\sum_{t=1}^{u'} \frac{R_t - H_t^{(w)} - M_t - G_t - T_t^{(o)} - T_t^{(w)}}{(1+i)^t} - \sum_{s=1}^{4} DS_s^{(n)}\right] Ca_{u'}$$

$$- V_{P(n)}^{(o+w)} \quad ; \qquad (n = 0,\ 21 \text{ or } 39 \text{ years})$$

Explanation of symbols:

$V_n^{(o)}$ = The present value sum of the discounting calculation; the base year of profitability comparison is the age of the stand, n years according to the yield series (transition from age n to age n + 1); the present value sum has been calculated according to the principle of ownership revenue (o).

$V_n^{(o+w)}$ = same as above but the present value sum has been calculated according to the principle of the sum of ownership revenue plus the net earnings for the owner's work of harvesting the timber himself (o + w).

t = time, in terms of years, calculated towards the future from the base year n of profitability comparison.

u' = rotation, i.e. the interval between the two final cuttings of the stand.

i = calculation rate of the discounting method, or correspondingly the internal rate of return.

R_t = revenue obtainable by delivery sale of roundwood in the t^{th} year counted from the base year n.

$H_t^{(o)}$ = incremental costs, at market values, of roundwood harvesting in the t^{th} year counted from the base year n.

$H_t^{(w)}$ = wear and tear on material production factors (depreciation of equipment, and fuel costs, requisites, etc.), caused by roundwood harvesting in the t^{th} year counted from the base year n.

M_t = incremental costs arising from the sale, marking and delivery of roundwood felled in the t^{th} year counted from the base year n.

G_t = overhead (which is not incremental cost arising from timber harvesting or silviculture) directed to the stand in the t^{th} year counted from the base year n.

$T_t^{(o)}$ = taxes payable to the state, commune and church for stand ownership (basal area taxation), and the corresponding social security costs, in the t^{th} year from the base year n.

$T_t^{(w)}$ = taxes payable to the state, commune and church for the net earnings of the forest owner for the work of harvesting the timber himself, and the corresponding social security costs in the t^{th} year from the base year n.

$\sum_{s=1}^{4} (DS)_s^{(n)}$ = the present value sum of incremental costs arising from silviculture for the period of u' years counted from the base year n.

$(DS)_s^{(n)}$ = the value of the s^{th} silvicultural expenditure item discounted to the base year n (see table 4).

$Ca_{u'}$ = the capitalization factor of revenues to be had and expenditures to be paid periodically, at intervals of u' years, ad infinitum, $= 1 + \frac{1}{(1+i)^{u'}-1}$. It is presupposed that the 1st periodic item is immediately payable.

$V_{P(n)}^{(o)}$ = value of the stand at the age of n years, determined according to the principle of ownership revenue.

$V_{P(n)}^{(o+w)}$ = value of the stand at the age of n years, determined according to the principle of the sum (o + w) of ownership revenue and net earnings of the owner for the work of harvesting of the timber himself.

Table 4. Detailed contents of term $\sum_{s=1}^{4} DS_s$ of Formulas 3 and 4 [1])

Alternative determined by date of comparison and mode of regeneration	Contents of the term				Remarks
1	2				3
$\sum_{s=1}^{4} DS_s^{(0)}$					
— Shelterwood and border stand regeneration	$S_1(1+i)^6$		$+ S_3(1+i)^{-(9+a)}$	$+ S_4(1+i)^{-(18+a)}$	The a values can be seen from the low edge of the square indicating the relevant alternative in Table 1 (p. 103)
— Seeding or planting	S_1	$+ S_2(1+i)^{-4}$	$+ S_3(1+i)^{-(9-a)}$	$+ S_4(1+i)^{-(18-a)}$	In seeding $a = 0$ and in planting $a = 2$ with all age-of-maturity alternatives
$\sum_{s=1}^{4} DS_s^{(21)}$					
— Seed-tree regeneration	$S_1(1+i)^{-(u-33)}$		$+ S_3(1+i)^{-(u'-12)}$	$+ S_4(1+i)^{-(u'-3)}$	$u' = u-a$, where u = age of maturity of the stand. The a values obtainable from the Table 1 squares indicated above
— Shelterwood and border stand regeneration	$S_1(1+i)^{-(u-27)}$		+ —»—	+ —»—	$u' = u + a$; For a values, see Table 1
— Seeding or planting	$S_1(1+i)^{-(u-21)}$	$+ S_2(1+i)^{-(u-17)}$	+ —»—	+ —»—	$u' = u-a$
$\sum_{s=1}^{4} DS_s^{(39)}$					
— Seed-tree regeneration	$S_1(1+i)^{-(u-51)}$		$+ S_3(1+i)^{-(u'-30)}$	$+ S_4(1+i)^{-(u'-21)}$	See explanations above at age of 21 years
— Shelterwood and border stand regeneration	$S_1(1+i)^{-(u-45)}$		+ —»—	+ —»—	—»—
— Seeding or planting	$S_1(1+i)^{-(u-39)}$	$+ S_2(1+i)^{-(u-35)}$	+ —»—	+ —»—	—»—

[1]) These parts of formulas 3 and 4 are based on periods of time (years) indicated in Table 2 (p. 105). See also the footnote of Table 2.

Explanation of symbols:

S_1 = In seed tree regeneration, and shelterwood and border stand regeneration = the incremental cost of clearing and preparation of ground surface. When regeneration is effected by seeding or planting = the incremental cost of seeding or planting (including clearing and other preliminary work);
S_2 = the incremental cost of blanking;
S_3 = the incremental cost of the first weeding and spacing;
S_4 = the incremental cost of the partial second weeding and spacing.

Contribution profit schedule based on the principle of o w n e r s h i p r e v e n u e: [1])

			Fmk	Fmk	%
+	1.	Sales revenue from delivery sale of roundwood, total		4 448	100.0
		11. Logs	2 926		(65.8)
		12. Pulpwood	1 522		(34.2)
—	2.	Cost of harvesting for delivery sale, total		1 354	30.5
		21. Logs	615		(45.4)
		22. Pulpwood	739		(54.6)
=	3.	Stumpage price revenue, total (1—2)		3 094	69.5
		31. Logs (11—21)	2 311		(74.7)
		32. Pulpwood (12—22)	782		(25.3)
—	4.	Incremental cost of sale, marking of the trees to be cut, and delivery		64	1.4
=	5.	Contribution profit I_0 b.t.[2]) (3—4), or chronological ownership contribution towards supply b.t.		3 030	68.1
—	6.	Incremental cost for silviculture		43	1.0
=	7.	Contribution profit II_0 b.t. (5—6), or chronological ownership contribution towards production and sale b.t.		2 987	67.1
—	8.	Overhead		250	5.6
=	9.	Contribution profit III 1_0 b.t. (7—8), or discounting value of the stand b.t.		2 737	61.5

		Fmk	%			Fmk	%			Fmk	%
10 a.	Value of stand at date of comparison is not deducted	—	—	— 10 b.	Value of the stand (b.t.) at date of comparison[3])	1 650	37.1	— 10 c.	Value of stand (a.t.) at date of comparison[3])	1 452	32.6
= 11 a.	Contribution profit III 1_0, b.t. (Item 9)	2 737	61.5	= 11 b.	Contribution profit III 2_0 b.t. (9—10 b), or chronological ownership contribution towards business b.t.	1 087	24.4	11 c.	—	—	—
— 12 a.	Area tax	263	5.9	12 b.	—	—	—	— 12 c.	Area tax	263	5.9
= 13 a.	Contribution profit IV_0 a.t. (11 a—12 a), or the discounting value of the stand a.t.	2 474	55.6	13 b.	—	—	—	= 13 c.	Contribution profit V_0, a.t. (9—10 c—12 c), or chronological ownership contribution to forest holding a.t.	1 022	23.0

[1]) For the numerical values, see text.
[2]) b.t. = before taxes, i.e. without tax reduction;
a.t. = after tax reduction.
[3]) Value of the stand = value of land when the date of comparison in the calculation is stand age 0.

Contribution profit schedule based on the principle of ownership revenue and earnings from timber harvesting work done by the forest owner himself: [1])

			Fmk	Fmk	%
+	1.	Sales revenue from delivery sale of roundwood, total		4 448	100.0
		11. Logs	2 926		(65.8)
		12. Pulpwood	1 522		(34.2)
—	2.	Cost of material production factors in roundwood harvesting, total		166	3.7
		21. Logs	73		(44)
		22. Pulpwood	93		(56)
=	3.	Sum of stumpage price and net earnings from the work of harvesting the timber (1—2) b. t.[2]) total		4 282	96.3
		31. Logs (11—21)	2 853		(66.6)
		32. Pulpwood (12—22)	1 429		(33.4)
—	4.	Incremental cost of sale, marking of the trees to be cut, and delivery		64	1.4
=	5.	Contribution profit I_{0+w} b.t. (3—4), or chronological ownership and work contribution towards supply b.t.		4 218	94.9
—	6.	Incremental cost for silviculture		43	1.0
=	7.	Contribution profit II_{0+w} b.t. (5—6), or chronological ownership and work contribution towards production and sale b.t.		4 175	93.9
—	8.	Overhead		250	5.6
=	9.	Contribution profit III 1_{0+w}, b.t. (7—8), or discounting value of the stand based on the principle of ownership and work contribution b.t.		3 925	88.3

		Fmk	%
10 a.	Value of stand at date of comparison is not deducted	—	—
= 11 a.	Contribution profit III 1_{0+w} b.t. (Item 9)	3 925	88.3
— 12 a.	Tax for area and work in harvesting	357	8.0
= 13 a.	Contribution profit IV $_{0+w}$ a.t. (11 a—12 a), or the discounting value of the stand based on the principle of ownership and work contribution (a.t.)	3 568	80.3

		Fmk	%
— 10 b.	Value of the stand based on the principle of ownership and work income (b.t.) at date of comparison [3])	2 699	60.7
= 11 b.	Contribution profit III 2_{0+w} b.t. (9—10 b), or chronological ownership and work contribution towards business b.t.	1 226	27.6
12 b.	—	—	—

		Fmk	%
— 10 c.	Value of stand based on the principle of ownership and work income (a.t.) at date of comparison [3])	2 416	54.3
11 c.	—	—	—
— 12 c.	Tax for area and the work of harvesting	357	8.0
= 13 c.	Contribution profit V $_{0+w}$, a.t. (9—10 c—12 c), or chronological ownership and work contribution to forest holding a.t.	2 059	26.0

[1]), [2]) and [3]), see contribution profit schedule based on the principle of ownership revenue.

Table 5. A schedule in broad outline, of the assumptions of the environmental state and strategies of forest treatment in the profitability calculations per stand, based on classical partial models.

Region to which calculation applied	Assumption of the chronological development of the price and outlay components	Scope of the income concept in the profitability criteria	Mutually exclusive timber growing alternatives, and stand age at date of comparison [1]	Definition characterizing environmental states and calculation principle
1	2	3	4	5
I. The Lake District of Finland, average	I_1: Stumpage price and delivery price levels, and all expenditures, remain, in the future, at the real level determined for the cutting year 1967/68 in the Lake District of Finland.	a. Ownership revenue b. Ownership revenue and work earnings	All 249 alternatives of Table 1 (p. 103). The ages of comparison are 0, 21 and 39 years[2]	Calculation at fixed mean prices
»	I_2: Stumpage price and delivery price levels in the Lake District of Finland will in the future, remain the same as under Item I_1 above, but will fluctuate to either side according to the cyclic pattern, as do the costs that depend on stumpage prices (i.e., taxes, silvicultural fee). Other costs remain at the real level of Item I_1.	a. Ownership revenue	All 81 alternatives of medium heavy thinnings of Table 1. Age of comparison, 21 years.	Calculation at cyclical prices
»	I_3: Stumpage price level and the delivery price level for logs remain on the real level of Item I_1. Harvesting costs in the Lake District of Finland increase, except for the best final cutting stands. Their probable increase, however, is considered to prevent the real increase in the mean harvesting cost corresponding to the mean stumpage price of logs, and thus also the increase in the mean delivery price for logs. Some of the costs independent of the stumpage price level, other than the timber harvesting costs, undergo a real increase.	»	All 249 alternatives of Table 1. Age of comparison, 21 years.	Calculation with rising costs
»	I_4: Stumpage price and delivery price levels undergo a real increase, as do most costs. However, the mean harvesting cost corresponding to the mean stumpage price of logs does not increase.	»	»	Calculation with rising prices and costs
II. The area of minimum stumpage prices in the Lake District of Finland	II_1: The same principle as under Item I_1.	a. Ownership revenue b. Ownership revenue and work earnings	All alternatives of Table 1. Ages of comparison, 0, 21 and 39 years[1]	Calculation at fixed minimum prices
III. The area of maximum stumpage prices in the Lake District of Finland	III_1: »	»	»	Calculation at fixed maximum prices

[1]) Alternatives at the 39-year date of comparison, classified as described in Chapter 4133.

[2]) At stand age 0, however, the alternatives of seed tree regeneration could not be compared with the others, since there was no bare soil phase. At age 0, therefore, there were 222 mutually exclusive alternatives, otherwise they totalled 249.

in a situation in which the forest owner also takes into account, as an income item, the timber harvesting he has carried out, at its current value (this timber growing alternative, however, is no longer the best).

The formation of the present value sums of the contribution profits in the formulas follows a certain order of priority of the outlays (for the order of priority of costs in general, see Saario 1949). The priority of outlays in these formulas is determined by the two main principles: (a) the causation principle for expenditure, which can be approximately identified with the principle of incremental expenditures, and (b) the length of their effective period. The first to be deducted are the expenditures which, according to the causation principle, are connected with the roundwood harvesting in the stand, i.e. are incremental costs to the manufacturing and short-distance transport of saleable products. In the calculation situation of the present study, they are almost exclusively costs of short-term effect. The problem of fixing the limits of relevant items of costs of timber harvesting, was solved, using the profitability criterion of the ownership and work revenue sum, in a way in which only the value of the use of material production factors was classified as expenditure. A similar procedure might be justifiable, in certain calculation situations, also for the share of the forest owner's own work in other outlay categories, although the owner's labour input often is not immediately compensated by the coincident cutting revenues. After subtraction of the timber harvesting costs of short-term effect the costs of silviculture, which have a long-term effect, are subtracted. This cost creates the basis of continuous availability of mature stands, which are future raw material of timber harvesting. After clear cutting, the Finnish law imposes planting or seeding on privately owned forest. The overhead deductible after the incremental silvicultural costs is common for timber growing and harvesting, and not, as according to the causation principle, attributable separately to timber harvesting and growing. In the Finnish conditions, the taxes payable per surface area unit by forest site types further reduce the forest owner's share of the sales income. Taxes, also other taxes than property tax, must be paid on the forest, regardless of whether it has yielded income during the taxation year. The analysis of ownership revenue and income earned by work taken together differs from that of the ownership revenue alone also in that it takes into account, as a deduction, the taxes and tax-like dues the forest owner must pay for the work of timber harvesting he undertakes himself. In the discussion of ownership revenue and the income earned by work, they were also taken into account when the initial values of the stand were reviewed, provided the initial value was determined according to the »after taxes» principle (details in Chapter 4422).

In the present study the sequence of subtracting expenditure from revenue could have been different. Juridically, taxes, wages and salaries (irrespective of the outlay category under which they are entered) must be paid first e.g. in the event of bankruptcy. The stand models of the study, however, lead to such high yields and revenues that taxes payable expressly for forestry by no means remain unpaid, although they should be ranked last. The main thing here was to distinguish taxes from the expenditure spent on the purchase of production factors. The schedule contains no profit distribution to outsiders in the form of payable sums of interest (S a a r i o 1959, p. 58), the assumption being that the business of the normal forest in question is financed entirely by its own capital.

The s t a n d v a l u e s, in the form of negative components, are given in formulas 3 and 4 in the base years of the profitability calculations. There are, however, positive and negative items contained in all the alternatives compared, and they can be excluded from the profitability comparison based on the present value method. In profitability calculations at ages 0 and 21 years the value of land or stand in the base year does not affect the profitability ranking of the alternatives. The same is valid for the stand age of 39 years if the alternatives compared are only those with exactly the same initial growing stock (the intensity of thinning up to that age has been the same). This broadness of the definition of the material content of the profitability criterion is one of the reasons why the present value sums of contribution profits have been calculated after the subtraction of various kinds of expenditure.

In profitability calculations per stand it may be necessary to include the value of the stand (in extreme cases, only land or growing stock) for at least the following reasons:

(a) The forest owner, society or other interested party tries to make timber growing alternatives comparable with other investment projects. The alternative is »debited» for the use of land (at stand age 0) or the use of the stand for timber growing.

(b) The mutual profitability of timber growing in two or more stands, which are different in the base year, is compared. Even according to the principles of the present value method, the differences in the initial values of the production machinery must be taken into account.

(c) Let us assume that the internal rate of return method is applied and the initial value of the stand is not included in the profitability calculation. In such a case the series of revenues and expenditures per stand would represent a so-called spurious investment in the

base year 21 and 39 at least under certain cutting and silvicultural treatment alternatives. The result might be a negative internal rate of return, problematic to interpret (cf. E. Schneider 1964, p. 10—12). For profitability calculations by means of the internal rate of return method in any of the above three base years, all that was said in Chapter 243 above concerning the effect of truncating the flows of revenues and outlays, is also valid here. It was found desirable to study this aspect also with the aid of initial stand values determined according to different principles. Details will be given in Chapter 4422.

43. The combined partial model (forest in a personal enterprise)

According to Chapter 411, a forest holding in Finnish conditions is always a part of a higher-level economic unit, usually a personal enterprise. For this reason the combined multiperiodic planning model in the present study was applied expressly to a personal enterprise. The entrepreneur was defined — solely from the point of view of forest ownership — as a forest owner, one that has some time also been called in Finland an »amateur» forest owner (see Reunala 1972, especially the preface). The subject of the study was constrained in this way e.g. because, as far as the present author knows, no earlier studies in this particular sector have been made, whereas various types of combined models have already been applied e.g. to running a farm (e.g. von Malmborg 1967, 1969; Kallio 1969).

A general description of the circumstances of the fictive personal enterprise to which this (global) combined investment and financing model, i.e. financial plan, was to be applied, was given in Chapter 412, and for a forest holding, especially, in Chapter 4134. The linear programming model, however, was presented here in a general form, solely by symbols (Formulas 5—15 and non-negativity constraints). In the example of application, the parameters of this deterministic dynamic model were given certain numerical values. These empirical or fictive values do not affect the structure of the model. From the viewpoint of the principle of the model, certain assumptions concerning the operations of the enterprise studied are necessary.

A person desires the maximum value (Z) of enterprise assets at the end of the planning period, at the same time as he withholds varying amounts of money annually for his consumption (on the basis of his consumption plan). For this goal, the person must invest his capital profitably and, in addition to internal financing, use borrowing opportunities, assumed to be restricted by the total of his assets, to such an extent as proves to

Goal instruction: $Z = \max!$

Definition of goal:

$$(5)\quad Z = (1+i_B)\,B^{(N)} + D^{(N)} + (1+i_\omega)^{(N)}\,(\hat{\Gamma}^{(N)} + \hat{\hat{\Gamma}}^{(N)}) + (1+i_\omega)^N \eta\, Q^{(N)} + \sum_{k=1}^{K}\sum_{j=1}^{Jk} x_{kj}\, V_{kj}^{(N)} + i_D\, D^{(N)} + (1+i_\omega)^N (i_{\hat{\Gamma}}\,\hat{\Gamma}^{(N)} + i_{\hat{\hat{\Gamma}}}\,\hat{\hat{\Gamma}}^{(N)}) + (1+i_\omega)^N i_Q \eta\, Q^{(N)} + \sum_{k=1}^{K}\sum_{j=1}^{Jk} x_{kj}\, E_{kj}^{(N)} + \sum_{k=1}^{K}\sum_{\nu=1}^{N} \delta_k\, y_{k\nu}\, G_{k\nu}^{(N)} + O^{(N)} - L^{(N)} - i_L\, L^{(N)}$$

Other equations of definition:

$$(6)\quad B^{(1)} = a^{(0)} - (1+\lambda_d)\, d_+^{(1)} - (1+\lambda_\Upsilon)\, \Upsilon_+^{(1)} - (1+\lambda_q)\,\eta\, q_+^{(1)} + L^{(1)}\ ;\quad (a^{(0)} \geq a)$$

$$(7)\quad B^{(n)} = (1+i_B)\,B^{(n-1)} + (1-\lambda_d)\, d_-^{(n)} - (1+\lambda_d)\, d_+^{(n)} + (1+i_\omega)^{n-1} \times \left[(1-\lambda_\Upsilon)\,\Upsilon_-^{(n)} - (1+\lambda_\Upsilon)\,\Upsilon_+^{(n)}\right] + (1+i_\omega)\,\eta\left[q_-^{(n)} - (1+\lambda_q)\, q_+^{(n)}\right] + i_D\, D^{(n-1)} + (1+i_\omega)^{n-1} (i_{\hat{\Gamma}}\,\hat{\Gamma}^{(n-1)} + i_{\hat{\hat{\Gamma}}}\,\hat{\hat{\Gamma}}^{(n-1)}) + (1+i_\omega)^{n-1} i_Q \eta\, Q^{(n-1)} + \sum_{k=1}^{K}\sum_{j=1}^{Jk} x_{kj}\, E_{kj}^{(n-1)} + \sum_{k=1}^{K}\sum_{\nu=1}^{N} \delta_k\, y_{k\nu}\, G_{k\nu}^{(n-1)} + \sum_{k=1}^{K} (1+i_\omega)^{n-1}\,(1+i_k)^{n-1}\,\delta_k\, y_{k\nu}\, \Pi_k^{(0)} + O^{(n-1)} + L^{(n)} - L^{(n-1)} - i_L L^{(n-1)} \qquad (n = 2,\ldots,N)$$

$$(8)\quad D^{(n)} = \sum_{\nu=1}^{n} d_+^{(\nu)} - \sum_{\nu=1}^{n} d_-^{(\nu)} + D^{(0)}\ ;\quad (n = 1,\ldots,N)$$

$$(9)\quad \hat{\Gamma}^{(n)} + \hat{\hat{\Gamma}}^{(n)} = \sum_{\nu=1}^{n} \Upsilon_+^{(\nu)} - \sum_{\nu=1}^{n} \Upsilon^{(\nu)} + \hat{\Gamma}^{(0)} + \hat{\hat{\Gamma}}^{(0)}\ ;\quad (n = 1,\ldots,N)$$

$$(10)\quad Q^{(n)} = \sum_{\nu=1}^{n} q_+^{(\nu)} - \sum_{\nu=1}^{n} q_-^{(\nu)} + Q^{(0)}\ ;\quad (n = 1,\ldots,N)$$

$$(11)\quad \sum_{j=1}^{Jk} x_{kj} + \delta_k \sum_{n=1}^{N} y_{kn} = 1\ ;\quad (k = 1,\ldots,K)$$

Constraints:

(12) $B^{(n)} \geq a\ (>0) \quad ;\quad (n = 2,\ldots,N)$

(13) $\hat{\Gamma}^{(n)} \leq b\ (>0) \quad ;\quad (n = 1,\ldots,N)$

(14) $L^{(1)} \leq \beta^{(1)}\ (a^{(0)} + D^{(0)} + \hat{\Gamma}^{(0)} + \hat{\hat{\Gamma}}^{(0)} + \eta Q^{(0)} + \sum_{k=1}^{K} \delta_k \Pi_k^{(0)} + F^{(0)})$

(15) $L^{(n)} \leq \beta^{(n)} \Big\{(1 + i_B) B^{(n-1)} + D^{(n-1)} + (1 + i_\omega)^{n-1}\ (\hat{\Gamma}^{(n-1)} + \hat{\hat{\Gamma}}^{(n-1)})$
$+ (1 + i_\omega)^{n-1} \eta Q^{(n-1)} + (1 + i_\omega)^{n-1} \Big[\sum_{k=1}^{K} \delta_k (1 + i_k)^{n-1} \Pi_k^{(0)} (1 - \sum_{\nu=1}^{n-1} y_{k\nu})$
$+ F^{(0)}\Big]\Big\} \quad (n = 2,\ldots,N)$

Non-negativity constraints

$D^{(n)} \geq 0 \quad (n = 1,\ldots,N)$

$\hat{\Gamma}^{(n)} \geq 0 \quad$ "

$\hat{\hat{\Gamma}}^{(n)} \geq 0 \quad$ "

$Q^{(n)} \geq 0 \quad$ "

$L^{(1)} \geq 0$

$L^{(n)} \geq 0 \quad (n = 1,\ldots,N)$

$d_+^{(n)} \geq 0 \quad$ "

$d_-^{(n)} \geq 0 \quad$ "

$\gamma_+^{(n)} \geq 0 \quad$ "

$\gamma_-^{(n)} \geq 0 \quad$ "

$q_+^{(n)} \geq 0 \quad$ "

$q_-^{(n)} \geq 0 \quad$ "

$x_{kj} \geq 0 \quad (k = 1,\ldots,K;\ j = 1,\ldots,J_k)$

$y_{k\nu} \geq 0 \quad (k = 1,\ldots,K;\ \nu = 1,\ldots,N)$

Explanation of symbols:

i_B = annual tax-free yield from bank deposit (cash funds) related to face value

i_ω = relative annual increase in prices (measured e.g. by some price index)

i_D = estimated tax-free yield of government bonds held, related to face value

$i_{\hat{\Gamma}}$ = yield of those shares and stock held which are exempt from state income tax (see $\hat{\Gamma}$), after other taxes, related to face value

$i_{\hat{\hat{\Gamma}}}$ = yield of shares and stock held, subject also to state income tax (see $\hat{\hat{\Gamma}}$), after taxes, related to face value

i_Q = yield of standard-size investments (e.g. the renting out of a certain type of residential apartment), after taxes, related to real value

i_L = interest and other cost on loans, after taxes, related to face value

i_k = the relative annual real price increase on the k^{th} stand which is in demand for use as recreation grounds, building lots, or the like

δ_k = 1 if the owner can or wishes to sell stand k for use as recreation grounds or the like
= 0 if the owner cannot or does not wish to sell stand k — » —

N = length of planning period, years

a = minimum of bank deposit (cash funds) during the planning period, Fmk

$a^{(0)}$ = cash funds transferred from the year preceding the planning period, Fmk

b = maximum value of shares and stock held, totally exempt from state tax during the n^{th} year, in terms of the value of money at the beginning of the planning period, Fmk

$B^{(n)}$ = bank deposit during the n^{th} year of the planning period, Fmk

$D^{(0)}$ = face value of the bonds transferred from the year preceding the planning period, Fmk

$D^{(n)}$ = face value of the bonds held in the n^{th} year, Fmk

$\hat{\Gamma}^{(0)}+\hat{\hat{\Gamma}}^{(0)}$ = total stock and shares transferred from the year preceding the planning period, in terms of the value of money at the beginning of the planning period, Fmk

$\hat{\Gamma}^{(n)}$ = total stock and shares held in the n^{th} year, in terms of the value of money at the beginning of the planning period, Fmk; the part totally exempt from state income tax

$\hat{\hat{\Gamma}}^{(n)}$ = total stock and shares held in the n^{th} year, in terms of the value of money at the beginning of the planning period, Fmk; the part also subject to state income tax

K = number of stands in the forest holding at the beginning of the planning period

J_k = number of mutually exclusive cutting and silvicultural strategies for the k^{th} stand during the planning period

$Q^{(0)}$ = number of standard-size investment projects transferred from the year preceding the planning period

$Q^{(n)}$ = number of standard-size investments held in the n^{th} year

$V_{kj}^{(N)}$ = value of the k^{th} stand, Fmk (= cash flows associated with the optimum strategy of the future discounted to the end of the planning period) per total stand (ready converted into the value of money of that year), if the j^{th} cutting and silvicultural strategy of the planning period is applied to the stand or part thereof

$E_{kj}^{(n)}$ = net cash flow, Fmk, connected with the j^{th} cutting and silvicultural strategy of the k^{th} stand, before tax (contribution III 1_o b.t. principle) at the end of the n^{th} year of the planning period, ready converted into the value of money of that year

$G_{k\nu}^{(n-1)}$ = cash flow, Fmk, connected with the ν^{th} sales strategy of the k^{th} stand at the end of the $(n-1)^{th}$ year (however, not including the possible sales income of the area), ready converted into the value of money of that year. If $\nu = 1, \ldots, (n-1)$, i.e. if at least a part ($y_{k\nu}$) of the stand is sold before year n, $G_{k\nu}^{(n-1)}$ refers to a cost reduction item, i.e. tax saving on the stand in the year n—1 (the tax was included in money received; see $0^{(n)}$). If $\nu = n, \ldots, N$, $G_{k\nu}^{(n-1)}$ refers to the overhead cost of the stand

$O^{(n)}$ = broadly understood money received at the end of the n^{th} year converted into the value of money of that year, i.e. the difference: personal earnings after taxes less money received from personal enterprise for consumption, less the so-called area tax payable for the forest holding (on its size at the beginning of the planning period) less silvicultural costs and overhead for stands from which no cutting income can be obtained during the whole planning period, because of their young age

$L^{(n)}$ = total loans, at their face value, during the n^{th} year, Fmk

$\Pi_k^{(0)}$ = price obtained for the k^{th} stand when sold for use as recreation grounds or the like, Fmk per stand at the beginning of the planning period, at the value of money at that date

$F^{(0)}$ = lender's opinion, independent of the cutting and silvicultural strategy, of the value of the part of the forest holding which is not in demand for use as recreation grounds or the like, or which the owner does not wish to sell ($\delta_k = 0$)

η = exchange value of standard-size investments, Fmk, at the value of money at the beginning of the planning period

$\varkappa_{kj}$ = the relative share of stand k to which the j^{th} cutting and silvicultural strategy is applied

$\gamma_{k\nu}$ = the relative share of stand k which is sold at the beginning of the ν^{th} year

λ_d = commission for purchase or sale of government bonds related to total price

λ_γ = commission and stamp duty for purchase or sale of stock and shares related to total price

$\beta^{(n)}$ = coefficient indicating the highest relative proportion of the entrepreneur's assets at the end of the $(n-1)^{th}$ year that the lender is prepared to lend for the period of the n^{th} year

$d_+^{(n)}$ = bonds bought at their face value at the beginning of the n^{th} year, Fmk

$d_-^{(n)}$ = bonds sold at their face value at the beginning of the n^{th} year, Fmk

$\gamma_+^{(n)}$ = stock and shares bought at the beginning of the n^{th} year, at the value of money at the beginning of the planning period, Fmk

$\gamma_-^{(n)}$ = stock and shares sold at the beginning of the n^{th} year, at the value of money at the beginning of the planning period, Fmk

$q_+^{(n)}$ = number of standard investment projects bought at the beginning of the n^{th} year

$q_-^{(n)}$ = number of standard investment projects sold at the beginning of the n^{th} year

λ_q = stamp duty for the purchase of standard investment projects related to the total price.

be profitable. It is essential that both investment and financing problems should be optimally solved by the model. All activities of the model other than the cutting and silvicultural strategies of timber growing represent investment or financing other than that on production. The majority of these other possible strategies are financial investments. According to the numerical starting assumptions of the model, the proportion of revenue obtained from the forest holding, even by intense cutting, is only a relatively small part of the total economy of the personal enterprise. For this reason, during the planning period the entrepreneur may not consider it necessary to prevent an even intense realization (by regeneration cuttings) of the growing stock of the forest holding (stands 5 and 6 of the example). The assumption is that none of the alternative cutting and silvicultural strategies during the planning period is contrary to the legislation in force.

On the other hand, the person's money received was made proportionate to his salary and other income which were estimated to remain approximately constant. This was done to ensure that even intense cuttings could not be able to jeopardize his subsistence after the end of the planning period. In such a case, the capital gave a better profit when invested in projects other than the forest. The entrepreneur never even considered the sale of the forest holding as such, but he could sell certain parts for recreational and other comparable purposes. It was assumed that forestry did not incur any appreciable disadvantage from the loss of these areas, especially as replacement was possible by the purchase of forest areas e.g. from the neighbouring farms at their forestry prices. This possibility, admittedly, is not explicitly included in the model.

Should the entrepreneur so desire, the cuttings, structure of the removal, areas to be regenerated, method of regeneration, etc. can be regulated by means of the restricted or fixed goals of the model, and by constraints. The same applies to planning situations in which shortage of the production factors of primary or secondary forestry, or the like, is foreseen within the planning period. Often such a shortage depends on many factors and is difficult to estimate in advance. Constraints due to a shortage of production factors are apparently most realistic in the planning models of relatively large forest holdings. When an overall review of a personal enterprise is in question, it is usually pointless, from the entrepreneur's point of view, to plan certain activities in greater detail than others. If, however, a steady income from forestry, from year to year, is of essential importance to the person's subsistence (including earnings from work), the continuity of income must be ensured in the model in the way described. The same applies in general to situations in which the chronological uniformity of forest holding activities is of considerable importance.

As regards the chronological direction of the cash flows and assets of the model under review, the following should be borne in mind:

The cash flows are thought of as being directed towards the turn of the calendar year. To put this more precisely, the various income-yielding assets are bought or sold at the beginning of each year, whereas their net yield, or the expenditures and money received, are directed to the end of each year. In reality, this means that the purchases or sales of assets of the n^{th} year run through the cash account of the n^{th} year, whereas the various running returns and expenditures of the corresponding year affect the amount of cash kept »open» at the moment between the end of one year and the beginning of the next. As a result, the running returns and expenditures of the last (N^{th}) year of the planning period have been directly taken into account in the goal function (the cash is open N times but cash flow events take place at N + 1 dates). The loans were assumed to be organized

so that a loan for the whole year is taken at the beginning of each year, and at the same date the total loan of the preceding year is repaid, etc. (at the beginning of the planning period the enterprise had no loan carried over from the preceding year). A great part of the cash flows was inflated by the probable increase percentage of the prices and fees (see Hämäläinen 1971) in order to make the cash flows, and especially the liquidity constraint, as true as possible. The fact that e.g. the enterprise loans were kept at their face value, conforms to present-day reality in Finland. Bonds, if sold, were also taken to have been sold at their face value. The running cash flows of the forest holding (the »constant mean prices» of the Lake District of Finland; see Table 5) are quoted in the model converted into the value of money of each year involved (1, . . . ,N). This was necessitated by technical calculatory factors connected with the empirical material.

The present personal enterprise model is linear, and can therefore be solved by using the calculation techniques of linear programming. »Linear programming is a mathematical technique which yields the optimum solution to problems defined by a linear objective function subject to a set of linear constraints» (Naylor and Vernon 1969, p. 157). »Linear programming deals with the problem of allocating limited resources among competing activities in an optimal manner» (Hillier and Lieberman 1968, p. 127). The linear programming model can be solved e.g. by means of the so-called simplex algorithm (see Gass, 1958, especially p. 50—70; Manninen 1967, p. 79—107). In this model, activities are represented e.g. by the various cutting and silvicultural strategies for the stands, potential sales of certain stands for purposes of recreation, investment in bonds, shares and stock, etc. An alternative term in general use is process. These processes can be used (implemented) at different positive levels within the limits the available resources permit. In order that the process and their given conditions can be formulated into a problem that can be solved by linear programming in its basic form, the following assumptions must be met (Danø 1968,p. 31—32; Hillier and Lieberman 1968, p. 135—138; Naylor and Vernon 1969, p. 158—159):

(1) All prices are constant independent of the level of any possible processes. This is an assumption of perfect competition (cf. Naylor and Vernon 1969, p. 158).

(2) Linearity, or the output volume bears a constant ratio to the amount of the production factors available. When the amount of all inputs is doubled, the output also becomes double.

(3) Divisibility. Every alternative process can be used at any positive level as long as the adequate resources are available. There is no

incomplete use of the production factors due to their indivisibility. As a result, each activity can be contained in the optimum plan to any positive extent permitted by the resource constraints.

(4) A d d i t i v i t y. Let us assume that two or more processes can be used simultaneously within the resource constraints given. The amount of inputs in relation to outputs is independent of whether only one process is used or whether several processes are simultaneously in use. Bearing in mind the assumptions under Items 1—3 and 5, it can be said that the revenue of the enterprise is the sum of the revenues of the different processes, and the expenditure is the sum of the corresponding expenditures.

(5) F i n i t e n e s s. The number of the processes is finite.

In discussing financial investments, it is naturally somewhat strange to use the terminology of production sector, but it does not change the principle itself. The present model of personal enterprise fulfils all the above conditions of linear programming. This was largely manifested in the above bases of calculation, although all details could not be specified here. It may be said, in conclusion, that the revenue and expenditure of the small and medium-sized forest holdings usually found in a personal enterprise, especially in Finnish conditions (the taxable revenue is even essentially determined by the site quality of the stand compartments) can with little trouble be directed to a stand according to the causation principle. This is the case particularly when, for example, the management of the forest holding uses outside services for projects (marking the stand for cutting, supervision of timber conversion, roundwood delivery, silvicultural project, etc.). The number of personal enterprises of this type will apparently increase greatly with the structural change of society. This is another reason why it is useful to review a forest holding as a component of a personal enterprise.

44. Determination of the variables and parameters of the models

441. General

The premises on which the determination of yields per stand was based, were described in Chapters 4131 and 4132. Table 5 showed that, in the profitability calculations per stand according to the classical partial models, alternative assumptions were made concerning the development (after 1967/68) of roundwood prices and the various kinds of expenditure. The underlying fact was that a prediction of prices and unit costs, especially at »long sight», is uncertain. Probabilities, at least objective ones, cannot be combined with the alternative conditions of these environmental variables. In the present study, however, time series were compiled concerning

timber assortment prices and the various kinds of expenditure, and were processed to suit the calculation situations in question. Using the method of least squares, various forms of functions in which time seemingly was the independent variable, were then tried out on the time series of the annual regional mean values of the dependent stumpage price or unit cost.

The formation of roundwood prices and various costs in the past has been influenced by numerous factors. In an evolutionary economy, the influence of these factors, and therefore also their ability to predict and/or explain the phenomenon studied, changes with time. When the environmental conditions presupposed by the planning model are involved, the influence of certain variables may cease completely, and they may be replaced by new variables in the course of time (see Chapter 222).

Against this background, one should not overemphasize the possibility of forecasting future phenomena at long sight by means of prognostic methods based on a causal connection, ascertained by regression analysis over a certain period or only at a certain point of time, between certain influencing factors of an economic system (independent variables) and the dependent economic variable studied. From the point of view of the reliability of the forecast, it is always necessary to use sound criticism in projecting into the future any causal connections that have been established by past or present observations (cf. Gerfin 1964, p. 15, 29).

Even if the causal connections between the phenomenon to be forecast and the economically influencing factors explaining it, were valid also in the future, they would, — e.g. when a partial analysis similar to a regression analysis is used — have to be (a) unequivocal and (b) in only one direction, in the sense that only the independent variable affects the dependent variable (Gerfin 1964, p. 44). The use of independent variables in forecasting a phenomenon is naturally only sensible when their future development can be predicted more reliably and/or more easily than that of the dependent variable itself. This is a fact that is often forgotten (Gerfin 1964, p. 45).

442. *Price and cost elements in forestry*

4421. Roundwood prices and harvesting expenditures

44211. Principles of determining removal prices

An individual forest owner has little chance of affecting the stumpage or delivery price level obtainable for a roundwood lot of certain quality standards, at a certain date and in a certain place. The price level for roundwood is for him perhaps the most important environmental variable. Usually

all that is left for the forest owner to do, is to adjust the volume, quality and size (logs) of the timber to be felled, to the price that can be derived from the prevailing stumpage price level on the basis of the individual characteristics of the area of timber marked for cutting or the volume to be delivered. Both in Finland and many other countries today, forest owners' organizations, by negotiation with other interest groups, can affect the proportion that the forest owners obtain from the price of the finished forest industry product, in other words, the formation of the roundwood price level in the different parts of the country. This apportioning of revenue is therefore a result, mainly, of collective bargaining. In principle, therefore, it is no longer relevant to say that the roundwood price level is the residual revenue, that is to say, what remains of the market price of the finished forest industry product after the other interest groups have first taken the shares they deemed fit. In today's society the most essential income division agreements, at least in principle, are made as the simultaneous compromises of several interest groups, and the result depends very much on each party's power of active influence.

The final d e l i v e r y p r i c e obtained by an individual forest owner for his roundwood, within the framework of the regional price level, depends mainly on the geographical location of his forest holding vis-à-vis the roundwood users, mainly forest industry. In Finnish conditions, so far only for logs, it also depends on the quality and stem size of the roundwood lots. The s t u m p a g e p r i c e, both for the sale of standing trees and remaining to the forest owner for delivery sales, is additionally influenced mainly by the individual cost of felling and short-distance transport per area of timber marked for cutting. These were also taken into account in the present calculations.

A starting alternative of price determination for yield series per stand was the average delivery price level for logs and pulpwood in the privately owned forest holdings of the Lake District of Finland. Formula 16 and the accompanying description reveal, broadly, how the d e l i v e r y p r i c e ($p_t^{(d)}$) and further the corresponding s t u m p a g e p r i c e (p_t) of roundwood lots felled at different ages, according to each stand treatment alternative, were derived from the average delivery price ($\bar{p}_t^{(d)}$) in the Lake District of Finland.

$$\underbrace{s_t \overbrace{(\bar{p}_t + \bar{h}_t)}^{\bar{p}_t^{(d)}}}_{p_t^{(d)}} - h_t = p_t \tag{16}$$

The delivery price ($p_t^{(d)}$) of a p i n e p u l p w o o d l o t to be felled t years after the date of comparison of the profitability calculation was estimated on the basis of the principle that the delivery price obtained

by the forest owner that year was the sum of the average stumpage price ($\bar{p}_t$) for privately owned forests in the Lake District of Finland and the average unit cost for timber harvesting ($\bar{h}_t$). The result he obtained for timber harvesting was, therefore, ± 0. The main reason for choosing this procedure was that no suitable time series were available for a direct estimation of the delivery price. Furthermore, it could be assumed that heaviness of logs, quality and other similar factors even in the future would not affect the d e l i v e r y price of pulpwood, in other words, the value ratio coefficient s_t had to be given the value 1. This was not a matter of principle but a matter of practice: (a) the quality of the yields of yield series had not been investigated; (b) payment according to quality has not been applied in Finland to pulpwood sales, and no empirical material was therefore available. The stumpage price remaining to the forest owner for each lot of pulpwood depended on the individual harvesting cost of this lot (h_t); this cost also included the cost of planning and supervising the work. When the delivery price of p i n e l o g s felled from the stand at different points of age was determined, it was taken into account that the unit price (delivery price) for a consignment of logs delivered to a certain place and of a certain volume also varies (value ratio coefficient $s_t \gtreqless 1$). Especial factors affecting the delivery price naturally include the stem size and quality. In the absence of field observations, however, the present study had to disregard the effect of stand treatment methods on the quality of the logs, and therefore also the quality as a factor affecting the price. But an estimated allowance was made for the influence of branchiness on the cost of log harvesting. The only individual factor affecting the delivery price of logs cut from the stand at a given time that could be taken into account was, therefore, the average heaviness of logs. This was done with the aid of a value ratio coefficient (s_t) based on a certain value ratio grading. The grading was built on study results reported by H e i s k a n e n (1968 a, b) and H e i s k a n e n and A s i k a i n e n (1969). In principle, the effect of the heaviness of saw logs on the delivery price should be determined as a function of time. This determination, in a kind of basic year of the price and cost estimates of the present study, 1967/68, was associated with certain difficulties and a partial subjectivity (cf. H e i s k a n e n 1968 a). It was therefore considered appropriate to keep the value grading as an unchanged function of time.

Chapters 44212 and 44213 describe the additional features which the price determination of removals per stand acquired in the situations outlined in Table 5, Items I_2, I_3 and I_4.

In the calculations concerned with the m i n i m u m and m a x i m u m s t u m p a g e p r i c e r e g i o n s of the Lake District of Finland (Table 5, Item II_1 and III_1), $\bar{p}_t$ referred separately to the mean stumpage price

of either timber assortment in these subregions. However, the unit cost of harvesting corresponding to the average stumpage price, and the relevant unit cost per lot, were the same as in the average calculations for the Lake District of Finland (the same timber harvesting tariffs were valid throughout the Lake District). In calculations using the sum of ownership revenue and the work earnings as profitability criterion, p_t referred to a delivery price from which only the value of the use of material production factors had been subtracted, viz. the price that made the basis for calculating the income type of Item 3 in the schedule contained in Chapter 42 (p. 118).

44212. Determination of the stumpage price level for roundwood

In order to eliminate from the long-term profitability calculations the relatively heavy variations in time series of stumpage prices for roundwood, trend values were also used in calculations at the constant average prices of the Lake District of Finland (Table 5, Item I_1). The time series of the average stumpage prices for the Lake District of Finland were constructed using the following main principles.

No materials were available on the stumpage prices of pine logs; the basis used was stumpage price statistics for coniferous logs (pine and spruce together). Statistics on the stumpage prices of pine pulpwood for the felling seasons 1955/56 to 1967/68 were available from the Forest Research Institute. The stumpage price statistics for pine pulpwood and coniferous logs in the felling seasons 1949/50 to 1954/55, published by Selin (1957), were also based on Forest Research Institute materials. The stumpage price statistics for privately owned forests kept by the Forest Research Institute, therefore constituted the main source. Annual mean stumpage prices by timber assortments in the Lake District of Finland were calculated from them, and weighted by roundwood sales in the subregions. The stumpage prices for coniferous logs were converted into those for pine logs, multiplying them by 1.05. This figure was based (a) on determining the approximate proportion of pine among the industrially processed coniferous logs in 1955—66 (from the Archives of the Forest Research Institute, Department of Forest Economics), and (b) on the difference between the stumpage prices of pine and spruce logs in the felling seasons 1966/67 and 1967/68, according to various sources. The stumpage price series for the felling seasons 1949/50 —1967/68 were converted into the value of money at the end of the time series by using the total index for wholesale prices, with 1949 = 100.

Other types of time series of stumpage prices for coniferous logs were also formed for the purpose of checking the functions calculated on the basis of the stumpage price time series covering the Lake District of Finland. A time series for the stumpage prices of coniferous logs in the whole of Finland from 1913 to 1967 was compiled from data obtained from the following publications supplemented by other sources: Heikinheimo 1954, p. 4, 7; Saari 1923, p. 96, 1932, p. 42, 102; Selin 1957, p. 66; Sivonen 1964, p. 15, and the Finnish Sawmill Owners' Association. The compiled time series applies to stumpage prices paid on the sale of standing timber. Its material for 1913—19 and 1927—32 consisted exclusively of the stumpage

prices for the sales of standing timber from state-owned forests. Various approximation methods were used to make the coverage of the time series identical to that of its other chronological parts. This time series reflects in the first place the long-term trend of the level of stumpage prices paid by large and fairly large sawmills for coniferous logs bought on the stump (the annual stumpage prices were converted into the value of money of the felling season 1967/68, using the total index for wholesale prices, with 1913 = 100).

Regression equations in which calendar time was the only independent variable for the stumpage price, were formed on the basis of the stumpage price time series. This regression ratio can be expressed by the formula

(17) $y = f(x) + \varepsilon$, in which

x = calendar time in years from a certain zero year (in later equations, from the felling season 1900/01);

ε = a random variable, representing the so-called errors of the equation. They are produced by variables which may affect the value of y but are not contained in the equation as independent variables. In order that the statistical reliability tests for the parameters of the function can be carried out by the customary methods, ε must meet the following requirements (T i n t n e r 1960, p. 42):

— its mean value = 0;
— it has a constant finite dispersion;
— its values are normally distributed;
— its values are stochastically independent.

All of these requirements cannot usually be met in practice. Specialized studies have shown, on the other hand, that the usual statistical reliability tests (the t-test and the F-test) are valid, although the population may not be normally distributed, provided the skewness is not »very» great (T i n t n e r 1970, p. 29—30). In the time series, in particular, the ε values, or residuals, contrary to the above requirements, are usually intercorrelated; in other words, an autocorrelation exists between the residuals (see e.g. T i n t n e r 1960, p. 188—294).

The classical least-squares method is one of the methods that can be used to determine the values of the parameters of the regression function (T i n t n e r 1960, p. 31—34). The autocorrelation of the residuals does not distort the parameter values obtainable by the least-squares method, but it affects the standard deviation of the regression coefficients and thus their statistical reliability test (T i n t n e r 1960, p. 302). However, if there is only one independent variable, it is possible to calculate a figure with which the t-value of regression coefficient (here also = correlation coefficient), calculated as usual from the autocorrelated series of observations, is multiplied. This product is fit for the reliability fest (T i n t-

n e r 1960, p. 302—305). In the present study, the models best fitted for the application of the least-squares method to the time series were to help in the outlining of the possible long-term main trend alternatives. In this connection, therefore, no time functions indicative of a fluctuation of the stumpage price were tried out.

The gauge measuring the »validity» of the models, i.e. the information provided by calendar time, was the so-called coefficient of determination, r^2 (r = correlation coefficient), which expresses that part of the total variation of variable y (stumpage price) that can be determined with the aid of variable x (time) (M a t t i l a 1960, p. 59). The prerequisites of the routine statistical reliability test (t-test) of regression coefficient and correlation coefficient were studied by calculating the first-order autocorrelation coefficient of each stumpage price series (T i n t n e r 1960, p. 289—290), eliminating the trend with a relevant equation. When testing the significance of the deviation from zero of the autocorrelation coefficient, the t-value must be calculated by the method of approximation. M a t t i l a has presented such a method in his lectures on statistics. Under this method, $\frac{1}{n}$ (n = number of observations) is added to the value of the autocorrelation coefficient, s_r is calculated with the aid of the autocorrelation coefficient corrected in this way, and the t-value is further calculated as usual.

Table 6 shows that in the long-term stumpage price series for coniferous logs in the whole country from 1913 to 1967/68, the autocorrelation of the residuals is statistically highly significant. It is apparent that, should the series for the Lake District of Finland cover a longer period, the autocorrelation would be statistically significant. For pulpwood, in particular, the short-term Korean boom, in other words, the peak price of the 1951/52 felling season, reduced the values of both the autocorrelation coefficient and the coefficient of determination. It also greatly increased the dispersion of the regression coefficient and thus reduced the t-values of the parameters quoted in Table 6. The t-values shown in Column 5 were obtained by multiplying the routinely calculated values (Column 4) by the coefficients given by T i n t n e r (1960, p. 302—305), to which reference was made earlier. The higher the first-order autocorrelation coefficient, the greater the said correction coefficient. For example, with pine logs, the significance of the deviation from zero of the regression coefficient, according to the corrected t-value, becomes statistically almost significant in the linear model (the probability of error $P \leq 0.05$).

Due to the heavy variations in the stumpage price series, each time function not corresponding to these variations can explain only a part of the stumpage price variation. The calculation of the functions was intended to show, in the first place, the smoothed stumpage price each function gives

Table 6. Real stumpage prices presented as linear functions of calendar time. x is the time between the given calendar year and the year 1900. The stumpage prices are given in the value of money of the felling year 1967/68; Fmk/piled cu.m. of 2-metre pulpwood including bark and Fmk per cu.ft. for logs.

Timber assortment and time series	Stumpage price Fmk as a function of time	r^2	$t_r = t_b$		1. order autocorrelation coefficient	t-value	$\bar{P}$ 1967/68 Fmk	The real increase of the stumpage price, per cent 1967/68	Coefficient by which the price extrapolation, presupposed by the model, is obtained from the mean stumpage price of the felling year 1967/68, when it has passed:				
			uncorrected	corrected [1]					10 years	20 years	40 years	60 years	80 years
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Coniferous logs, whole country, time series 1913—1967/68 (total index for wholesale prices, with 1913 = 100)	$\bar{P}=0.1937+0{,}01860x$	0.563	8.271***	19.470***	0.694	7.461***	1.44	1.29	1.129	1.258	1.517	1.775	2.033
Pine logs, the Lake District of Finland, time series 1949/50—1967/68 (total index for wholesale prices, with 1949 = 100)	$\bar{P}=0.1684+0.02316x$	0.172	1.880	2.591*	0.310	1.650	1.72	1.35	1.135	1.269	1.539	1.808	2.077
Pine pulpwood, 2-metre incl. bark, the Lake District of Finland, time series 1949/50—1967/68 (total index for wholesale prices, with 1949 = 100)	$\bar{P}=7.1686+0.04614x$	0.006	0.316	0.339	0.070	0.523	10.26	0.45	1.045	1.090	1.180	1.270	1.360
Coniferous logs, whole country, time series 1949/50—1967/68 (total index for wholesale prices, with 1913 = 100)	$\bar{P}=-0.2900+0.02735x$	0.268	2.497*	4.237***	0.485	2.702*	1.54	1.77	1.177	1.355	1.709	2.064	2.419
Coniferous logs, whole country, time series 1949/50—1967/68 (total index for wholesale prices, with 1949 = 100)	$\bar{P}=-0.3124+0.02770x$	0.265	2.477*	4.070***	0.459	2.528*	1.54	1.79	1.179	1.359	1.718	2.077	2.436

[1]) The t-values of this Column have been obtained by making the corrections of the values of Column 4, derived from the autocorrelation of the time series, mentioned in the text.

for the felling season 1967/68 and in the future, after periods of different lengths. The linear equations of the mean stumpage prices for coniferous logs in the whole country, presented in Table 6, also indicate the extent to which the years covered by the time series (the years to which it is applied), and the length of the series affect the parameter values of the regression equation, and the forecasts calculated from the equation. The differences in the stumpage price sources make it difficult to say with certainty whether the mean stumpage price of coniferous logs (the price of standing timber) in 1949/50—1967/68 really increased more in the whole country than in the privately owned forests of the Lake District of Finland.

The linear model, calculated on the basis of the »long» time series of the stumpage price of coniferous logs in the whole country shows, however, in 1967/68, almost the same increase percentage as the linear equation calculated on the basis of the »short» time series for the private forests of the Lake District of Finland. Hence the ratios of the extrapolated linear models based on the »long» series for the coniferous logs of the whole country and the »short» series for pine logs in the Lake District of Finland remain almost unchanged over a long period of time.

The $\bar{p}$ for pine logs at the level of the felling season 1967/68 (Table 5, p. 119, Items I_1—I_3) was taken to be Fmk 1.72/cu.ft. as indicated by the linear model. Practically the same trend value was also obtained with the other models estimated. The linear model was also applied to calculations in which the real stumpage price level of pine logs was assumed to increase in the future (Table 5, Item I_4), because over a long period it gave results which subjectively seemed plausible. In selecting the form of function, emphasis was placed also on the long-term trend development of coniferous logs in the whole country. An increase was assumed to continue for 80 years onwards from the base year (stand age of 21 years) of the calculation, after which the stumpage price level was assumed to remain constant at the level it had reached. The time series for the stumpage price of pine pulpwood is too short and too varying to permit compilation of an ex post trend that could be based on statistical parameters. In the absence of better knowledge, both the determination of the trend value (Fmk 10.26 piled cu.m. of 2-metre pulpwood including bark), and the price estimates indicating future stumpage price increases, were based on the linear equation of Table 6. In this case, too, the increase was assumed to continue for 80 years, after which the real stumpage price level was assumed to remain at the level it had reached (Fmk 13.95/piled cu.m.). Apparently the difference between the relative increases in the linear trends of the stumpage prices of pine logs and pine pulpwood shown in Column 9 of Table 6 (in 1967/68) shows the true trend. Although the stumpage price level is also affected by many factors independent of forestry, the contin-

uous increase in the unit costs of harvesting has adversely affected the chances of any increase in the stumpage price of pulpwood. A continuing increase in harvesting costs in the future will obviously augment the pressure against the stumpage price of pulpwood.

Forecasts of the development of the stumpage price level are extremely difficult, and are ultimately a matter of subjective deliberation and a knowledge of this branch. Mechanical extrapolations only indicate the direction in which certain possible developmental trends may lead.

Other roundwood market phenomena which an individual forest owner cannot affect, are the irregular and cyclical variations in stumpage prices. The variation is usually widest in the development of raw material prices (Kostiainen et al. 1970, p. 41). The cyclical variations in roundwood stumpage prices are an obvious reality in the near future. By adjusting his fellings to cyclical variations as well as possible, the forest owner can improve the business-economic profitability of timber growing. But adjustment of sales to sudden and unpredictable, irregular stumpage price variations incurs difficulties, especially in the case of large forest holdings. The calculation variant of Table 5, Item I_2 is an attempt to illustrate how the profitability ranking of a stand's cutting and silvicultural strategies is affected by a forest owner who cuts irrespective of the cyclical variations in stumpage prices. With a view to this alternative of roundwood price determination, the stumpage price series of Table 7 were studied to see whether they showed any cyclical variation.

First, the cyclical variation indices were determined from these real stumpage price series. The trend was eliminated by means of linear models, and the irregular variations were eliminated by calculating three-year moving averages from trend-free indices. Then the following procedure was applied to each time series separately: the depressions and booms of the cycles (the periodically recurring minima and maxima of the cyclical indices) that were contained in the time series were established. The percentage by which each minimum index was below, and that by which each maximum index was above the basic index (100) was determined. Mean values of the minimum and maximum indices were calculated separately. The results are shown in Table 7. The mean duration of cycles was determined by dividing the interval from the first to the last depression of the price series by the number of the business cycles.

The time series of coniferous logs in Table 7 shows that the duration of the stumpage price cycle, and especially the amplitude of the depressions, in the course of decades, have been reduced. On the basis of the figures of the table, the duration of the business cycle, for purposes of determining the »cyclical prices» of the removals, was estimated as 10 years both for pine logs and pine pulpwood, and the amplitude of the cyclical index, both for the time of depression and boom, was estimated as 15 per cent of the

Table 7. Mean amplitudes (per cent of the basic value of 100) of business cycles calculated from time series[1]) of stumpage prices, and the mean durations of the corresponding cycles

Time series of stumpage prices	Interval of cyclical survey [2])	Depression amplitudes		Boom amplitudes		Mean duration of business cycle, years
		No. of depressions during interval	Mean amplitude, per cent of the basic index	No. of booms during interval	Mean amplitude, per cent of the basic index	
1	2	3	4	5	6	7
Coniferous logs, whole country	1913 —68/69	5	—30	5	+35	12
	1947/48—68/69	3	—23	2	+23	10.5
	1957/58—68/69	2	—16	1	+24	11
Pine logs, the Lake District of Finland ..	1947/48—68/69	3	—23	2	+19	10.5
	1957/58—68/69	2	—18	1	+18	11
Pine pulpwood, the Lake District of Finland ..	1947/48—67/68	3	—24	2	+31	10
	1958/59—68/69	2	—17	1	+31	9

basic value. These figures equal approximately the values of the last cycle, apart from pulpwood which showed a much larger amplitude of the upswing. It seems probable that the stumpage price cycles in the future will be gradually smoothed (cf. G e r f i n 1964, p. 4—5).

The graphs (waves) of the cyclical indices of stumpage prices, eliminated from trend and irregular variations, are by no means symmetrical. Sometimes the expansion is steeper than the recession, or vice versa, and the rate of change varies irregularly from one year to the next. Since it is impossible to forecast precisely the cyclical indices even within a given duration and amplitude of the cycle, the s i n e c u r v e was chosen as the schematic graph of the cyclical index. The graph of the cyclical indices (basic index 100), therefore, has the form:

$$(18) \qquad y_n = 100 + 15 \sin \frac{\pi}{5} (n + n_0), \text{ where}$$

n = ordinal number of the year of the business cycle from one minimum to the next ($n = 0 \ldots 10$);

n_0 = phase of the cycle. When the cycle is 10 years long and begins from its minimum (year 0) on the ordinate, n_0 has the value —2.5.

[1]) The annual stumpage prices of the time series have been converted into the value of money at the end of the time series.

[2]) This includes the felling season 1968/69 in those cases in which this was the year of depression in a business cycle, calculated as the moving averages of three years. The stumpage price sources are the same as for the earlier years. The time series of pine logs and pine pulpwood began as late as 1949/50. To establish the year of depression in the business cycle coinciding with the beginning of these time series, the pre-1949/50 stumpage prices of pine logs and pine pulpwood were, if possible, estimated. The assumption was that the unknown annual prices of the time series were similarly related to their 1949/50 numerical values as were those of the coniferous logs in the time series for the whole country.

Table 8. Cyclical indices of the stumpage prices in stand calculations at cyclical prices in the years of the first half of the business cycle, and the stumpage prices derived on the basis of the indices from the trend prices (index = 100) of the felling season 1967/68

Explanation	The nth year of business cycle [1]					
	0	1	2	3	4	5
1	2	3	4	5	6	7
Cyclical index y_n	85	88	95	105	112	115
Stumpage prices corresponding to y_n:						
— pine logs, Fmk/cu.ft.	1.46	1.51	1.63	1.81	1.93	1.98
— pine pulpwood (2-metre, incl. bark) Fmk/piled cu.m.	8.72	9.03	9.75	10.77	11.49	11.80

The cyclical indices calculated on the basis of Formula (18), and the corresponding stumpage prices, are shown in Table 8.

The schematic business cycle model presented would seem to be based on an assumed mechanical analogy according to which the future cyclical variations in stumpage price were regular and recurred irrevocably (cf. V a i v i o 1955, p. 60); no mathematical probabilities of this recurrence could be calculated. It should be emphasized, therefore, that this business cycle model is no price forecast. It is only an effort to quantify approximately the influence of possible cyclical stumpage price variations on the profitability ranking of cutting and silvicultural alternatives per stand.

In reality, the base year (here, a stand age of 21 years) of the profitability calculation per stand can fall on any year of the cycle. For this reason, the stumpage prices of the years 0. . .9 of the cycle were each in turn inserted as the base year of the profitability calculations. The fluctuation of the real mean stumpage price beginning from each of these years was assumed to continue for 80 years, that is, during 8 cycles. After this, the mean stumpage price was assumed to settle at the constant mean price level of the cycle (Fmk 1.72/cu.ft. and Fmk 10.26/piled cu.m.).

Profitability calculations by the stand were also carried out applying the 1967/68 trend level of the m i n i m u m and m a x i m u m s t u m p a g e p r i c e s for the Lake District of Finland (see Table 5, Items II and III). Table 9 shows the results concerning both these extreme stumpage prices and the mean stumpage prices of the Lake District of Finland. The maximum and minimum stumpage prices used in profitability calculations were: pine logs Fmk 2.02/cu. ft. and Fmk 1.18/cu. ft., pine pulpwood, 2-metre incl. bark, Fmk 13.78/piled cu.m. and Fmk 5.15/piled cu.m. The following procedure was used to determine the extreme stumpage prices.

[1]) In the case of an individual cycle, half the 0th year belongs to the previous and half the 10th year to the following cycle. The figures for years 6, 7, 8, 9 and 10 of the cycle are the same as those for years 4, 3, 2, 1 and 0, in the corresponding order.

Table 9. Real stumpage prices of pine logs and 2-metre long industrial cordwood incl. bark (at the value of money of the felling season 1967/68), and corresponding price relations [1]) in different price conditions of the Lake District of Finland.

Time series of stumpage prices, and its utilization	Stumpage price, average for the Lake District of Finland		Stumpage price in communes, with								Price relations	
			highest stumpage price of coniferous logs		highest stumpage price of industrial pine cordwood		lowest stumpage price of coniferous logs		lowest stumpage price of industrial pine cordwood		10x Col.4 / Col.7	10x Col.8 / Col.11
	Pine logs, Fmk/ cu.ft.	Pine cordwood Fmk/ piled cu.m.	Pine logs, Fmk/ cu.ft.	Pine cordwood Fmk/ piled cu.m.	Pine logs, Fmk/ cu.ft.	Pine cordwood Fmk/ piled cu.m.	Pine logs, Fmk/ cu.ft.	Pine cordwood Fmk/ piled cu.m.	Pine logs, Fmk/ cu.ft.	Pine cordwood Fmk/ piled cu.m.		
1	2	3	4	5	6	7	8	9	10	11	12	13
1. Trend values for 1949/50—1967/68[2])	**1.72** (1.676)	**10.26**	**2.02** (1.715)	11.78	1.85 (1.343)	**13.78**	**1.18** (2.088)	5.65	1.21 (2.350)	**5.15**	**1.466**	**2.291**
2. Mean for 1958/59—67/68 (the last business cycle)	1.60 (1.606)	9.96	1.83 (1.652)	11.08	1.71 (1.313)	13.02	1.15 (2.043)	5.63	1.17 (2.171)	5.39	1.406	2.134
3. Annual means in 1955/56—1967/68	1.54 (1.606)	9.59	1.81 (1.644)	11.01	1.66 (1.289)	12.88	1.06 (2.008)	5.28	1.08 (2.245)	4.81	1.405	2.204

[1]) The figures in brackets in the table refer to the ratio (10 times the stumpage price of pine logs per cu.f.t. divided by the stumpage price of industrial pine cordwood, 2-metre, incl. bark, per piled cu. m.) in the price conditions specified in the top part of the heading. For example, 10×1.72 divided by $10.26 = 1.676$ etc. The figures in boldface were used as mean stumpage prices for the calculations in Table 5. p. 119, Items I_1 and I_3, and II_1 and III_1.

[2]) Figures other than those of Columns 2 and 3 were derived, in the way described in the text, from figures for the felling seasons 1955/56 through 1967/68 (line 3), since no minimum and maximum stumpage price information existed prior to 1955/56.

Mean stumpage prices per commune, supplied by the Forest Research Institute were only available from 1955/56 onwards. From these price lists were found, from 1955/56m to 1967/68, fro each cutting season, the Lake District commune(s), in which the stumpage price of industrial pine cordwood and that of coniferous logs, separately, were (a) at their minimum, (b) at their maximum. The stumpage prices of Table 9, lines 2 and 3, could then be calculated from stumpage price series that had been converted as to be real. The 1967/68 trend values (line 1) of the maximum and minimum stumpage prices of the two timber assortments were determined by the approximation method. For this purpose, the maximum and minimum figures by timber assortment of line 3 were multiplied by the ratio, the average for the Lake District of Finland, of the 1967/68 trend value of the same timber assortment (line 1) and the mean value for the felling seasons 1955/56—1967/68; for pine logs this ratio was 1.117 and for cordwood 1.070.

The method described has probably given slightly too high 1967/68 trend values of the maximum stumpage prices. But the ratios of the maximum stumpage prices apparently corresponded almost exactly to those that would have been obtained by calculation, had price material been available also for the period 1949/50—1954/55. It is evident that the trend values of the minimum stumpage prices are slightly lower than the true values, at least for industrial cordwood. Consequently, the price ratio of 2.291 for the trend values of the minimum stumpage prices, of Column 13, probably equals the lowest-priced parts, even in a commune representing the minimum stumpage price of pulpwood.

The extreme stumpage prices of two timber assortments used in the present study refer, separately, to the extreme prices of both timber assortments. It is true that the minimum prices of both timber assortments in many felling seasons were obtained from the same commune. The maximum stumpage prices of the calculations correspond approximately to the trend level (1967/68) of the stumpage prices of individual forest holdings situated in the southern parts of the Lake District of Finland, within a short distance of a highly competitive sawmill plant and also an industrial plant using pulpwood. The level of the minimum stumpage prices corresponds to the prices fetched by forest holdings situated in the eastern parts of North Karelia, at awkward distances from industrial plants of these two types.

44213. Determination of the cost of roundwood harvesting

Before the stumpage price of wood quantities felled from a stand could be determined, it was necessary to determine the mean harvesting cost ($\overline{h}_t$) by timber assortments, against each mean stumpage price ($\overline{p}_t$) of the roundwood market, and the harvesting cost (h_t) for the pulpwood and log removals from the stand at the relevant ages. Like $\overline{p}_t$, the real values of $\overline{h}_t$ and h_t in the different calculation variants (Table 5) were also assumed either to remain constant or increase as a function of time.

No time series to show the development of the cost of roundwood harvesting in privately owned forests were available. For this reason the

mean cost of harvesting ($\bar{h}_0$) in 1967/68, by timber assortments, had to be estimated in some way other than trend calculations. The calculation of the mean cost of pine pulpwood harvesting in 1967/68 was based on the principle used by the parties to the agreement on a price recommendation for pulpwood in another region comparable to the Lake District of Finland. The unit cost of harvesting a medium-quality pine pulpwood stand, marked for cutting was determined for the agreement. According to the cost level of the felling season 1967/68, the value obtained for $\bar{h}_0$ was Fmk 9.65 per piled cu.m., for 2-metre pulpwood incl. bark. The figure includes the social security costs and the cost of work supervision, on grounds identical to those applied to unit costs per felling quantity (h_t), to be described in detail later. The $\bar{h}_0$ of pine logs (Fmk 0.44 per cu.ft.) was estimated in much the same way as the corresponding mean value for pulpwood.

The mean cost of harvesting either of the two timber assortments was taken to be the same, both in profitability calculations with the minimum and maximum stumpage prices and those with the mean stumpage prices of the Lake District of Finland. This was because the cost of harvesting, according to the workers' union contract, was the same throughout the Lake District. Since, in the calculations at cyclical prices it was assumed that the trend of the mean stumpage price remained constant at the 1967/68 level, the same assumption was made, for the sake of uniformity and simplicity, also concerning the mean cost of harvesting. Another assumption made was that the mean cost of harvesting does not fluctuate, despite the fact that the actual harvesting cost obviously contains a certain amount of cyclical variation. However, this will also have affected the annual mean stumpage prices of the past and therefore, in principle, the cyclical indices of the stumpage prices.

Estimates that were felt to be realistic, concerning the main development of $\bar{h}_t$ in the future (Table 5, Items I_3 and I_4) were attempted in order to keep down the number of calculations. The real development of harvesting costs in the future is governed by two main groups of factors: (a) real increase in the forest workers' wage level, increased social benefits, and changes in the real price level of forest machines and their requisites, repairs, etc.; (b) rationalization of the harvesting — including appropriate mechanization — and the resulting increased productivity of the work. Simonen (1970, p. 34—44) has published index figures on the nominal value development of forest wage rates for piece work in South Finland in the 1960s. These indices are converted here into the real value of the felling season 1967/68 (total index for wholesale prices, 1949 = 100). The annual mean increase, for 8 and 10 years separately, in the real piece rates index was calculated from the initial date of the time series, June 22, 1960. The mean increases, against the real 1967/68 index, were 2.7 and 2.6 per cent, respectively.

The Yearbook of Forest Statistics provides information, from 1957, on the development of the mean daily earnings (after deduction of power saw expenses) of the cutters working at piece rates (e.g. Yearbook . . . 1968, p. 96). The annual indices of the mean daily earnings in 1957—67 were converted into the 1967/68 real value (total index for wholesale prices, 1949 = 100). The annual mean increase of this real index series in 1957—67 was 3.3 per cent of the 1967/68 real index. In the light of these figures, it seems probable that the daily earnings of the cutters in any case have increased even more heavily than the norms for the officially valid piece rates. One reason may be the increase in productivity due to the more general and more effective use of the power saw.

No studies or statistics published in Finland were available to show how the real increase in the contract wages paid in the last few years had affected the real mean unit costs of roundwood harvesting. In Sweden, however, calculations had been made concerning the development of the forest workers' level of daily earnings on the one hand, and that of the unit costs (per solid cu.m.) of cutting and haulage (Beståndsvård . . . 1969, p. 93—99).

The calculations are based on approximate means. However, they are considered reliable enough for the emerging trends to reflect the true development (Beståndsvård . . . 1969, p. 97). The nominal-value indices of daily earnings and harvesting costs in 1950 were converted into the 1966 real value using both the Swedish consumer price index (total index, 1949 = 100) and the general wholesale price index (1949 = 100) (Statistical abstract . . . 1969, p. 109—210; Kommersiella Meddelanden . . . 1958, p. 33). The real change (mean value) per year in the level of daily earnings and the unit cost index was then calculated as a percentage of the corresponding index value in 1966.

The results of these calculations can be seen from the following table.

The variable:	Real annual change 1950—66, percentage of the 1966 value [1]	
	a	b
Cutter's daily earnings	+3.8	+3.3
Hauler's daily earnings	+3.5	+2.0
Unit cost for cutting	+1.8	+1.0
» » » haulage	—1.8	—3.1
» » » cutting + haulage	±0.0	—1.1

The populations of these calculations of the annual change in daily earnings and unit costs are not identical. However, the figures of the table can be considered to show that, despite the real increase in the cost of human labour, the real unit cost in timber harvesting in Sweden was successfully kept more or less constant in 1950—66. But the cost of cutting

[1]) In calculation of the Column a figures, the 1950 index of daily earnings or unit costs was inflated to the 1966 value of money with the Swedish general wholesale price index, and in that of Column b, with the corresponding consumer price index.

could not be kept on the same real level. On the other hand, the real unit cost of haulage has fallen. Up to 1960, this was achieved mainly by shortening the distance of haulage, and subsequently especially by mechanizing the transports (Beståndsvård . . . 1969, p. 97).

The mean annual increase (1957—67) in the real daily earnings of cutters, compared with the 1967/68 earnings (3.3 per cent), was almost the same in Finland as in Sweden, on an average for 1950—66 compared with the 1966 level. But in 1957—66 the mean annual increase in the real daily earnings in Sweden considerably exceeded the average for 1950—66: for cutters, 4.9 per cent, and for haulers, 4.8 per cent compared with the 1966 level (the standard of the value of money was the Swedish wholesale price index). Apparently the increasing influence of the higher level of real earnings on the unit costs of timber harvesting can be held in check in Finland in the next few years e.g. by reducing unessential timber sorting standards (limbing, length, etc.), by raising the timber volume to be harvested per area unit, and so on. This also involves a higher degree of mechanization, and technological and organizational innovations (cf. Beståndsvård . . . 1969, p. 127—133; H e i s k a n e n 1970; T e n h o l a 1970).

While the unit costs of timber harvesting must be kept in check, manpower apparently demands higher real earnings. The same probably applies to the forest owners' stumpage price demands. It is therefore difficult to predict the future development of the real mean cost of harvesting ($\bar{h}_t$) and mean stumpage price ($\bar{p}_t$). Difficulties increase if the development of harvesting costs is to be predicted in stands in which the difficulty of the working conditions, and other circumstances, are different.

The profitability calculations of Table 5, Item I_3 presuppose an increase in the real unit costs corresponding to the mean stumpage price of p u l p w o o d, and only those of its harvesting, after the felling season 1967/68. The basic starting point was the practically certain real rise in the level of work earnings in the future, as discussed above. In the foreseeable future, it will be necessary to cut the bulk of pulpwood from stands to be thinned, and therefore only a part of the increase in the real mean cost of harvesting can be controlled. The existing, less expensive harvesting methods can, of course, be more widely introduced, and a temporary reduction of the real mean cost could be achieved in the next few years if the real piece rates (daily earning goals) would annually increase no more than an amount equalling the said 2.7 per cent of the 1967/68 felling year level. To avoid excessive detail, however, the cost development estimates should be made more schematic on this point.

The majority of the stands to be cut by thinnings in Finland, now and apparently far into the future, is characterized by a small growing stock volume per area unit, and a low mean tree height (cf. V u o k i l a 1969,

p. 96—140). To ensure that the Finnish pulp and paper industry, which already suffers from a shortage of raw material, can obtain the necessary roundwood and that forest owners will have the revenue they desire, it is necessary to treat these stands with relatively slight thinnings. This naturally makes rationalization more difficult, and when the wage level rises it evidently leads to a real rise in the mean cost of harvesting pine pulpwood. After a time, it will be impossible to compensate for this by reducing the stumpage price: there is the risk that roundwood supply areas will diminish and that forest owner organizations will take counter-measures. If, therefore, the mean harvesting cost of pulpwood increases, and the above conditions remain valid, its delivery price must also increase. With these fundamental assumptions, the real unit cost of pine pulpwood harvesting, according to this variant of profitability calculation, was assumed to increase as follows.

The piece rates were assumed to increase annually by an amount of money equal to the stated 2.7 per cent of its 1967/68 value. Rationalization would, to a certain extent, eliminate this increase, and the better the harvesting conditions in the stand to be cut, the more complete would be the elimination. Schematically, the annual increase in the real cost of harvesting per piled cu.m. in the stand with the poorest harvesting conditions was 2.3 per cent, i.e. 85 per cent of the real increase in piece rates. In the best stand, on the other hand, the effect of the increase in contract wages could be completely eliminated by rationalization. The percentage of unit cost increase in harvesting the stands that fell between the best and the poorest (1967/68) one, was obtained by interpolation. The procedure is schematic but leads to main trends that can be considered probable: the poorer the economic harvesting characteristics of a stand in 1967/68, the greater the rise, even relatively, in its future harvesting costs compared with the 1967/68 level (cf. Beståndsvård ... 1969, p. 133—144).

The mean cost ($\bar{h}_t$) of pine pulpwood harvesting, under this assumption of the development of harvesting costs (Table 5, Item I_3), increased annually by an amount of money which equalled 1 per cent of the 1967/68 level i.e. Fmk 0.0965 per piled cu.m./year. The increase was considered to continue for 80 years from the basic year of the profitability calculation, after which the mean cost was assumed to remain on the real level it had reached. The same time span also applies to the harvesting cost per quantity cut from a stand (h_t). Since this calculation variant presumed that the mean stumpage price of pulpwood also remained at its 1967/68 trend level, the delivery price would annually increase only by the amount of the increase in the mean harvesting cost. However, in the price alternative for pine pulpwood of Table 5, Item I_4, the mean stumpage price was assumed to increase according to its linear trend, i.e. by Fmk 0.046 per piled cu.m./year.

In the calculation variant I_3 of Table 5 it was assumed that the real mean harvesting cost ($\bar{h}_t$) of p i n e l o g s was to remain at the 1967/68 level, and that the increasing influence of the rise in the real wage level on

the mean cost of harvesting can be totally eliminated by a change in harvesting policy: in the future, the higher the real wages, the larger would be the proportion of the marketed saw logs harvested from final cutting stands. In the forest wage rate schedules, the real harvesting cost of the best stand, marked for cutting was considered to remain constantly at the cutting season 1967/68 level. The stand of this kind was defined in the same way, in principle, as for pulpwood. The same applies to the poorest stand (cost increase, 2.3 per cent/year), and the increase percentage of the cost of harvesting per stand. This development of harvesting costs would lead to a gradual decrease of the stumpage price, at least for log quantities obtained from thinning cuttings. Also in Item I_4 of Table 5 it was assumed that the mean harvesting cost of the logs would remain at its 1967/68 level, and that the harvesting cost per area of timber marked for cutting would increase in the same way as under Item I_3. Since in this case the mean stumpage price of pine logs was also assumed to increase according to the linear model of Table 6 (Fmk 0.023/cu.ft./year), the real mean delivery price would also increase in the future by this annual amount.

The 1967/68 harvesting cost (h_t) per stand, for each of the two timber assortments, was determined according to the workers' union contract in forestry at that time (the forest wage rate schedules quoted above). The stand characteristics of the removals, admittedly, were classified more individually than in practical determination of the price of standing timber, but the classification principles were the same. The procedure gave the harvesting costs per stand, of a level correctly related to the harvesting cost ($\bar{h}_t$) corresponding to the mean stumpage price.

The cost of roundwood harvesting, by timber assortments, contains two types of cost: (a) the incremental cost of harvesting, (b) the share of each timber assortment in the common cost of the assortments. The incremental cost of harvesting a timber assortment includes the direct wages for cutting and haulage, and the relevant statutory social security payments. According to the forest wage rate schedules, the total volume of roundwood harvested from a stand compartment did not, at the time the present calculations were made, affect the rates for cutting and haulage. The growing stock characteristics governing the difficulty of the work were determined per hectare in the tables. Therefore, when the i n c r e m e n t a l cost of harvesting was determined, every thinning and the final cutting of the stand could be considered to form a cutting and haulage compartment with its own work difficulty factors. This is no longer valid today (1972), especially not in large-scale forestry. The incremental harvesting costs for the roundwood quantities cut on each occasion, and the proportion of the common costs in 1967/68 were determined according to the following principles.

Pine pulpwood: When the incremental cost of harvesting was determined, it was assumed that the methods for the cutting and short-distance haulage, and factors affecting the cost, other than the growing stock factors, were the same as in a medium-quality stand corresponding to the mean stumpage price of the market. The stem size of the removal and the density of the compartment were determined on the basis of the removal from the stand. The class of branchiness was assumed to be II in slight thinning, the mean of II and III in the series of medium thinning, a combination of the two in slight/medium thinning, and III in heavy and radical thinning.

Väisänen (1967, p. 17) estimated the cost of planning and supervision (including separate measurement of quantities cut and hauled), incurred by the buyer of standing timber, at Fmk 1.02/solid cu.m. in a pulpwood area marked for cutting of 100 solid cu.m. and at Fmk 0.78/solid cu.m. in one of 200 solid cu.m. (in terms of the felling season 1966/67 money). Linear interpolation on the basis of these figures, considering that the cost categories were not quite identical in Väisänen's and in the present study, gave a share of Fmk 0.50 per piled cu.m., of 2-metre wood incl. bark, of the common costs of timber harvesting, corresponding to the mean stumpage price of pine pulpwood. All the stands of the 37 ha normal forest, which were to be annually treated by cuttings, were understood as one area of timber marked for cutting. This alternative cost was based on the assumption that the forest owner himself carried out the final division into compartments and the determination of the haulage tracks, in the way planned in cooperation with the advisor when the trees were being marked for cutting, and also that he supervised the harvesting himself. No separate measurement of the quantities cut and hauled was foreseen.

A considerable proportion of the common costs of timber harvesting is fixed per compartment. The smaller the removal per hectare, the higher is the cost per piled cu.m. A relevant, though unmistakably slight allowance, was made for this, in that the common cost per piled cu.m. of pulpwood removed from the stand at each age was determined as a percentage of the incremental cost of harvesting (including social security costs). The percentage (5.46 per cent) referred to the share of the mean common cost of Fmk 0.50 per piled cu.m. in the incremental cost corresponding to the mean stumpage price.

Pine logs: the incremental costs of harvesting were determined according to the same forest wage rate schedules as for pulpwood. The mean distance of haulage (0.2—0.4 km), the snow allowance for cutting and haulage (+ 1 per cent), and the social security cost percentage were assumed to be the same as for pulpwood. The logs hauled were not stacked.

According to Väisänen (1967, p. 17), the cost of the planning and supervision of the harvesting by the buyer, per solid cu.m. of logs cut was higher than that in an area of timber marked for pulpwood. On the basis of the cost per solid cu.m. quoted by Väisänen, it could be calculated that the cost of planning and supervision, converted into the value of money in 1967/68, was Fmk 0.076 per cu.ft. in an area of timber of 100 solid cu.m. and Fmk 0.064 per cu.ft. in one of 200 solid cu.m. Considering the differences between the cost categories in Väisänen's and the present study, the common cost share of the logs in the area of timber corresponding to the mean stumpage price, was estimated at Fmk 0.04 per cu.ft. This is 10 per cent of the incremental cost corresponding to the mean stumpage price in log harvesting.

The value of the use of material production factors per volume unit cut (Table 5) was determined as follows.

Data concerning the variable costs, depreciations, and interest on capital for the power saw per day of work, based on a sample of men working with power saws in January-February 1967 were obtained from the manuscript of a study by Lauri Heikinheimo et al. (1970). Variable costs consisted of expenses paid in money. The same study also gave the mean daily earnings of the power saw workers. This daily cost of the power saw was 16 per cent of the daily earnings. Wear and tear on the material production factors of a power saw was therefore schematically assessed at 16 per cent of the direct cutting wages.

The parties to the agreement on pulpwood price recommendation, when determining the cost of the short-distance haulage of a medium-quality area of timber marked for cutting in the felling season 1968/69, foresaw the haulage as being half by horse and half by tractor. Especially the tractor cost per unit of performance depends considerably (depreciation and interest) on the situation in which the calculation is made. To avoid excessive subjectivity, the data on expenses for the use of the production factors of horse haulage, obtained from the study by Heikinheimo et al. (1969), were used to determine the share of the wear and tear of the production factors of short-distance haulage. The figure obtained was 14 per cent of the hauler's daily earnings, and this percentage was applied to both timber assortments in all cutting volume alternatives.

4422. *Other expenditures of the forest holding*

Other expenditures refer to items other than roundwood harvesting in the stand calculations (Formulas 3 and 4). In so far as determination of these expenditure types is different in the calculations based on ownership revenue from those based on ownership revenue and work earnings, the differences will be described. Expenditure was determined per hectare, the stand being part of a 37 ha normal forest. The method of organizing the forest holding operations, the nature of Finnish forest taxation, and other similar factors, lead to the result that an unexpectedly large proportion of the expenditure can be allocated to individual stands, according to the causation principle.

Expenditures for sale, for marking the trees to be cut and for delivery per hectare to be treated with cuttings were determined, in the main, as follows.

The incremental expenditures for roundwood sale (negotiations and conclusion of the sales contract), for the normal forest of 37 ha, were estimated at Fmk 10,— per year. According to the causation principle, the cost for roundwood sale is a cost of the stands from which the roundwood is sold. For this reason, during stand rotation, the cost of sale was allocated only to those ages at which fellings were carried out in the stand. The basis of allocating was the area subjected to annual cuttings, corresponding to each cutting strategy of the normal forest. The cost, Fmk per hectare to be treated with cuttings (m_t) was obtained from the formula:

$$m_t = \frac{10\ u'}{37\ n}\ , \text{ in which} \qquad (19)$$

n = number of cuttings per rotation (u').

The expenditures for marking the trees to be cut included also the cost of evaluation of the stand. The principle according to which the expenditures were determined was the following: (1) The marker team consisted of a forest technician and the forest owner himself; (2) The estimation of the total time expended by the team was based on Väisänen's (1967, p. 7) time consumption figures indicated as a function of the amount of solid cu.m. marked. It was desired, however, to distribute the marking expenditures of the normal forest, according to the causation principle, as precisely as possible into the stands to be marked. For this reason, the time consumption was here divided into three components: (a) A fixed time (1.5 hours) of the marking team's movement to and from the stand to be marked; i.e., 1.5 u': 37 n hours per hectare treated with cuttings. (b) A fixed component of the time expended on movement inside the stand. On various grounds, this was estimated at 0.58 hours per hectare to be treated. (c) Time consumption dependent on the volume of the growing stock to be marked. It was determined on the basis of the total time consumption according to Väisänen (1967) and the above fixed time components (0.017 hours per solid cu.m., excl. bark of marked merchantable timber). The value of the working time expended by the marking team was determined on the basis of data obtained from the Committee on the Costs of Forest Planting and Seeding (a working day was taken as 8 hours). The marking expenditures (st^t), in Fmk per hectare to be treated, were obtained from the formula

$$st_t = 4.90 + \frac{12.74\ u'}{37\ n} + 0.15\ v_t, \text{ in which} \tag{20}$$

v_t = cutting volume of merchantable timber, solid cu.m. excl. bark, per hectare to be treated.

Calculations of the expenditures of roundwood delivery were also based on the total time consumption figures of Väisänen's study (1967, p. 18) as a function of the solid cu.m. quantity delivered. The team's time consumption was here also divided into a fixed component, and one dependent on the volume of roundwood to be delivered. Giving the time consumption of the team a value on the same grounds as for marking expenditures, the delivery expenditures (d_t) per hectare to be treated were

$$d_t = \frac{6\ u'}{37\ n} + 0.15\ v_t, \tag{21}$$

in which the symbols are those explained under formulas 19 and 20.

The time consumption figures on which formulas 19—21 are based are of course approximate. However, the procedure described takes the nature of these costs into consideration better than would the division into only variable or fixed costs.

The expenditures for sale, marking and delivery (M_t) per hectare to be treated with cuttings, in Fmk, in a normal forest of 37 ha were obtained as a sum of formulas 19—21, from formula

$$M_t = 4.90 + \frac{28.74\ u'}{37\ n} + 0.30\ v_t \tag{22}$$

In those cases in which the costs were assumed to have had a rising trend since the felling season 1967/68 (Table 5, Items I_3 and I_4), the costs

calculated by means of Formula 22 were considered to show a real increase, every year, of a constant amount equalling 1.7 per cent of their 1967/68 level. This increase was assumed to continue in the same way as that of the other kinds of expenditure and stumpage prices for 80 years, after which the real costs were assumed to remain on the level reached. Estimates of the increase percentages were based on the assumption that the real earnings of salaried employees in forestry, and their travel and other allowances, will increase in the future. In 1957—67, the annual linear rise, in the time series of the level of earnings index for salaried employees, converted into real values (Yearbook of Forest Statistics 1968, p. 96), was 3.5 per cent of the 1967 trend value ($r^2 = 0.989$; $t_r = 29.633$***). It was estimated, therefore, that increased productivity (e.g. omission of unessential work) could, in the calculation variants used, cut the real increase in expenditures for sale, marking and delivery to about half the corresponding increase in the level of earnings of the salaried forestry employees.

The incremental costs of silviculture are of several types. Table 10 shows the costs per hectare, used in calculations with the mean prices, cyclical prices, and minimum and maximum stumpage prices for the Lake District of Finland (Table 5). These costs are based on the material on privately owned forests obtained from the Committee on the Costs of Forest Planting and Seeding (CFPS-Committee), from which the weighted means for the Lake District were calculated.

The mean cost of seeding and planting per hectare was obtained by weighting the subregional costs with the approximate Vaccinium type areas of their private forests. These areas were derived on the basis of data published by Ilvessalo (1957, p. 13, 16, 20). The same method of weighting was used also for the calculation of other silvicultural expenditures of Table 10. They included the cost of clearing and possibly of broadcast burning the area to be seeded or planted, the cost of scarifying or making the planting holes, the price of seed or seedlings, wages including social security costs, and the cost of equipment and work supervision. The cost of blanking per originally regenerated (clear-cut) hectare was obtained, by subregions, from the material of the CFPS-Committee. The same source also supplied, by subregions, the percentages of the areas which had needed blanking, among the Vaccinium type cultivated lands of the private forests. The planting and seeding ratios in blanking were also obtained from the same source. On the basis of these costs and percentages, the mean cost of blanking per clear-cut hectare was calculated.

The cost of weeding and spacing comprised wages including social security costs, and the cost of equipment and work supervision. According to the subregional figures of the CFPS-Committee, the average numbers of treatments were 1.72 for seeded and 1.60 for planted seedling stands. In the absence of material, the number of treatments in naturally regenerated seedling stands was assumed to be the same as in seeded stand.

The total cost per hectare arising from the number of these treatments was obtained from the materials and subregional results of the CFPS-Committee. These costs

Table 10. The incremental costs used in this study, of silviculture per stand of 1 hectare adjusted to the price level of the felling season 1967/68 (total index for wholesale prices, with 1949 = 100). [1]

Cost Fmk/hectare [2]																
Artificial regeneration								Natural regeneration								
a. Seeding				b. Planting				By both main methods								
Seeding	Blanking	Weeding and spacing		Planting	Blanking	Weeding and spacing		Clearing and site preparation	Weeding and spacing, at varying intensities of thinning							
									Slight and slight/medium		Medium		Heavy		Radical	
		1st treatment	2nd treatment			1st treatment	2nd treatment		1st treatment	2nd treatment	1st treatment	2nd treatment	1st treatment	2nd treatment	1st treatment	2nd treatment
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
211	47	71	51	313	72	57	57	121	61	53	61	61	61	70	61	86

[1]) When these costs were supposed to have a rising trend (table 5, Items I_3 and I_4), the rise was considered to be 1.4 per cent of the level prevailing in the years 1967/68. Tables 1 (p. 103) and 2 (p. 105) show the phases of development of the stand, to which the treatment measures will be directed.

[2]) Costs are originally per hectare to be regenerated and not per hectare, which each time was the immediate object of the measure (for instance blanking).

were here divided, on the basis of an estimate, between the 1st and 2nd treatments of the seedling stand. The principles observed corresponded as precisely as possible to the biological, technological and economic conditions and requirements of the different cutting and silvicultural strategies.

The cost of clearing and preparation of the ground surface, to promote further natural regeneration, covers the wages including social security cost, and the cost of equipment and work supervision. The cost per hectare of stands to be regenerated was calculated from figures on privately owned forests, by forestry board districts, supplied by the CFPS-Committee. The figures on clearing referred (a) to the percentage of the naturally regenerated Vaccinium type soil which had required clearing, (b) to cost per hectare to be cleared. Preparation of the ground surface was considered indispensable (the percentage was always 100) to achieve the stem distribution series complying with the yield series.

In the calculations of Table 5, Items I_3 and I_4, each of the above types of silvicultural expenditures was assumed to increase annually for 80 years by an amount equalling 1.4 per cent of its numerical value in the felling season 1967/68. This percentage is here based on estimated trends of the various kinds of silvicultural cost (Table 11). The longest, practically uninterrupted time series on the cost of silvicultural work published in Finland are concerned with the forests owned by forest industries. Although the factual content and absolute level of these costs are not the same as in privately owned forests, the trends calculated on their basis nevertheless give an idea of the main trend of the real costs per hectare of the various silvicultural works over the last few decades in Finland. The time series on the real costs of the various works per hectare treated were extended from the calendar year 1967 as far back as information was available.

The costs of seeding per hectare were available from 1929 (Lindfors 1930, p. 170; 1933, p. 142; 1938, p. 128; 1941, p. 93; 1954, p. 5; 1965, p. 33; Linnamies 1966, p. 7; 1968, p. 7). The cost includes only the price of seed and the expenditures for work and the supervision of work (Lindfors 1965, p. 33). Similarly, data on the cost of planting per hectare, available since 1929, includes only the cost of seedlings and the expenditures for work and the supervision of work. The annual costs are based on various publications (Lindfors 1933, p. 144; 1938, p. 130; 1941, p. 94; 1954, p. 5; 1965, p. 33; Linnamies 1966, p. 7; 1968, p. 7).

Costs of clearing the regeneration areas per hectare since 1923 were calculated on the basis of the following sources: (Lindfors 1929, p. 104, 123; 1933, p. 145, 156; 1938, p. 132, 143; 1941, p. 95, 105; 1954, p. 7; 1965, p. 39; Linnamies 1966, p. 5; 1968, p. 4). The costs for preparation of the ground surface for natural regeneration contain the expenditures for work and the supervision of work (Lindfors 1965, p. 38). Data was available from 1923 (Lindfors 1929, p. 123; 1933, p. 156; 1938, p. 143; 1941, p. 105; 1954, p. 9; 1965, p. 39; Linnamies 1966, p. 5; 1968, p. 4). Material was also available on the cost of broadcast burning per hectare since 1923, however not for the war years of 1941—45. The cost per hectare for these years was determined linearly by interpolation. The thinning of young growth and young stands refers to

Table 11. Real costs of some kinds of silvicultural work, taken separately per hectare treated by each silvicultural measure in the forests of Finland's forestry enterprises. These are expressed as a linear function of time. The contents of cost species have been explained in the text.

The measure of silvicultural treatment	Costs per hectare as a function of time, Fmk[1])	r^2	$t_r - t_b$	y 1967	The real increase of the cost, per cent. in 1967	Coefficient, by which a cost extrapolation, presupposed by the model, is obtained from the hectare costs of the year 1967, after:				
						10 yrs.	20 yrs.	40 yrs.	60 yrs.	80 yrs.
1	2	3	4	5	6	7	8	9	10	11
Seeding without preliminary work, time series: 1929—67	$y = 6.9331 + 1.7159x$	0.654	8.360***	121.90	1.41	1.141	1.282	1.563	1.845	2.126
Planting without preliminary work, time series 1929—67	$y = 59.1943 + 3.5137x$	0.404	5.013***	294.61	1.19	1.119	1.239	1.477	1.716	1.954
Clearing of the cutting area, time series 1923—67	$y = 2.4913 + 0.6470x$	0.750	11.344***	45.84	1.41	1.141	1.282	1.565	1.847	2.129
Preparation of ground surface of the area to be regenerated, 1923—67.	$y = -16.2066 + 1.4368x$	0.868	16.800***	80.06	1.79	1.179	1.359	1.718	2.077	2.436
Broadcast burning, time series 1923—67.	$y = -13.4880 + 1.3508x$	0.762	11.740***	77.01	1.75	1.175	1.351	1.702	2.052	2.403
Thinning of a young stand and a young growth, time series 1923—67.	$y = -2.6422 + 0.9255x$	0.721	10.541***	59.36	1.56	1.156	1.312	1.624	1.935	2.247

[1]) x is the time between the given calendar year and the year 1900.

clearing and thinning which did not provide enough usable wood to cover the cost of the work (Lindfors 1965, p. 41). The cost data was obtained from several sources (Lindfors 1929, p. 124; 1933, p. 157; 1938, p. 144; 1941, p. 106; 1965, p. 42; Linnamies 1966, p. 8; 1968, p. 7).

The mean cost of a certain type of work per hectare in forests owned by forest industries also varies randomly from year to year. This is due to annual variations e.g. in work difficulty factors, the size of working sites, the regional distribution of work, and other variables in the population. The analysis of trends must also take into account the fact that the performance at a cost entered in the statistics has not remained the same. For example, the number of seedlings used for planting and the quantity of seed used for seeding, per hectare, seem to have decreased with time, whereas the thinnings of the young growth apparently have become more intense (Lindfors 1965, p. 31—45). It seems that the preparation of the ground surface has become more thorough as the work has been mechanized. A graphic analysis of the real time series of the different silvicultural cost categories showed that the main trend approximately corresponded to the linear model. The coefficient of determination, however, has been diminished by a variation, associated with the time series and other than that of the main trend. The increase percentages of the real cost of the various cost categories at the 1967 level are of the same order of magnitude. In privately owned forests the increase in real costs may have been even more marked than in the forests of forest industries. Their projects of work, on the average, are smaller, and the chances of rationalization are therefore poorer. The future increase in silvicultural cost predicted above (1.4 per cent of the 1967/68 level) presupposes, in the privately owned forests, a rationalization perceptibly more efficient than before.

The various overheads were as follows:

1. Silvicultural fee.
2. Forest insurance premium.
3. Forest management planning costs.
4. Cost of the maintenance of permanent roads.
5. Miscellaneous overhead.

The silvicultural fee, legally stipulated in Finland (Act 558/1950), could be included in the taxes since it is comparable to a tax. But it can also be classified among expenditures for the use of production factors, since it enables the organizations of private forest owners to offer their services at prices lower than the current prices. The silvicultural fee is a fixed cost item, dependent on the stumpage price level but independent of the cutting and management strategies of the forest holding. It was

assumed in the present study that the forest owner pays the so-called full silvicultural fee. The basis on which the mean silvicultural fee of the Lake District of Finland was calculated was obtained from Tapio's Yearbook 1966 (p. 181). Since the amount of the silvicultural fee is firmly attached to the principles of the Finnish forest taxation system, the amount of this fee was assumed, under the assumptions of the development of the environmental state made in Table 5, to follow the same main trend models as the amount of the area tax.

The forest insurance premium is in reality a reduction in income rather than an expenditure. It is a means of transferring to the insurance company the risk of a total or partial destruction of the growing stock and/or a reduction in the yield capacity of the stand, and consequently smaller revenue flows than were presupposed by the yield series underlying the calculations. The forest insurance applied here was a fixed-term policy which would compensate both for damage by fire, and for several other types of forest devastation. Part of the risk of devastation, however, remains as the forest owner's own responsibility (see Kaila-Kauhanen 1967, p. 30; Metsävakuutuksen . . .).

The insurance premium per hectare was determined in each alternative of stand treatment, in the various phases of age, according to the same principles as in practical insurance. This did not imply that the procedure was considered theoretically irreproachable.

Under each alternative of the cutting and silvicultural strategy of the stand, its insurance value was determined as the cost value of the growing stock in the 1—31st years of age (Endres 1911, p. 108—109). From the age of 32 years onwards, the expectation value of the growing stock exceeded its cost value. The expectation value was obtained by multiplying the felling value of the growing stock by the so-called expectation value coefficients (Kaila-Kauhanen 1967, p. 39—40). From the age of 60 years onwards the insurance value of the growing stock was calculated as its felling value according to the contribution profit I_0 principle (see contribution profit schedule p. 117). The value of land in these calculations was fixed at Fmk 100—/ha, and the calculation rate of interest was the usual 5 per cent, customary in this connection in Finland (see Mietola 1965, p. 229—230). The insurance premium was determined as a share to comply with the so-called primary premium (1.24 per thousand) of the growing stock value corresponding to each cutting and silvicultural strategy at the various points of the age of the stand (Metsävakuutuksen . . .).

Calculations at cyclical prices used the same insurance premiums, in terms of money, as those at the constant mean prices. When profitability calculations were based on the assumptions of Table 5, Item 4, the insurance premium after the seedling stage was considered to increase proportionately to the value of the growing stock according to the contribution profit I_0 principle.

An estimation of the forest management planning costs starts from the premise that forestry based on the comparison of alternatives will require intensive planning. For this reason the cost of the planning cannot remain at the level it in reality has, as an average per hectare of forest, on the private forest holdings of the Lake District of Finland. The cost of planning used in the calculations was Fmk 0.40/ha annually. It was assumed that a management plan, containing the most essential monetary calculations, should be made every tenth year. The cost was estimated after an interview with the manager of a forest office, and using the rates applied by the Central Forestry Board Tapio. The cost of a forest management plan as charged by the Västmanland Forest Owner Association of Sweden, for a 37 ha forest holding, would be Sw.cr. 0.71/ha/year (von Malmborg 1965 c, p. 4:68). Taking a rate of exchange of 82.55, this equals Fmk 0.59/ha.

The cost of the maintenance of permanent roads, excluding the incremental costs of road maintenance required for short-distance transport included in the cost of harvesting, was given by the Committee on the Costs of Forest Planting and Seeding (in terms of the money of the felling season 1967/68, Fmk 0.35/ha/year). The figure is small considering that, in the future, e.g. the timber harvesting machines will apparently need roads of higher class than earlier. As a result, roads will have to be completely re-built from time to time, but the cost of re-building was not considered here.

Miscellaneous overhead was estimated at Fmk 0.16/ha/year, a figure that was calculated on the basis of the subregional figures given by the Committee on the Costs of Forest Planting and Seeding. This heading covers the expenditures arising e.g. from various contacts with consulting experts, forest workers and others concerned, and which are not included in the cost categories described above.

To simplify the calculations and because the matter is of little significance, the amount of the last three overhead items was assumed to be valid also in the areas of minimum and maximum stumpage prices, in calculations at cyclical prices, and when certain other costs were assumed to show a rising main trend.

The profitability calculations presupposed a knowledge of the amount of the taxes and certain social security costs comparable to taxes, payable to state, commune and church on the basis of the so-called net income. These are called, in the following, by the general name of forest holding tax. Secondly, it was necessary to calculate the amount of taxes and social security costs the forest owner has to pay for the timber harvesting work he does himself; these, in the following are called the work income tax.

The tax imposed represents a percentage of the taxable income. Owing to the progressive character of the state income and property taxation gradings (Act 888/1943 and its amendments), the tax rate grows as taxable income and property increase. Locally, the tax rate can vary according to the rates of the proportional communal and church tax percentages. To calculate the amount of tax, an attempt was made to determine the mean tax rate of the private forest owners in the Lake District of Finland. The same mean value principle as applied above for the determination of the numerical values of various cost categories was adopted. Forest revenue is only a part of the forest owners' total income. In calculations based on average values, there is no reason to deal with one item according to e.g. marginal theories, in preference to others. However, no ready prepared information was available on the average tax rate and taxable income of the private forest owners in the Lake District of Finland. For this reason, approximation methods had to be used to obtain the basis on which to calculate the forest holding tax and the work income tax.

The tax percentage of the average forest owner in the Lake District of Finland was estimated on the basis of the results of the 1966 household inquiry. This inquiry provided data on the revenue of farmer families from production, the income transfers received, and the direct taxes paid (L i n n a i l a 1969, p. 2, 11). On the basis of various sources (e.g. Statistics on forest holdings . . ., p. 60—75) it was ascertained that the population of the household inquiry in general corresponded to the population of forest owners from among whom the mean area of the forest holding (37 ha) was calculated. In determining the final average tax percentage, the differences between the true earnings from the forest and the so-called net income of the area taxation were taken into consideration (R u n e b e r g 1968, p. 18—29), as were the changes in state income taxation grading, social security cost percentages and communal tax level since 1966 (Acts 592/1967 and 614/1967; Kunnallisverotus . . . 1969). On these grounds, the share of the direct taxes and social security costs paid by an average forest owner was assessed at 15 per cent of the income after subtraction of expenditures for obtaining and maintaining the earnings, in all computational variants of Table 5. It is not possible in this connection to report on all details of the very specialized forest taxation in Finland. Summarizing, the taxable income, broadly speaking, depends on the site type quality of each forest soil and on the stumpage price level of the various timber assortments which, according to the authorities, prevail in the district concerned. Neither the true revenue nor usually the true expenditure on a forest holding affect the amount of taxable income for the forest holding (Act 543/1967 and Statute 352/1968).

The basis for the determination of taxable income, the net yield of a stand on Vaccinium type soil, was calculated taking into account the said statutory decrees. The amount of tax obtained for the price determination alternatives of Table 5, Items I_1 and I_3, was Fmk 7.90/per ha. In the calculation at cyclical prices, the cyclical variation of stumpage prices was taken into account. Accordingly, in the calculation with increasing stumpage prices the net income was also assumed to increase. In the calculations at the constant minimum and maximum prices, the corresponding roundwood stumpage price levels were taken into consideration when the net income of taxation was calculated.

The taxes payable for the current value of timber harvesting by the forest owner himself in his own forest were also determined according to the tax laws and statutes in force (e.g. Acts 543/1967 and 582/1967, and Ohjeita veroilmoituksen . . ., p. 25). For the sake of simplicity, the tax percentage was fixed at 15.

Chapter 42 discussed the question as to whether or not the initial value of the forest holding was to be taken into account as a negative item in the profitability calculations. The most common calculation situation in practice is that profitability of the different methods of stand treatment is calculated for a forest holding which is already in the owner's possession, and not one that he intends to acquire. Expenditures previously incurred for a transfer of ownership rights of the forest holding are therefore not relevant in calculations for the future. The principle based on historical purchase values, therefore, seldom enters into question in determining the initial value of a stand. In the calculation situation, the forest owner looks at the matter from the angle of the lost profit principle (alternative thinking) (Fog-Rasmussen 1960,p. 55—57). This lost profit is represented by the use of land or stand for a purpose other than (mere) timber growing, or by the sale income from a sale of the whole stand or part thereof. In many places in Finland, a forest area or a part thereof is already being used for a main purpose other than timber growing. In such a case, the sale value of the forest area usually increases to exceed its »customary» forestry (discounting) value. With rational thinking, this leads to abandonment of mere timber growing.

To cut down the number of calculations, the forest owner, in the calculations with classical partial models, was assumed to consider two alternatives in addition to continuing to grow timber: the sale of the whole forest holding, or felling of the merchantable growing stock and the sale of the remainder, i.e. the bare land and the remaining seedling areas (liquidation value of the forest holding; see Hämäläinen 1969, p. 154). In Finnish conditions, the clear cutting of a young forest with a good growing capacity is not permissible (Act 412/1967 and Statute 537/1967), but this was disregarded in the present study. As can be seen from Table 12, the two principles were applied in full only to profitability calculations at the constant (1967/68) mean prices of the Lake District of Finland.

The sale price of a forest holding is not known until the sale is concluded. Therefore, the discounting value of the forest holding had to be used as the estimate of the sale price. In reality, it is often affected by factors other than expectations of net income obtainable from the sale of timber. Here the value of the stand, however, was considered to be its discounting value based on timber growing; it was calculated alternatively at calculation rates of interest of 3 and 4 per cent. In a normal forest, where the various kinds of expenditure could reasonably well be allocated to individ-

Table 12. The principles according to which the values of land and stand were determinated in the basic years of the profitability calculations per stand, at the constant mean stumpage prices and costs of the Lake District of Finland (Table 5, $Item_1$).[1])

Age of stand in the base year of calculation, years	Starting value is	
	Estimate of the sale price of a whole stand	Liquidation value of a stand
	Making part of a normal forest	
1	2	3
0	Estimate is the maximum discounting value of land according to the best seeding and planting alternative when the calculation rate of interest is a) 3 % b) 4 %	Same as Column 2
21	Estimate is the maximum discounting value of the stand, when the calculation rate of interest is a) 3 % b) 4 %	Estimate: The value of growing stock according to contribution profit principle I + value of land. Value of land is, alternatively: *1.* maximum discounting value according to the best seeding and planting alternative when the calculation rate of interest is a) 3 % b) 4 % *2.* 0
39	Estimate is the maximum discounting value of the stand separately for each intensity of thinning, when the calculation rate of interest is a) 3 % b) 4 %	Same as at the age of 21 years but separately for each intensity of thinning

ual stands according to the causation principle, the necessary discounting values of the stands as a part of the normal forest could be calculated. The stand's discounting value per hectare, at the age of 21 years and 39 years, was calculated according to optimum strategy. Analogously, the estimate of the sale price of bare land was considered to be the discounting value of its optimal planting or seeding alternative. In this case, too, the influence of land values determined with 3 and 4 per cent calculation rates of interest were separately tried on the results of the profitability calculations.

Depending on whether the criterion of profitability used was the ownership income, or the sum of ownership income and net work income, the starting values of land and stand were determined according to the same principle. When these criteria followed the »before taxes» principle, the discounting values of stand and land also followed the same principles, contribution profit $III1_0$ and $III1_{0+w}$. When the criteria accorded with the »after taxes» principle, the discounting values used as start-

[1]) In the calculations of the other Items (I_2—III_1) of Table 5, to reduce calculation work, the starting values were determined only as contribution profit I of growing stock. The forest owner, therefore, did not consider a sale of the stand or of clear-cut land, or the sale price of land was = 0. The starting values are explained in detail in the text.

ing values complied with contribution profit IV_0 and IV_{0+w} (see schedules on p. 117, 118). When the liquidation values were determined, the felling value of the growing stock, accordingly, followed the contribution profit I_0 and contribution profit I_{0+w} principle. The latter acquired different values depending on whether the profitability criterion was before or after taxes.

The figures of Items 10b and 10c of the examples of contribution profit schedules when using the 4 per cent calculation rate of interest, correspond to the obtained optimal discounting values of the stand. With the present value method, the most suitable profitability criteria are probably contribution profit IV_0 after taxes, and if work earnings are included, IV_{0+w} after taxes. These criteria are apparently also suitable for profitability comparisons at stand age 0 with the internal rate of return method. The use of the internal rate of return method for a profitability comparison of the growing alternatives of stands aged 21 and 39 years is problematic, because the starting values for the stand are subjective.

443. *The variables and parameters of the combined model*

Chapter 412 gave the broad outline of the activity assumptions of the personal enterprise studied by means of a combined model. The fundamental solutions made concerning the variables and parameters of the model can be seen from the linear model described in Chapter 43 and the explanation of its symbols. A few details should be added.

In the timber growing alternatives, the prices and unit costs were determined according to the principle of Table 5, Item I_1. The real values of roundwood prices and various cost items were assumed to remain at the 1967/68 felling season level. However, the roundwood prices and the costs were inflated to correspond to the probable value of money for each of the years of the planning period. The same procedure was adopted concerning the other price and cost elements of the combined model. An exception was made for stands 2 and 4 (Table 3); their sale prices for recreational etc. purposes were assumed to undergo also a real rise from one year of the planning period to the next. In pine stand 2 this real rise in value was considered to be 10 per cent (a heavy increase in the scenic and other value of the young growing stock), whereas for stand 4, of mature age, the real annual price increase was estimated at 6 per cent.

The yield percentages of financial investments were determined on the basis of empirical knowledge (cf. H ä m ä l ä i n e n 1971, and its literature references). The tax-free nominal income from bank deposits was estimated at 4.5 per cent and from government bonds at 8 per cent. The real yield percentage of stock and shares was assessed at 12 (before taxes) and that of standard-size investment projects at 8 (also before taxes). Even this example of the combined model shows that taxation often essentially affects the mutual profitability of the different investment projects and must therefore be taken into account in profitability calculations (cf. J o h a n s-

son 1961 and Saario 1958). The tax rate of a private person in state taxation depends on the amount of his total income. As a result, the tax rate of the calculations must be determined as a function of the income. On this point, however, the matter was simplified. It was also assumed that the person pays his annual tax and social security costs according to the scales valid at the beginning of the planning period. A state income tax in agreement with the marginal tax rate was considered payable for any possible dividends and returns from standard-size investment projects. This marginal tax rate, however, was standardized so that it approximately equalled the income level the person could be considered to reach, bearing in mind e.g. the limitations of his financing opportunities. The income level of the enterprise taken as an example was much higher than that of the average forest owner in the Lake District of Finland described in Chapter 4422.

The value of the assets of a personal enterprise at the end of the planning horizon was determined as the exchange value of the assets. The value of the forest, in the way described in Chapter 4134, was determined as the discounting value of the stands.

5. CONCLUSIONS

The main purpose of the present study was to define the underlying models for timber growing. To this end, those general foundations on which profitability comparisons of alternatives are based in business economics and decision theory, were investigated. A genuine need for methods of profitability calculations arises in so-called non-programmed decision situations. In these situations, the calculations used for a mutual comparison of the profitability of alternatives are a part of the multi-phase decision making process, to be advocated as an essential phase in habitual programmes of forestry.

The premises of the calculation models for profitability comparison of the alternatives were derived from the systems theory. It was found that the general profitability calculations with time dimensions (investment calculations) were anchored to time and to the specific object of research or study. Business-economic models, explicitly expressed (and often mathematical) can be classified according to different grounds. For an enterprise engaged in timber growing, dynamic multi-periodic normative models serving decision making can be considered of central importance. Owing to the long production period required by timber growing, the models in question are therefore mostly planning models in the narrow sense of the word; it is, they take into account the evolutionary environment of the model.

A discussion of the objectives and goals of the enterprise was necessary in order to recognize that the calculation models are no mere exercises in applied mathematics. From the viewpoint of general and business economics, the most important task is to express the goal function of the model with the aid of precisely defined economic concepts.

In the same way, a division of enterprises into firms and personal enterprises proved to be a fruitful basis for the treatment of the enterprise's possible or probable goals in the normative models. The majority of forestry units, e.g. in the Nordic countries, belong to personal enterprises. Hence this precision of the customary concept of enterprise facilitates a fully comprehensive discussion of the problems in the business economy of physical persons, and the linking of these problems with their

consumption goals. Such multiperiodic planning problems of frequently extensive entities can be most realistically treated with the aid of so-called combined models which solve simultaneously both investment and financing problems. The so-called classical partial models, primarily used in profitability comparisons of individual investment projects, are based on constructing, as it were, simplified combined models of the investment projects by broad assumptions of financing and of re-investment of the released funds.

Concerning the possible operational goals of the forestry units — as parts of total enterprise — it was found that the legally stipulated, broad goals of forestry, especially those of the National Board of Forestry, converted into financial quantities, mainly fulfil the aspiration of augmenting assets, in other words, of increasing future revenue. The financial goals of the forest holdings integrated in personal enterprises apparently depend largely on the person's other income, his readiness to consume, his opportunities and willingness to invest, and so on.

The various incompleteness of information and the problems of the time perspective acquire a particularly great weight in the profitability calculations of timber growing. They were therefore most appropriately to be commented on in the section of the present paper dealing with forestry calculations. The same applies to the calculation rate of interest required especially in the classical partial models. Owing to the simplifying assumptions of these models, this rate is of great importance to the results of the profitability comparisons. Sensitivity analysis is suitable for an approximate study of the risk involved in calculating the profitability of timber growing by means of classical partial models. The decision maker may outline very different alternatives of environmental states, depending on his natural temperament and other comparable factors, and he may, additionally, find it possible to combine his subjective probabilities with the alternative environmental states. A sensitivity analysis in which the variables consisted of roundwood prices, various costs, calculation rate of interest, and the length of the time perspective of the calculations, was applied to those profitability calculations which, in the empirical section of the present study, were carried out by means of classical partial models.

The sensitivity to parameter changes of the solution of a multiperiodic deterministic model can, if certain conditions are met, be studied by shadow price analysis. Transformations of linear programming have also been developed, with a model structure that explicitly takes into account the risk factor. The present study involved constructing a deterministic, multiperiodic linear model mainly to meet the needs of a personal enterprise where the decision maker is interested in financial investments and engaged in timber growing, and subjecting the model to empirical testing.

The yield series of Vaccinium type pine stands of the Lake District of Finland, used in the present profitability calculations of timber growing, are based on V u o k i l a 's study results, which were extended and modified on certain points for the present purposes. The particular problems of yield theory, therefore, were not included in the present study. The empirical section of the study devoted the main attention to an analysis of the price and cost components of the models and to obtaining the appropriate material related to them. The aim was to formulate developmental forecasts, that seemed to be realistic, for the most important environmental variables. Such variables comprised the level of roundwood stumpage prices, incremental costs in timber harvesting and silviculture, and various overheads. Alternative estimates of their future development were formulated. The main weight in the profitability calculations of timber growing falls on the future development of the level of stumpage prices for roundwood.

The forestry alternatives of the combined model were built up, by way of examples, of the available felling and silvicultural alternatives of the stands. The aim was also to make the empirical values of the investment alternatives, other than those on forestry, as close to reality as possible. The model also contains the possibility, widespread today, of selling the forest area for recreational etc. purposes. At the individual enterprise level, this reflects the complex process of transformation in the needs and demands of society today.

Among the traditional profitability models of forestry, F a u s t m a n n 's formula of bare forest land was found to represent, factually, the present value method belonging to the classical partial models. The process behind the various economic plans for a forest holding, investment and other budgets, was found to have been affected also by the corresponding general business economic methods. It was recognized in the present study that general models of profitability comparison can, and necessarily must, be applied also to the profitability comparisons in forestry. The calculation models of different types, their variables and parameters are given a different form, content and weighting according to the sector to which they are applied.

The traditional forestry models proved to be specific applications of the general business economic models. In this way, the traditional models of forestry can be expanded to include the operations of the forest-owning enterprise as a whole, be it a personal or firm-type enterprise, which corresponds to the managerial needs of modern forestry. By making use of available data, the constructed models and their results show an operational way towards achieving this purpose.

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ABBREVIATIONS:

AFF = Acta Forestalia Fennica
DST = Dansk Skovforenings Tidskrift
HBR = Harward Business Review
JBE = Liiketaloudellinen Aikakauskirja — Journal of Business Economics
LTJ = Liiketaloustieteellisen Tutkimuslaitoksen julkaisuja
MA = Metsätaloudellinen Aikakauslehti
MTJ = Metsäntutkimuslaitoksen julkaisuja — Communicationes Instituti Forestalis Fenniae
MS = Management Science
MSS = Meddelanden från Statens Skogsforskningsinstitut
SST = Sveriges Skogsvårdsförbunds Tidskrift

HARVESTING OF STUMP AND ROOT WOOD BY THE PALLARI STUMPARVESTER

A sub-project of the joint Nordic research programme for the utilization of logging residues

PENTTI HAKKILA and MARKKU MÄKELÄ

KANTO- JA JUURIPUUN KORJUU PALLARIN KANTOHARVESTERILLA

Yhteispohjoismaisen hakkuutähdetutkimuksen alaprojekti

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PREFACE

The Stumparvester was designed and built originally by Mr. Kyösti Pallari. The development work was done in 1971 and 1972 under the direction of the stump committee set up by the Central Association of Finnish Forest Industries. The working team consists of Pentti Hakkila (Finnish Forest Research Institute) as chairman, Uolevi Sarapää (Kemi Oy) as vice-chairman, Matti Ahonen (Kemi Oy), Aarne Elovainio (Metsäteho) as secretary, Erkki Huhanantti (Oulu Osakeyhtiö), Juhani Järvinen (Tehdaspuu Oy), Jorma Klami (VAPO), Raimo Koskinen (Oy W. Rosenlew Ab), Osmo Lehtonen (Enso-Gutzeit Osakeyhtiö), Lauri Lähteenmäki (National Board of Forestry), Markku Mäkelä (Finnish Forest Research Institute), Pentti Nisula (Finnish Forest Research Institute), Ilpo Palenius (Finnish Pulp and Paper Research Institute), Osmo Räisänen (United Paper Mills Ltd) and Martti Siirilä (Oy. Vilh. Schauman Ab). The further development programme for Stumparvester was supervised by a smaller group consisting of Matti Ahonen as chairman, Lauri Lähteenmäki, Markku Mäkelä and Pentti Nisula. The work was financed by the forest industry and the Ministry of Trade and Industry.

After the completion of the development programme, a work study was conducted in the Vesijoki research forest of the Finnish Forest Research Institute. The drivers of the Stumparvester were Kari Hyöppinen and Olli Pallari. The designer and owner of the harvester, Kyösti Pallari, participated actively in the field experiments as a contractor. Matti Aitolahti, Risto Helkiö, Teuvo Hinttala and Kauko K. Luoma assisted in the organisation of the work site. This phase was financed by the forest industry, the Ministry of Trade and Industry, the research forest bureau of the Finnish Forest Research Institute and the joint Nordic research programme for the utilization of logging residues.

Mr. Erkka Eloranta, Miss Aira Päivöke, Miss Marjut Raivonen, Miss Pirjo Salonen, Mr. Heikki Takamaa, Mrs. Anita Törn and Mrs. Raili Voipio participated in the field work. Mrs. Taija Havanto, Miss Leena Paumola, Mrs. Aune Rytkönen and Miss Raija Siekkinen participated in the office work. The manuscript was checked on behalf of the Finnish Forest Research Institute by Professor Veijo

Heiskanen, who was initially chairman of the stump committee, and Professor Olavi Huikari.

The undersigned drew up the research plan jointly and were responsible for the actual research work. Dr. Pentti Hakkila led the research and compiled the main part of the manuscript. Markku Mäkelä, student of forestry, answered for the field work.

The colour photos are by courtesy of Oy Kone-Diesel.

The study was translated from Finnish into English by Miss Päivikki Ojansuu and checked by Mr. L. A. Keywort.

Helsinki, November 1972

Pentti Hakkila *Markku Mäkelä*

CONTENTS

	Page
1. Introduction	7
2. Technical data on Stumparvester	9
21. Basic machine	9
22. Special equipment	10
3. Work technique	12
4. Research material	14
41. Work sites	14
42. Stump material	17
43. Time studies	18
5. Results of the time studies	20
51. Moving from stump to stump	20
52. Extraction	21
53. Splitting	23
54. Combined extraction and splitting	25
55. Unloading	27
56. Total productive time	30
57. Delay time	32
6. The timber	33
61. Quantity of timber	33
62. Quality of timber	36
7. Output and costs	39
8. Scarification and preparation of the soil	45
9. Discussion	48
10. Summary	51
Literature	54
Lyhennelmä	55

1. INTRODUCTION

The last major raw material reserve of the Finnish forest industry lies in logging residues, of which stumps and roots constitute a considerable proportion. The dry weight of over 5 cm thick stump and root wood of saw timber trees in mineral soils is 23 % of the dry weight of the above-ground part of the stem, in peat lands even more (H a k k i l a 1972). At least 4 million tons of stump and root wood is left behind in the forest annually.

The principal obstacle to utilization is the high cost of logging. Great attention has therefore been paid in Finland in recent years to the development of stump and root wood harvesting methods. At the mill end, the most serious problems are stones and sand which hamper chipping. This drawback, however, is limited to mineral soils, and the industrial utilization of stump and root wood seems to be easiest to realise with swamp stumps.

A great proportion of the growing stock of undrained swamps is of fairly small size at present, which makes the harvesting of stumps and roots expensive. Drained swamps, however, yield larger-sized timber, and Finland already has 600,000 hectares of drainage areas which are over 40 years old. Of this total, 200,000 hectares is still in need of immediate regeneration. Furthermore, it is estimated that 2 million hectares of swamp forests will be regenerated in the course of the next 20 years (H u i k a r i 1972). Considerable quantities of stump and root wood can thus be obtained in the next few years from swamps alone, provided that the harvesting costs can be reduced to the level foreseen by the industry's capacity to pay.

As swamp stumps are free of stones and sand and as the amount of stump and root wood is especially great in swamps, a method of harvesting swamp stumps should be developed. To lower the costs the stump-root systems must be split before long-distance transport. It is just this phase of work that is becoming the bottleneck in mechanising the harvesting schedule. Several technically serviceable solutions are available for extraction on mineral soil: wheel tractor, crawler tractor, wheel loader and excavator (cf. C z e r e y s k i, G a l i n s k a and R o b e l 1965, H a k k i l a 1972), but splitting is still done by hand. It thus holds the key position in the mechanization of harvesting.

Cost and labour policy factors have led to the origin and generalization of harvesters and processors. For stump and root wood, too, the use of harvesters

offers certain advantages in the long-term view; the most important of them is the high productivity of human labour. As one machine can replace two or more machines, the organisation of the work is facilitated. At the same time, the cost of moving from one work site to another is reduced.

The working team set up by the Central Association of Finnish Forest Industries has been engaged since 1970 on developing stump and root wood harvesting methods on the basis of different alternatives. One solution model experimented with has been a harvester constructed on a RH-4 LC excavator-loader equipped with tracks, the Pallari Stumparvester. The development work was done in 1971—1972 and the following requirements were made of the machine:

- The machine must be capable of handling all the work phases except transport.
- The machine must be capable of negotiating poorly bearing terrain.
- The output of the machine must be sufficient in relation to the operating costs.
- The quality of the timber must meet the requirements of transport and processing techniques.
- The basic machine must be of standard manufacture and the special equipment must be easily and quickly installed.
- Scarifying and soil preparation in connection with harvesting work must be as advantageous as possible for regeneration, without forgetting environmental protection considerations.

After the first phase of the Stumparvester development work had been completed in May 1972, the present work study was performed. The most important aims of the study were:

- To develop for the machine a working technique applicable to different conditions.
- To analyse the structure of the working time from different part factors and the output of the machine per time unit in different conditions and especially in peat land.
- To discover the working reliability of the machine and to find its weak points.
- To study the quality of the timber obtained and when necessary to improve it.
- To establish the effectiveness of scarifying and soil preparation as a by-product.
- To acquire additional information about the amount of stump and root wood on peatland.

2. TECHNICAL DATA ON STUMPARVESTER

21. Basic machine

The basic machine of the Stumparvester must be able to negotiate difficult terrain. Of especial importance is the ability of the machine to operate also in swamps from which stump and root wood is often obtained free of stones. As extraction is confined to the summer season, only a machine with tracks comes into question in poorly bearing terrain. If the machine is not used for short-distance transport, its travelling speed is a less important consideration.

The work will be speeded up considerably if the machine is able to extract stump-root systems from all directions. A boom with a turning circle of 360° offers an advantageous solution in this respect. The special equipment needed in the harvesting of stump and root wood also requires effective hydraulics.

The basic machine selected for the Stumparvester was the West German RH 4 excavator-loader which can be equipped with 500, 600, 700 or 950 mm tracks. Narrow tracks are most suitable for mineral soil. As the present study concentrated primarily on peatlands, the RH 4-950 LC type equipped with wide tracks was used. Its average ground bearing pressure in operating conditions is only 0.19 kg/sq.cm., 2.7 psi. The technical data of the machine are given in the following list and Fig. 1.

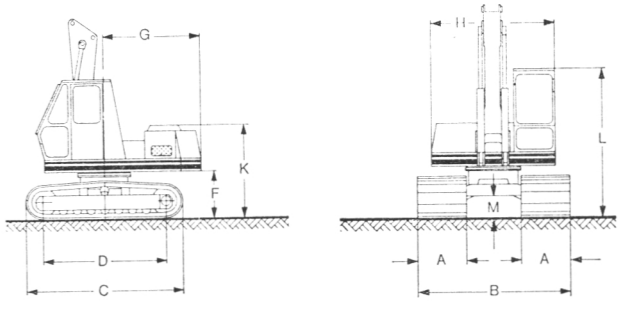


Figure 1. Technical measurements of the RH 4—950 LC excavator-loader. The symbols are explained in the text.
Kuva 1. RH 4—950 LC kaivukone-kuormaajan teknisia mittoja. Symbolien selitykset tekstissä.

Track pad width (A)	950 mm
Undercarriage width (B)	2,950 mm
Undercarriage length (C)	3,506 mm
Length of track on ground (D)	2,800 mm
Ground clearance of uppercarriage (F)	981 mm
Slewing radius (G)	1,960 mm
Maximum width of uppercarriage (H)	2,400 mm
Height to top of engine cover (K)	1,911 mm
Passage height (L)	2,846 mm
Ground clearance (M)	440 mm
Ground bearing pressure	0.19 kg/cm²
DIN horsepower of engine	51 HP/2,400 rpm
Hydraulic horsepower	2 × 23 HP
Pump flow	2 × 92 l/min
Working pressure	up to 250 kg/cm²
Cylinder forces, full face of piston:	
Jib cylinder	2 × 19,612 kg
Arm cylinder	28,317 kg
Shovel cylinder	19,612 kg
Crowd force at shovel tooth of backacter:	
Arm length 4' 11"	6,004 kg
Arm length 6' 10"	5,003 kg
Travel speed	up to 2.4 km/h
Uppercarriage slewing speed	18 rpm

22. Special equipment

The harvester comprises in addition to the basic machine two special equipments designed for stump and root wood. A combined extraction-splitting device was installed in the fore end of the machine in lieu of the backacter (Fig. 2). A rear box (Fig. 3) for bunching and transport was placed at the rear end.

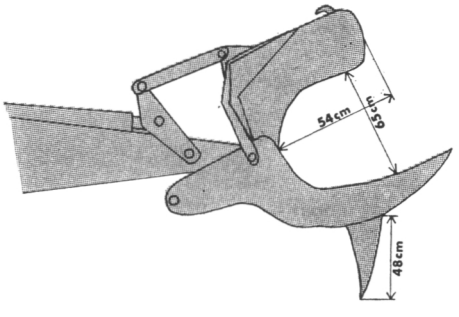


Figure 2. The structure of the extraction-splitting device.

Kuva 2. Nosto-paloittelulaitteen rakenne.

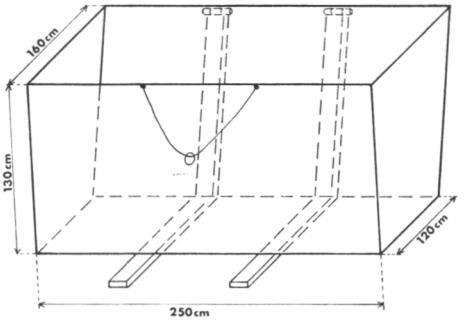


Figure 3. The structure of the rear box of the Stumparvester.

Kuva 3. Kantoharvesterin perälaatikon rakenne.

The extraction-splitting device consists of a shear blade moved by a hydraulic shovel cylinder and of its two-forked anvil (colour plate 1). The maximum aperture between the shear blade and anvil is 65 cm and the corresponding depth 54 cm. The blade angle is 34°. The blade cutting surface, thickness 40 mm, is covered with hardened steel.

Two extraction teeth are fixed to the under side of the anvil for the extraction of stump-root systems. They are 48 cm long and 32 cm apart. The total weight of the extraction-splitting device is 800 kg.

The rear box is fixed to the undercarriage of the excavator with two iron supports. There are hinges at the upper end of the iron supports for tipping. The vertical walls of the box are covered with 2.5 mm steel sheet. The bottom is made of 15 mm thick steel bars, spaced 8 cm apart through which the loose soil can drop. The box volume is 4.6 cu.m. The other dimensions are given in the diagram.

There is a wire rope link on the vertical wall of the rear box that faces the machine. For tipping, the box supported on its hinges is turned with the wire rope by raising the boom.

3. WORK TECHNIQUE

Various work techniques from which the final methods gradually emerged were experimented with within the scope of the development programme and time studies (colour plates 1 and 2). It proved expedient to vary the work technique with the tree species, the size of the stump-root system, the soil and the short-distance haulage distange. Only the most effective methods are described in the following.

Small stump-root systems are extracted intact. The extraction teeth are first placed behind the stump, after which uprooting is done by raising the boom and simultaneously pulling towards the machine. This technique is most suitable for spruce stumps of under 25 cm in diameter and for pine stumps of under 35 cm.

Larger spruce stump-root systems tend to break during extraction. The most suitable work technique for them is to tear off the thickest lateral branches singly by twisting crosswise. Extraction and splitting are thus done concurrently.

The tap root of large pine stump-root systems is so firmly lodged in the ground that it may be difficult to extract intact. To expedite the work, the stump portion is split by shear blade into two or more parts before extraction. Extraction and splitting are again done simultaneously. If the soil is very stony it is worth while splitting also medium-sized stumps, 25—35 cm in diameter, prior to extraction.

Stump and root wood is collected in the rear box of the Stumparvester in connection with splitting. Particle size is regulated as desired and most of the impurities and thin roots can be separated from the merchantable timber during splitting. The aim is to minimize transport costs and to facilitate the later mill-end phase of treatment.

When one split stump-root system has been loaded into the rear box the Stumparvester begins to extract the next. It is frequently able to handle more than one stump-root system from one spot without moving. The rear box takes 2—15 split stump-root systems.

Unloading is done by tipping the rear box on its hinges with a steel rope fixed to the boom. Unloading may be done in the compartment or the load can be taken to larger stacks better sited for further transport. When the rear box is tilted its lower edge rises 1.8 m above ground level, which enables emptying direct into a tractor trailer.

The Stumparvester can also be used for separate extraction and splitting work. For instance, the machine may be employed the whole year by concentrating on extration during the summer and leaving splitting to the winter season. Splitting alone comes into question also in fuel peat swamps where the stump-root systems have been extracted and bunched by other methods.

4. RESEARCH MATERIAL

41. Work sites

The investigation phase proper was preceded by a machine development programme which was carried out in its entirety in North Finland. In summer 1971, a total of 1,450 stump-root systems were extracted by the first prototype unit from mineral soil and 1,850 piled cu.m. of stump and root wood collected by other methods were split. The material consisted chiefly of Scots pine growing in sandy soil. The Stumparvester was built in its present form in spring 1972 on the basis of the experience gained in this work.

Preliminary experiments followed, still in North Finland, chiefly in mineral soil. The objects were to test the running of the machine and to accustom the drivers to the harvesting of stump and root wood before beginning the time studies. This phase comprised 150 work hours, after which the drivers were considered to have developed a work technique that was satisfactory for time studies. After minor structural changes, the Stumparvester was moved to work sites in South Finland.

The studies were carried out in the Vesijako research forest of the Forest Research Institute in June—July 1972. The main material was collected from two swamp plots, in addition to which 70 pine and 143 spruce stump-root systems were harvested from mineral soil. The last experimental plot was sloping, fairly stony moraine.

When the Department of Peatland Forestry of the Finnish Forest Research Institute was establishing experimental fields of H-culture, two experimental drainage areas of the Vesijako research forest were chosen as experimental fields where the harvesting of stumps from peat soil was to be carried out. Judging by old documents, experimental plot I, Sammallahti swamp, was originally an *Equisetum*-spruce swamp. It was first drained in 1907—1909 when drainage was only in the experimental stage. It was drained again in 1928—1933. As a result of drainage, the site type has reached in the past 60 or more years a stage which can be called transitional spruce swamp. The area of the swamp was 5.5 hectares. The depth of peat was commonly 1.5—2.0 m. The peat layer was thinner on the edges of the experimental plot but was at least 0.5 m everywhere (Fig. 4).

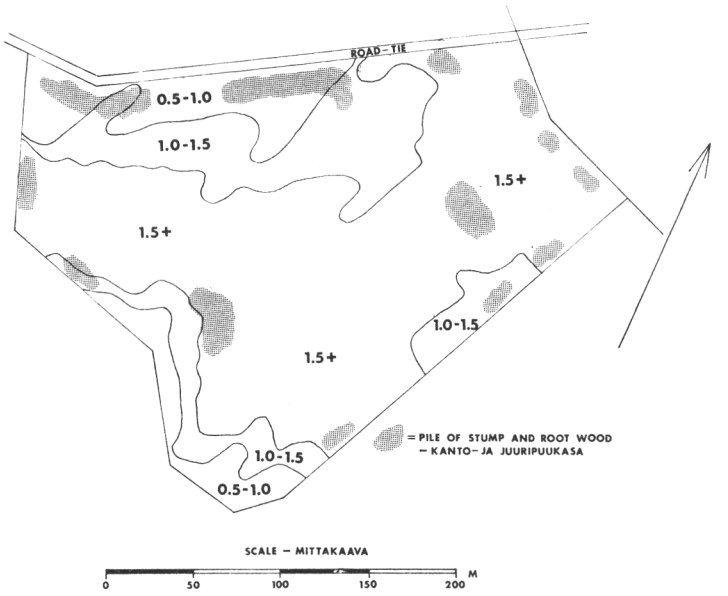


Figure 4. The depth of the peat layer (metres) in Sammallahti swamp (plot I).
Kuva 4. Turpeen syvyys (metreinä) Sammallahdenkorvessa (koeala I).

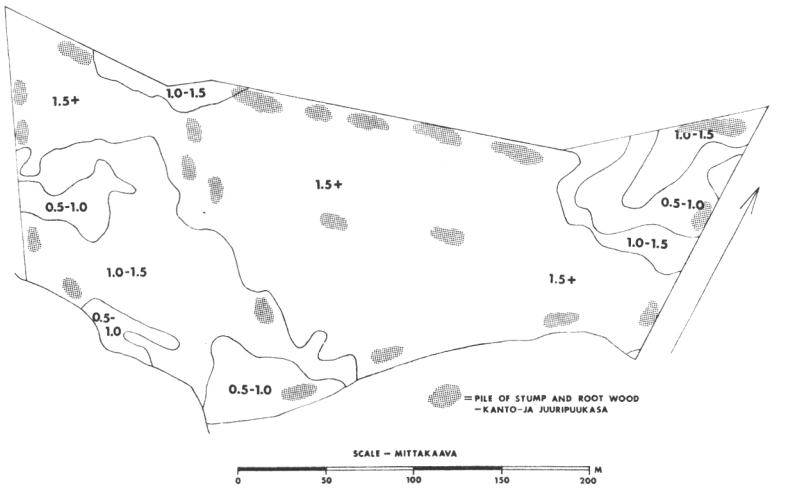


Figure 5. The depth of the peat layer (metres) in Kettula swamp (plot II).
Kuva 5. Turpeen syvyys (metreinä) Kettulansuolla (koeala II).

The growing stock of the Sammallahti swamp was measured accurately before it was harvested in early spring 1972. Stems totalled 2,660, two-thirds of them saw timber trees. Merchantable stemwood in the area amounted to 996 solid



Figure 6. The Sammallahti swamp before clear cutting in January 1972. (Photo by Hannu Kalaja).

Kuva 6. Sammallahdenkorpi ennen avohakkuuta tammikuussa 1972. (Kuvannut Hannu Kalaja).



Figure 7. The Kettula swamp before clear cutting in January 1972. (Photo by Hannu Kalaja).

Kuva 7. Kettulansuo ennen avohakkuuta tammikuussa 1972. (Kuvannut Hannu Kalaja).

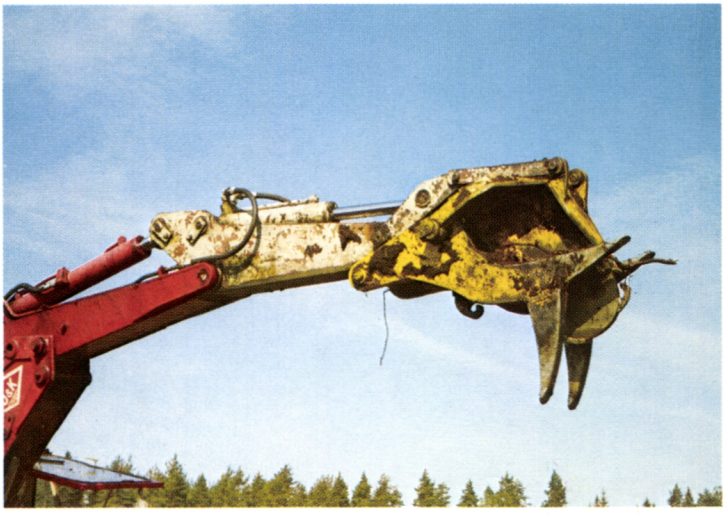
cubic metres including bark. The mean size of the saw timber trees was 9.7 technical cubic feet. Almost all the growing stock was Norway spruce, but there were also some Scots pines and white birches (Fig. 6).

Experimental plot II, Kettula swamp, was drained originally in 1910 and re-drained in 1932. The area was mostly *Eriophorum vaginatum* swamp growing Scots pine, partly spruce swamp growing spruce and pine. The area of the swamp was 6.0 hectares. The average depth of the peat was 1.8 m. However, small patches in which the thickness of the peat layer at its lowest was only 0.3 m were found on the edges of the area (Fig. 5). The swamp bordered on a lake whose surface was only 20—60 cm lower than the swamp surface. The bearing capacity was therefore poor in places, despite drainage.

The number of trees felled in Kettula swamp in spring 1972 was 1,877. Two-thirds of them were saw timber trees, average size 11.6 technical cubic feet. The stemwood harvest was 811 solid cubic metres including bark. Most of the growing stock was Scots pine, but in some parts of the sample plot Norway spruce was the dominant species (Fig. 7).

Both swamps were clear cut in early spring 1972 by the short wood method. A great deal of slash was left on the ground; the amount per hectare when dry was 31 tons in Sammallahti and 18 tons in Kettula (cf. Hakkila 1971). It was feared that the branches would obstruct the planting experiment carried out later, so they were destroyed before the stumps were harvested. This was done by collecting the branches in large piles with a Caterpillar D4 crawler tractor to the






RH4LC







Table 1. Tree data on Sammallahti spruce swamp and Kettula swamp.
Taulukko 1. Tietoja Sammallahdenkorven ja Kettulansuon puustosta

Variable — *Muuttuja*	Sammallahti	Kettula
	Number of trees — *Puita, kpl*	
Dbh, cm — $D_{1{\cdot}3}$, *cm* 7—10	108	193
11—20	910	430
21—30	1 515	989
31—40	123	258
41+	4	7
Total — *Yhteensä*	2 660	1 877
Saw timber trees — *Tukkipuita*	1 746	1 254
	Proportion, % — *Puulajisuhteet, %*	
Tree species — *Puulaji* Pine — *Mänty*	2	59
Spruce — *Kuusi*	96	39
Birch — *Koivu*	2	2
Total — *Yhteensä*	100	100

lower edge of whose bulldozer plate four ripper teeth were added. The piles were destroyed by burning. Removal of the branches made it easier to find the stumps in later studies, but it weakened the bearing capacity of the swamp.

42. Stump material

Before the time study phase, the stump diameters and heights were measured in both experimental plots. The diameter was measured crosswise at the cutting height above bark. Height refers to the distance of the cutting cross-section from the level of the swamp surface.

The average diameter was 28.4 cm and average height 28.6 cm in Sammallahti. The corresponding figures for Kettula were 32.3 and 34.2 cm. The distribution of the observations by diameter and height classes are given in Tables 2 and 3.

Table 2. The diameter and height distribution of the stump material in Sammallahti swamp
Taulukko 2. Sammallahdenkorven kantoaineiston läpimitta- ja korkeusjakautuma

Diameter cm *Läpimitta cm*	Height, cm — *Korkeus, cm*											Total *Yhteensä*	Average height, cm *Keskikorkeus, cm*
	—10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	55+		
	Number of observations — *Havaintoja, kpl*												
—20 ..	3	48	84	103	50	17	5	2	—	—	—	312	22
20—24 ..	—	22	76	118	82	45	13	1	1	—	—	358	24
24—28 ..	—	17	59	173	199	136	60	11	3	2	—	660	28
28—32 ..	—	1	30	112	187	141	81	25	8	—	—	585	30
32—36 ..	—	1	12	68	103	114	68	35	13	—	—	414	32
36—40 ..	—	1	3	21	62	58	41	25	7	2	—	220	33
40—44 ..	—	—	2	3	16	21	19	4	5	4	3	77	36
44+ ..	—	—	1	2	5	9	12	12	1	1	1	44	37
Total	3	90	267	600	704	541	299	115	38	9	4	2 670	—

Table 3. The diameter and height distribution of the stump material in Kettula swamp
Taulukko 3. Kettulansuon kantoaineiston läpimitta- ja korkeusjakautuma

Diameter cm *Läpimitta cm*	Height, cm — *Korkeus, cm*											Total *Yhteensä*	Average height, cm *Keskikorkeus cm*
	—10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	55+		
	Number of observations — *Havaintoja, kpl*												
—20 ..	4	8	17	37	21	12	9	4	—	1	—	113	25
20—24 ..	—	1	8	36	38	24	16	3	4	—	1	131	29
24—28 ..	—	3	6	32	53	44	33	16	3	—	1	191	31
28—32 ..	—	3	11	36	66	65	71	35	17	5	7	316	34
32—36 ..	—	2	5	27	59	79	91	35	28	7	6	339	35
36—40 ..	—	—	3	7	24	47	61	35	24	8	6	215	38
40—44 ..	—	—	2	8	15	30	43	31	25	6	7	167	39
44+ ..	—	—	1	2	10	19	39	30	25	19	3	148	41
Total	4	17	53	185	286	320	363	189	126	46	31	1 620	—

When stump diameter grows its height also increases. The stump heights are considerably greater in the present swamp material than the average for mineral soil (cf. Hakkila 1972). This is typical in drained swamps for the surface of the swamp is lowered by drainage and the underground butt swell of the trees is partly exposed. In the cutting phase a large butt swell prevents the tree from being cut close to the level of the swamp surface.

43. Time studies

The time studies were carried out daily at 0700—1500 hours in the period June 13 to August 8, 1972. The stop watch method was used. In this method the time is recorded at the end of each work phase and the hands of the watch are returned immediately to their initial position. The scheduled operating time of the Stumparvester was distributed in the following way (cf. Berard, Dibblee and Horncastle 1969):

- Productive time
  - Extraction
  - Splitting and loading
  - Moving from stump to stump
  - Unloading
    - Moving to unloading site
    - Preparing for unloading
    - Unloading proper
- Delay time
  - Mechanical delay time
    - In-shift repair
      - Basic machine
      - Accessories of Stumparvester
    - In-shift service
  - Non-mechanical delay time
    - Personnel time
    - Miscellaneous

Distinguishing between extraction and splitting caused difficulties in the time study. When the stump-root system was extracted intact the boundary line between these two work phases was clear. When the stump-root system was extracted in several parts extraction was considered in the distribution of working time to have ended when the first part of the stump-root system was extracted. The lapsed time after that was classified as splitting. The combined extraction and splitting time can in any case be regarded as unequivocal.

The diameter of each stump including bark was marked on the stump cross section before beginning the harvesting. The diameter for the time study forms was obtained from this. In addition, the number of particles in the split stump-root system was counted and the distances from stump to stump and the distance travelled in the unloading phase were measured.

A separate experiment was organised on mineral soil in which the Stumparvester was unloaded directly into a farm tractor. A concise time study of the use of farm tractor in forest transport was conducted in this connection.

The time study material comprised 986 spruce and 433 pine stump-root systems. They yielded 277 harvester loads.

5. RESULTS OF THE TIME STUDIES

The scheduled operating time of the Stumparvester was divided into two main parts, productive time and delay time. This chapter will be confined to productive time. Delay time, either mechanical or non-mechanical, will be discussed separately in section 57 and will then be taken into consideration in the calculation of output and costs of the work in chapter 7.

The results are presented partly as per-stump and partly as per-load observations. The degree of explanation of the variation of the latter is naturally higher as per-load observations in the different sample plots are at the same time means of 4—6 stump-root systems. Output in solid cubic metres in the different work phases is calculated in chapter 7 from the time expenditure per load.

51. Moving from stump to stump

For extracting and splitting the harvester has to move from stump to stump. When there are many stump-root systems per unit of area several systems can be extracted from the same position. An essential requirement for this is the fullest possible boom turning circle, preferably 360°. Increasing of the boom radius also reduces the need for movement.

The number of stump-root systems harvested per hectare was 485 in experimental plot I and 261 in plot II. An average of 1.4 and 1.3 stump-root systems was extracted from a single position. The moving distance from one stump to another was 6 and 7 m.

The moving time depends primarily on the moving distance and type of terrain. Stones in particular increase the time expenditure, and moving time was therefore greater on mineral soil than in swamp terrain. The average moving time per load in different conditions was as follows:

	Distance, metres	Moving time, cmin/load	
		$\bar{x}$	s
Swamp plot I	29	134	96
Swamp plot II	38	196	153
Mineral soil	31	202	196

The variation in the per-load moving time within an experimental plot is explained by distance and also by the number of stump-root systems per load. It illustrates at the same time the number of stops and starts. There was a small but significant difference also between the drivers in the investigation material. The following equations can be constructed for distance alone.

		R	$s_{x.y}$, cmin
Swamp plot I	$y_1 = 59 + 2.60x_1$	0.712	68
Swamp plot II	$y_1 = 31 + 3.92x_1$	0.909	65
Mineral soil	$y_1 = 102 + 0.0722x_1^2$	0.931	73

y_1 = Moving time, cmin/load
x_1 = Moving distance in extraction and splitting, m/load

Moving in connection with extraction and splitting constitutes a relatively small part of the total time consumption in harvesting. It is thus possible in this respect to collect stump-root systems also from clear cutting areas with a low per-hectare number of stems. Even a moving distance double that of the investigation conditions does not increase total time consumption seriously.

	Moving distance in extraction and splitting, m/load		
	10	30	50
	Moving time, cmin/load		
Swamp plot I	85	137	189
Swamp plot II	70	149	227
Mineral soil	109	167	283

When the per-load moving distance increased from 10 to 50 m, time consumption increased in the investigation conditions by 1—2 min., depending on the difficulty of the terrain. The structure of the working time, reported later, shows that only a small increase in total time consumption ensued. It may be concluded that if the harvester is not used for forest transport proper and the stump and root wood is unloaded in the compartment, output is affected relatively little by the number of stump-root systems per hectare. Consequently, harvesting a clear cutting area with a relatively low number of trees per hectare is also feasible provided that they are otherwise of sufficient size. However, terrains difficult to negotiate because of stoniness are exceptions to this. On the other hand, if the harvester is used solely for extraction, moving has a decisive influence.

52. Extraction

As mentioned when describing the method, extraction and splitting, especially of large stump-root systems, are events that are simultaneous to such an extent that distinguishing between them is often a fairly subjective matter in time studies. However, it may be desired to use the stump harvester in special cases

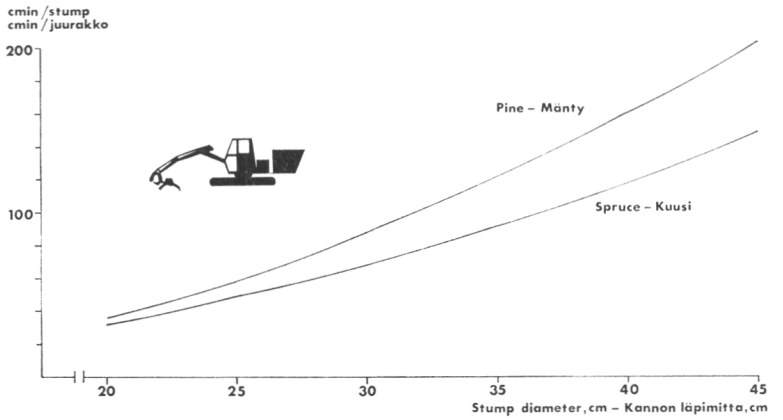


Figure 8. Extraction time per stump-root system as a function of stump diameter.

Kuva 8. Juurakkoa kohti kuluva irrottamisaika kantoläpimitan funktiona.

for, say, extraction alone. A time study was therefore conducted in experimental plot II in which these two phases of work were completely separated. First, 244 stump-root systems were extracted. The harvester then returned to the same site to perform the splitting.

		R	$s_{x.y}$, cmin
Spruce	$y_s = 3 + 0.072x_1^2$	0.748	53
Pine	$y_s = -6 + 0.103x_1^2$	0.565	63

y_s = Extraction time, cmin/stump
x_1 = Stump diameter above bark, cm

Extraction time grows with stump diameter (Fig. 8). Diameter, however, explains only a small proportion of the variation, 32 per cent for pine and 55 per cent for spruce, for the depth of the stump-root system and other logging technique properties, the nature and bearing capacity of the soil, and the location of the stump-root system in relation to the harvester all affect the consumption of time. When stump diameter increases from 20 to 40 cm, the average extraction time is lengthened 4—5-fold. On the other hand, if the moving time from stump to stump is considered the relative change is smaller.

The Stumparvester is capable at least in swampy ground of extracting even large stump-root systems without a decisive increase in time consumption in a certain size class. Working time decreases sharply with the growth of stump diameter per volume and weight unit of timber.

Large stump-root systems are best extracted in pieces. When this method was used, only the extraction of the first piece was included in the time study as extraction and the rest of the time was ascribed to splitting. The average per-load results for extraction are therefore smaller than the real values.

	Extraction time, cmin/load	
	$\bar{x}$	s
Spruce on swamp	216	149
Pine on swamp	326	154
Spruce on mineral soil	186	91

After finalising the correct work technique, even large stump-root systems caused no difficulties in extraction, provided that the ground was not very stony. For pines in mineral soil, which have a strong tap root in South Finnish conditions, splitting the stump with a shear blade facilitates extraction decisively.

53. Splitting

The work phase that is called here splitting comprises in addition to splitting proper also cleaning and loading of the particles into the rear box (Fig. 9). The purpose of cleaning is to reduce the amount of loose soil, humus and thin roots in stump and root wood. It is done partly by dropping the stump-root system on the ground from a height of 3—4 m, partly by tearing out the humus between the roots by means of the extraction teeth, and partly by cutting off from the lateral roots the parts under 5 cm in diameter.

As splitting is often performed simultaneously with extraction, the following analysis is limited to the material of 244 stump-root systems in which extraction was done as a completely separate measure. The combined time required by these work phases will be analysed in greater detail later.

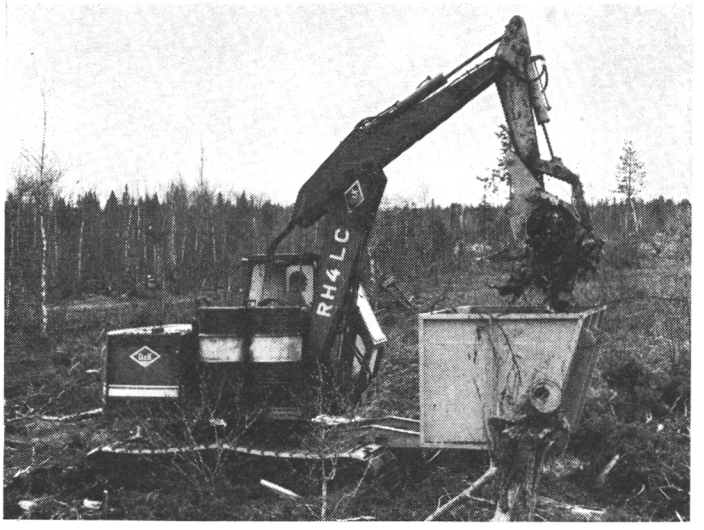


Figure 9. Simultaneous splitting and loading.
Kuva 9. Samanaikainen pilkkominen ja kuormaaminen.

The splitting time depends above all on the size and structure of the stump-root system, the size of the particles to be prepared and the cleaning requirement. A length of 60 cm and diameter of 30—40 cm were fixed originally as the maximum particle size on the basis of transport considerations and the limitations imposed by mill equipment. These target limits turned out in practice to be averages, but the particle size was on the whole sufficiently small for the subsequent phases. The number of particles made from the stump-root system in the separate material of 244 systems was as follows according to the stump diameter:

Stump diameter cm	Number of pieces/stump-root system	
	Spruce	Pine
20	4.5	5.2
25	6.2	6.3
30	7.5	7.3
35	8.6	8.3
40	9.6	9.3
45	10.5	10.3

Splitting time can be illustrated by equations in which stump diameter and the number of particles per stump-root system are the independent variables. However, the share of unexplained variation remains great, especially for pine; it is due above all to the irregularity of the cleaning time.

		R	$s_{x.y}$, cmin
Spruce	$y_s = -50 + 0.110x_1^2 + 36.2x_2$	0.882	93
Pine	$y_s = -26 + 0.123x_1^2 + 28.9x_2$	0.738	92

y_s = Splitting time, cmin/stump-root system
x_1 = Stump diameter above bark, cm
x_2 = Number of pieces per stump-root system

When stump diameter increases from 20 to 40 cm the time consumed on splitting the stump-root system is trebled (Fig. 10). It is shown later, however, that the time expended per unit of volume and weight contracts sharply with the growth in the size of the stump-root system. On the other hand, the average particle size grows with the size of the stump-root system.

The results for the per-load material concur relatively well with the preceding results. The splitting phase seems to have been shorter in mineral than in swampy soil. This is explained solely by the fact that cleaning is a considerably more laborious procedure in a swamp.

	Splitting time cmin/load		Stump diameter, cm	Number of stumps/load	Number of pieces/load
	$\bar{x}$	s			
Spruce on swamp	1 972	710	32	5.2	41
Pine on swamp	1 911	836	33	5.7	44
Spruce on mineral soil	1 607	553	30	6.1	40

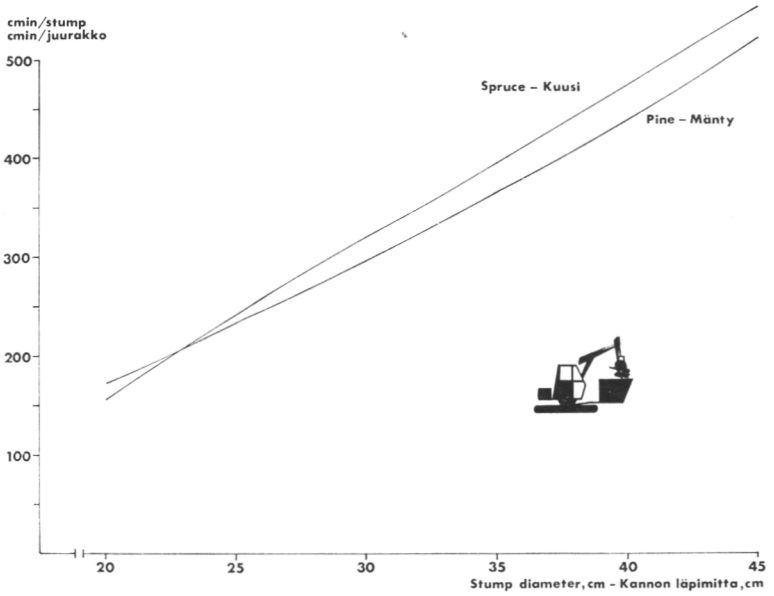


Figure 10. Splitting time per stump-root system as a function of stump diameter.

Kuva 10. Juurakkoa kohti kuluva paloitteluaika kantoläpimitan funktiona.

54. Combined extraction and splitting

Owing to the work technique of the harvester, distinguishing between the extraction and splitting phases caused difficulties in the time studies. On the other hand, it was always possible to determine reliably the sum of the extraction and splitting times. It is therefore possible in this section to examine the entire investigation material, first on a per-stump and finally on a per-load basis. Moving was included in the time consumed on extraction and splitting by assuming that the harvester had to move an average of 6 m per stump.

		R	$s_{x.y}$, cmin
Spruce on swamp	$y_s = -18 + 0.232x_1^2 + 28.1x_2 + 4.0x_3$	0.872	100
Pine on swamp	$y_s = -149 + 12.03x_1 + 22.6x_2 + 4.1x_3$	0.849	85
Spruce on mineral soil ...	$y_s = -2 + 0.133x_1^2 + 19.9x_2 + 10.4x_3$	0.843	85
Pine on mineral soil	$y_s = -688 + 2.310x_1^2/x_2 + 96.3x_2 + 6.9x_3$	0.755	233

y_s = Combined extraction, splitting and moving time, cmin/stump-root system
x_1 = Stump diameter above bark, cm
x_2 = Number of pieces/stump-root system
x_3 = Moving distance from stump to stump, m

The per-stump variation can be explained in the equation mainly by the size of the stump-root system, the number of the pieces prepared and the moving distance. There was a small but significant difference also between the drivers.

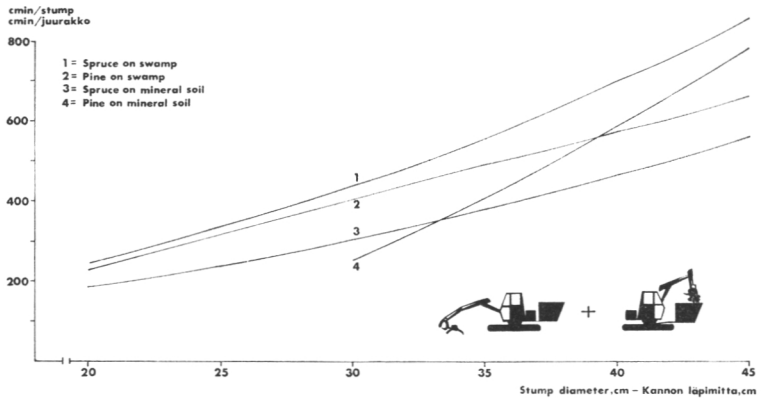


Figure 11. Combined extraction and splitting time per stump-root system as a function of stump diameter.

Kuva 11. Kantoa kohti kuluva yhteenlaskettu irrottamis- ja paloitteluaika kantoläpimitan funktiona (1 = suomaan kuusi, 2 = suomaan mänty, 3 = kangasmaan kuusi, 4 = kangasmaan mänty).

Of stump-root systems with the same stump diameter, peatland spruce required the longest time (Fig 11). This was due first and foremost to the time expended on the removal of ground vegetation and peat. It must also be noted, on the other hand, that a spruce stump-root system on peat land contains a considerable quantity of wood in relation to its stump diameter.

The time consumed per stump-root system on mineral soil was distinctly smaller in spite of the inconvenience of stones for moving. However, the largest pine stump-root systems, over 40 cm, constituted an exception as their tap root alone slowed down the work essentially.

The per-load time, too, seemed to be smaller on mineral soil than in swamps. The mineral soil pine material was too small to warrant reliable comparison. The difference for spruce was 15 %, but it should be mentioned that the load contained less merchantable wood on mineral soil.

	Combined extraction, splitting and moving time, cmin/load	
	$\bar{x}$	s
Spruce on swamp	2 322	789
Pine on swamp	2 433	988
Spruce on mineral soil	1 995	595

The per-load time was the mean for 5—6 stump-root systems, and hence the role of random variation is not as great relatively as for individual stump-root systems. Again, independent variables that can be used are those that illustrate stump diameter, number of stump-root systems in the load, number of pieces made, and moving distance. The small difference between the drivers is again significant, but it was disregarded in the following equations.

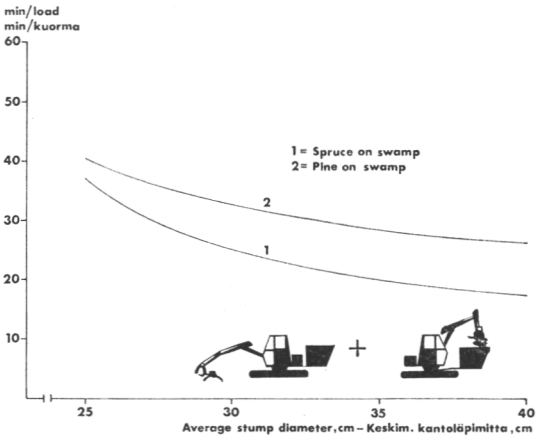


Figure 12. Combined extraction and splitting time per harvester load of one solid cubic metre, as a function of average stump diameter.

Kuva 12. Yhden kiintokuutiometrin harvesterikuormaa kohti kuluva yhteenlaskettu irrottamis- ja paloitteluaika keskimääräisen kantoläpimitan funktiona.

		R	$s_{x.y}$, cmin
Spruce on swamp ..	$y_1 = -706 + 13.39x_1x_2 + 96.7x_3/x_2 + 4.0x_4$	0.902	345
Pine on swamp	$y_1 = -381 + 12.30x_1x_2 + 0.440x_1^2 + 3.5x_4$	0.977	220

y_1 = Combined extraction, splitting and moving time, cmin/load
x_1 = Average stump diameter in a load, cm
x_2 = Number of stump-root systems/load
x_3 = Number of stump and root pieces/load
x_4 = Moving distance during extraction, m/load

Fig. 12 was drawn from the equations. The number of stump-root systems in a load was calculated theoretically from the results presented in chapter 6 on the assumption that every load contained 1.0 solid cubic metres of stump and root wood. The harvester was assumed to travel 6 m per stump during the loading operation.

Combined extraction and splitting time per load, including moving from stump to stump, depends markedly on the size of the stump-root system. The time consumption is doubled for spruce when the average stump diameter increases from 25 to 40 cm. The difference is smaller for pine.

55. Unloading

The rear box can be unloaded into the compartment in one-load stacks (Fig. 13), directly into a tractor trailer (Fig. 14) or into larger stacks to await long-distance transport. The total unloading time depens decisively on the length of the distance moved. In peatland terrain the harvester kept to the following

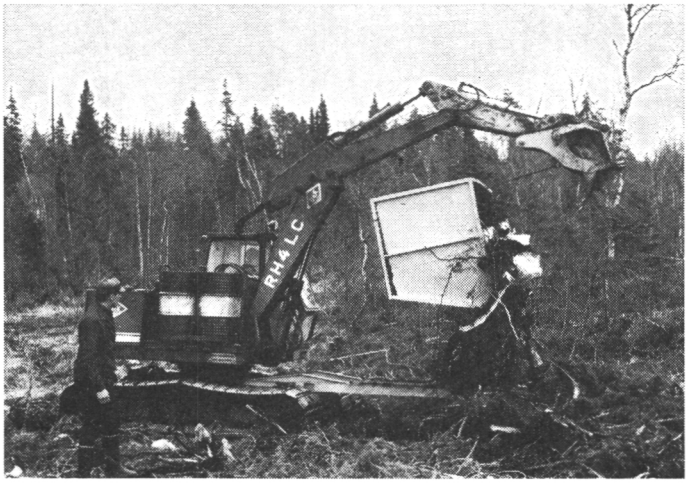


Figure 13. Unloading.
Kuva 13. Purkaminen palstalle.

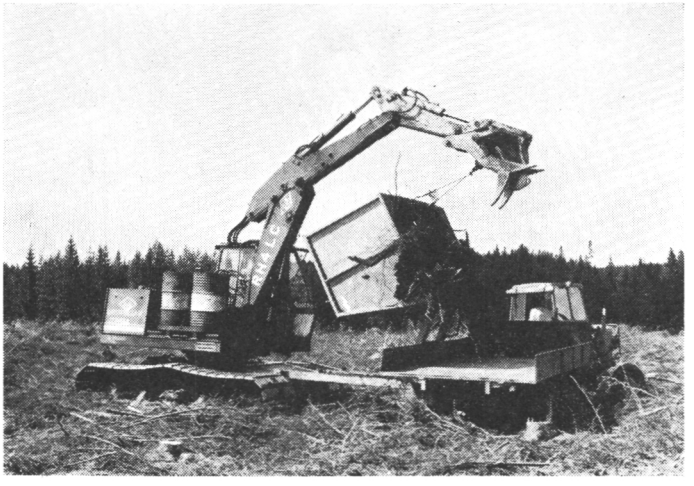


Figure 14. Unloading into a farm tractor.
Kuva 14. Purkaminen maataloustraktoriin.

equations which represent a favourable driving terrain. On mineral soil, the movements of harvester equipped with swamp tracks were hampered by stones and its speed was consequently essentially lower. The shortness of the distances made it impossible to form equations for the mineral soil experimental plot.

		R	$s_{x \cdot y}$, cmin
Swamp plot I	$y_1 = 37 + 3.50x_1$	0.906	56
Swamp plot II	$y_1 = 57 + 3.27x_1$	0.844	72

y_1 = Moving time in unloading, cmin/load
x_1 = Moving distance in one direction, m

The bunching distance was fairly limited in practice because of the low travel speed of the machine, but it is possible in advantageous conditions to take stump and root wood to within the reach of the truck. The average unloading distance in the investigation material was 40 m on peatland, only one-half of it on mineral soil. The total unloading time in the different experimental plots was 3 min. on average.

	Swamp plot I	Swamp plot II	Mineral soil
	Unloading time, cmin/load		
Moving to unloading site..	155	161	126
Preparing for unloading ..	89	84	124
Unloading proper	46	61	92
Total	290	306	342

In addition to moving, the time studies analysed as a separate phase preparing for unloading which consisted of fixing the rear box wire rope to a hook in the lower edge of the splitting device for tipping, and unfastening the wire after tipping (Fig. 15). Unloading proper, which is the tipping of the rear box,



Figure 15. Preparing for unloading. The wire of the rear box is being attached to the boom.
Kuva 15. Valmistautuminen purkamiseen. Perälaatikon vaijeria kiinnitetään puomiin.

accounted for only a small proportion of the time consumption in unloading. Its significance was slightly greater in the experiment on mineral soil when unloading was into a farm tractor.

56. Total productive time

Moving from stump to stump, extraction, splitting and unloading make up the total productive time of the Stumparvester. The average per-load time on peatland was 27 min., on mineral soil only 23 min. in spite of stoniness. This was primarily because the load contained a smaller amount of over 5 cm thick wood on mineral than on swampy soil.

	Total productive time, cmin/load	
	$\bar{x}$	s
Spruce on swamp	2 611	789
Pine on swamp	2 739	994
Spruce on mineral soil	2 338	605

Splitting took the greatest part of the working time (Table 4). Its share was almost 70 % for swamp pine and mineral soil spruce. Even more time was required for splitting peatland spruce; however, this was due partly to the time classification used in the study and partly to the difficulty of cleaning the stump-root system. Unloading inclusive of moving on svampy soil accounted for 11 % of total productive time, and on mineral soil for slightly more. Preparations for unloading required more time on mineral soil as tipping was done directly into a farm tractor.

Table 4. The structure of the total productive time of the Pallari Stumparvester
Taulukko 4. Pallarin kantoharvesterin tehotyöajan rakenne

Work phase — *Työvaihe*	Spruce on swamp *Kuusi suolla*	Pine on swamp *Mänty suolla*	Spruce on mineral soil *Kuusi kankaalla*
	Proportion, % — *Osuus*, %		
Moving from stump to stump — *Siirtyminen kannolta toiselle*	8.3	12.1	8.1
Extraction — *Irrottaminen*	5.0	7.3	8.6
Splitting — *Paloittelu*	75.3	69.7	68.8
Total — *Yhteensä*	88.6	89.1	85.5
Moving for unloading — *Siirtyminen purkamista varten*	6.1	5.8	5.6
Preparing for unloading — *Purkamisen valmistelu*	3.4	2.9	5.1
Unloading proper — *Varsinainen purkaminen*	1.9	2.2	3.8
Unloading, total — *Purkaminen yhteensä*	11.4	10.9	14.5
Total productive time — *Kokonaistehotyöaika*	100.0	100.0	100.0

The same variables that explained partial working times explain the variation of per-load productive time. The average stump diameter, the number of stump-root systems in a load and the number of pieces made explain most of the variation.

		R	$s_{x.y}$, cmin
Spruce on swamp ..	$y_1 = -516 + 12.93x_1x_2 + 93.2x_3/x_2 + 4.9x_4 + 2.5x_5 + 175x_6$	0.911	322
Pine on swamp	$y_1 = 540 + 11.23x_1x_2 + 5.0x_4$	0.967	259

y_1 = Total productive time, cmin/load
x_1 = Average stump diameter in a load, cm
x_2 = Number of stump-root systems per load
x_3 = Number of stump and root pieces per load
x_4 = Moving distance in extraction, m/load
x_5 = Moving distance in unloading, m/load
x_6 = Driver (either 0 or 1)

Fig. 16 is based on regression equations for total productive time. The load size was again assumed to be 1.0 solid cubic metres and the number of stump-root systems in the load was determined accordingly. The moving distance from stump to stump was taken to be 6 m and the moving distance in unloading 40 m. These curves will be used in chapter 7 in the calculation of output and costs. The total productive time per load depends markedly on the size of the stump-root system.

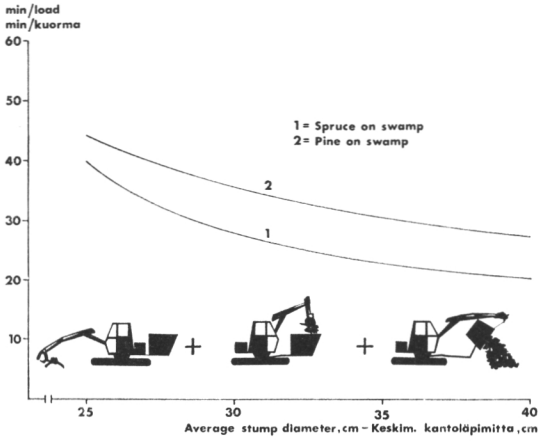


Figure 16. Total productive time per harvester load of one solid cubic metre, as a function of average stump diameter.

Kuva 16. Yhden kiintokuutiometrin harvesterikuormaa kohti kuluva tehotyöaika keskimääräisen kantoläpimitan funktiona.

57. Delay time

Most interruptions were of mechanical origin (Table 5). Almost all repairs were to the basic machine. The extraction-splitting device and rear box of the Stumparvester were quite durable and reliable in operation. Service time, too, was expended almost entirely on the basic machine.

Of the non-mechanical delays, the long rest intervals of the driver are to be associated with the exceptionally hot summer. The weather made work in the cabin of the excavator on a clear cutting area surrounded by forest truly hard for several weeks.

Table 5. The proportion of delay time when compared with productive time
Taulukko 5. Keskeytysten osuus tehotyöaikaan verrattuna

Cause of delay *Keskeytyksen syy*	Driver I *Kuljettaja I*	Driver II *Kuljettaja II*
	Proportion, % — *Osuus*, %	
Mechanical — *Mekaaninen*		
Repair of basic machine — *Peruskoneen korjaus*	6.6	5.5
Repair of special equipment — *Lisälaitteitten korjaus* .	3.4	—
Service — *Huolto*	6.3	3.5
Non-mechanical — *Muu kuin mekaaninen*		
Personnel — *Lepo*	10.9	1.3
Miscellaneous — *Sekalaista*	1.0	0.9
Total — *Yhteensä*	28.2	11.2

The Stumparvester sank into the swamp three times during the investigation. The fundamental reason was the height of the level of ground water which weakened the bearing capacity of the swamp. The reason why it bogged down when crossing a ditch can be attributed at least once to the rear box. These long delays were not included in the table.

There were two moves from one work site to another, but not during the investigation.

According to the general practice, 10 % of productive time was regarded as the proportion of interruptions in the output and cost calculations of chapter 7. This was significantly less than the percentage established in the time study. Furthermore, only a small proportion of the interruptions were caused by factors associated with the use and structure of the extraction-splitting device and rear box of the Stumparvester.

6. THE TIMBER

61. Quantity of timber

One of the part aims of the investigation was to study the dry weight and solid volume of wood per stump-root system and hectare on swamps. One hundred stump-root systems were selected by lot from experimental plots I and II and cleaned carefully with steel brushes. The stump and root wood were weighed green and these values were converted into dry weights by means of moisture samples. The volumes were obtained from the dry weights by conversion using the basic density of wood (Figs. 17 and 18). According to an unpublished material, 395 kg/solid cu.m. was assumed to be the basic density of spruce stump and root wood. For pine, the basic density value used was 450 kg/solid cu.m., the average measured from experimental plot II.

The results are compared in the following with earlier information conserning mineral soil and an undrained swamp in South Finland (cf. H a k k i l a 1972). It is seen that the quantity of stump and root wood is considerably greater on swamps.

	Diameter range, cm	Equation	R	$s_{x.y}$, kg
Present material:				
Spruce on drained swamp	25—45	$y_s = -36.1 + 0.118x_1^2$	.886	18.0
Pine on drained swamp	25—45	$y_s = -3.4 + 0.063x_1^2$	.871	16.5
Earlier material:				
Spruce on mineral soil	15—40	$y_s = -7.0 + 0.051x_1^2$	.948	9.1
Spruce on undrained swamp ..	20—25	$y_s = -1.8 + 0.109x_1^2$	.933	16.8
Pine on mineral soil	15—45	$y_s = -2.0 + 0.039x_1^2$	.923	8.2

y_s = Dry weight of stump-root system, excluding root wood less than 5 cm in diameter, kg
x_1 = Stump diameter above bark, cm

The point of comparison in the cost calculations for the harvesting of stump and root wood is generally pine pulpwood, that is the raw material to supplement which stump and root wood is needed in Finland in the first place. The following table shows the number of stump-root systems harvested from drained swamp that is equivalent to the dry matter content of a piled cubic metre of unbarked pine pulpwood in the conditions of southern Finland. The solid volume content of a pulpwood pile is taken to be 0.66 (cf. R i k k o n e n 1972).

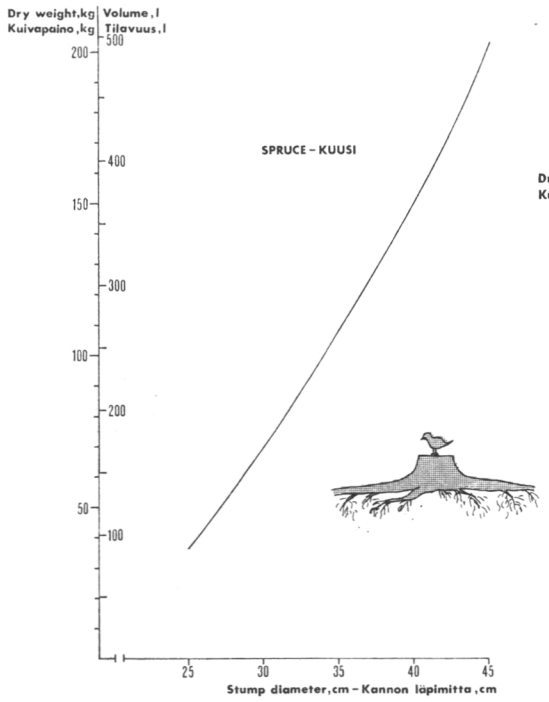


Figure 17. Dry weight of the stump-root system of spruce in Sammallahti and Kettula swamps, excluding rootwood less than 5 cm in diameter, as a function of stump diameter above bark.

Kuva 17. Kuusen juurakon kuivapaino Sammallahdenkorvessa ja Kettulansuolla kuorellisen kantoläpimitan funktiona. Ei sisällä alle 5 cm:n juuripuuta.

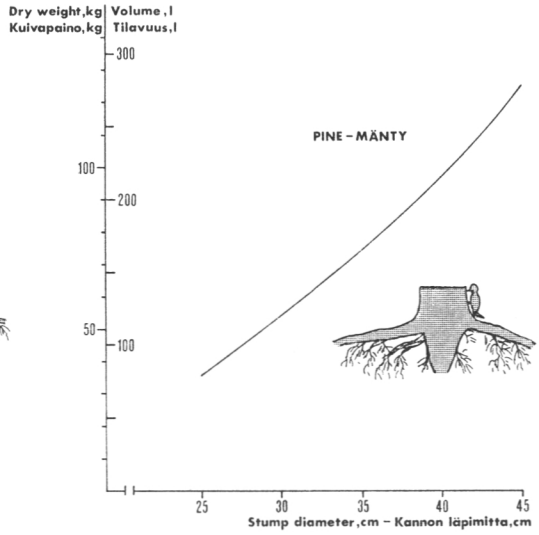


Figure 18. Dry weight of the stump-root system of pine in Kettula swamp, excluding root wood less than 5 cm in diameter, as a function of stump diameter above bark.

Kuva 18. Männyn juurakon kuivapaino Kettulansuolla kuorellisen kantoläpimitan funktiona. Ei sisällä alle 5 cm:n juuripuuta.

Stump diameter cm	Pine	Spruce	Pine	Spruce
	Number of stump-root systems corresponding to			
	solid cubic metre of pine pulpwood		piled cubic metre of pine pulpwood	
25	11.3	10.8	7.4	7.1
35	5.5	3.7	3.6	2.5
45	3.3	2.0	2.2	1.3

The diameter distribution of the stumps (Table 2 and 3) and regression equations can be used to calculate the total quantity of stump and root wood, again exluding root wood of under 5 cm. Experimental plot I contained 172 dry tons, i.e. 435 solid cu.m., of stump and root wood. The figures for experimental plot II were 129 tons and 300 solid cu.m., respectively (Table 6).

Table 6. The quantity of stump and root wood in Sammallahti and Kettula swamps, excluding root wood less than 5 cm in diameter

Taulukko 6. Kanto- ja juuripuun määrä Sammallahdenkorvessa ja Kettulansuolla. Ei sisällä alle 5 cm:n juuripuuta

Timber — *Puutavara*	Sammallahti		Kettula	
	Total *Yhteensä*	Per hectare *Hehtaaria kohti*	Total *Yhteensä*	Per hectare *Hehtaaria kohti*
Bole wood harvested — *Runkopuuta korjattu*				
Solid cu.m. — *K-m³*	996	181	811	135
Dry tons — *Tonneja kuivana*	388	71	336	56
Stump and root wood available — *Kanto- ja juuripuuta tarjolla*				
Solid cu.m. — *K-m³*	435	79	306	51
Dry tons — *Tonneja kuivana*	172	31	129	22
Stump and root wood harvested — *Kanto ja juuripuuta korjattu*				
Solid cu.m. — *K-m³*	412	75	286	48
Dry tons — *Tonneja kuivana*	163	30	121	20
Waste wood, % — *Hukkapuuta*, %				
Of bole wood [1]) — *Runkopuusta* [1])	3	3	3	3
Of stump and root wood — *Kanto- ja juuripuusta*	5	5	6	6
Available stump and root wood, % of bole wood — *Tarjolla oleva kanto- ja juuripuu, % runkopuusta*				
On a volume basis — *Tilavuuden perusteella*	42	42	36	36
On a dry weight basis — *Kuivapainon perusteella*	42	42	37	37

[1]) Estimated average figure in stands dominated by saw timber trees in South Finland. — *Arvioitu keskiarvoluku tukkipuuvaltaisessa leimikossa Etelä-Suomessa.*

However, it was not possible to harvest all the timber. The true yield was calculated from the number of harvester loads and the average load size. One load comprised 1.03 solid cu.m. of spruce stump and root wood or 0.86 solid cu.m. of pine stump and root wood. In experimental plot I, 5 % and in II, 6 % of the total available, excluding the old stumps, was not harvested. The reasons for this waste wood were:

- Small pieces of stump and root were left on the ground in the extraction and splitting phase.
- Stumps less than 20 cm in diameter were generally not harvested.
- A small number of stump-root systems escaped the drivers' notice.
- Some marginal areas with a thin peat layer were left untreated as it was desired to deliver completely stone-free timber for the mill experiments.

If the volume of unbarked bole wood, including the estimated 3 % of waste wood, is denoted by 100 %, the quantity of available stump and root wood on a dry weight basis was 42 % in Sammallahti swamp and 37 % in Kettula swamp. An earlier study gave 23 % as the corresponding figure for pine and spruce on mineral soil in southern Finland and 47 % for spruce on undrained swamp (H a k k i l a 1972).

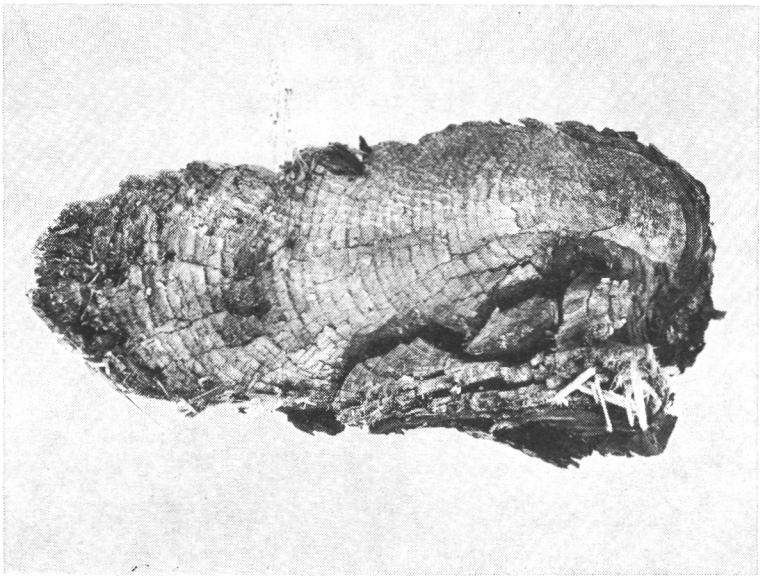


Figure 19. Shear damage on a cross-section of a spruce root.
Kuva 19. Leikkuuvaurioita kuusen juuren katkaisupinnalla.

62. Quality of timber

The splitting result of the harvester was unsatisfactory in the first experiments. The quality of timber improved considerably when the distance between the anvils of the splitting device was narrowed and the blade angle was reduced to 34 degrees. However, short checks typical of a hydraulic shear blade originate as a rule. In addition, cracks may appear that affect the solid volume content of a pile (Fig. 19).

The particle size of timber is determined by the restrictions imposed by the mill-end epuipment, solid volume content and splitting costs. The average length of the pieces of stump and root was 84 cm for driver I and 76 cm for driver II. The maximum width perpendicular to length was, correspondingly, 42 and 39 cm. The pieces were larger than the originally fixed measurements of the mill end, but they pass as such through the infeed aperture of most mill chippers. The number of pieces depends on the size of the stump-root system in the following manner.

		R	$s_{x.y}$, number
Spruce on swamp	$y_s = 3.0 + 0.0052x_1^2$	0.678	2
Pine on swamp	$y_s = 0.1 + 0.236x_1$	0.548	2
Spruce on mineral soil ...	$y_s = 1.6 + 0.0049x_1^2$	0.685	2
Pine on mineral soil	$y_s = 0.6 + 0.0046x_1^2$	0.600	3

y_s = Number of pieces per stump-root system
x_1 = Stump diameter above bark, cm

Table 7. The average volume (litres) of stump and root pieces in different stump diameter classes
Taulukko 7. Kanto- ja juuripuun palasten keskimääräinen tilavuus litroina kantoläpimitasta riippuen

Species and soil *Puulaji ja maaperä*	Stump diameter, cm — *Kannon läpimitta, cm*						
	20	25	30	35	40	45	50
	Volume of piece, l — *Palan tilavuus, l*						
Spruce on swamp	6	15	23	29	34	38	..
Pine on swamp	10	13	16	20	23	26	..
Spruce on mineral soil ...	4	13	15	17	18	19	..
Pine on mineral soil	..	..	16	17	18	18	19

The average number of pieces made from small stumps 20 cm in diameter on swamps was 5. The number of pieces from large stumps of 40 cm was 11—12 for spruce and 9—10 for pine. The average particle size was the greater the larger the stump-root systems split (Table 7).

The quantity of impurities, chiefly the amount of peat, is great initially in stump and root wood harvested from swampy soil (Fig. 20). However, a considerable proportion of the impurities is eliminated during the storage phase, often within a couple of weeks, by rain, wind, sun, frost and insects. Loading and haulage also help the cleaning process.

Stump and root wood harvested from mineral soil is outwardly cleaner looking after splitting. Sand and stones decrease further in the storage and long-distance transport phases, but a greater or smaller number of stones nevertheless always arrives at the mill, which interferes with chipping. There are stones also inside the stump-root systems.



Figure 20. Stump and root wood harvested from peatland includes at first plenty of impurities. However, considerable cleaning occurs during storage.

Kuva 20. Suomaalta korjattu kanto- ja juuripuu sisältää aluksi paljon epäpuhtauksia. Varastoinnin aikana tapahtuu kuitenkin huomattavaa puhdistumista.



Figure 21. Stump and root wood harvested from Sammallahti swamp by the Stumparvester. Left, the thin roots have been removed by hand.

Kuva 21. Kantoharvesterilla Sammallahdenkorvesta korjattua kanto- ja juuripuuta. Vasemmalla ohuet juuret on poistettu käsin.

It was sought by means of the working technique evolved in the study to limit the proportion of thin, under 5 cm roots to the smallest possible. Thin roots were cut off the stump-root system before splitting the merchantable part. It was possible in this way to remove most of them from spruce wood (Fig. 21), but numerous thin roots were left in the pine wood.

The solid volume content of stump and root wood was measured in northern Finland by immersion in water and in southern Finland by weighing and moisture determinations. As always, the results depended largely on the size of the measuring box. The solid volume content in the 4.6 cu.m. rear box of Stumparvester was 0.19 for Sammallahti spruce and 0.18 for Kettula pine. The solid volume content of timber prepared in the pilot experiments in North Finland was 0.23 for spruce and 0.22 for pine in a 15 cu.m. box.

The solid volume was appreciably greater, 0.38, for spruce wood of Sammallahti swamp when measured in a truck load of 53 cu.m. in which the pieces were placed partly manually. The timber had already been stored for 4 months by then and most of the impurities had disappeared with the autumn rains.

7. OUTPUT AND COSTS

The output of the Stumparvester in the experimental plots of Sammallahti and Kettula was calculated per working day of 8 hours, assuming the share of interruptions to be 10 % of the productive time. In the examples in Table 8 and Figs. 22 and 23, the load size is the same as in the average for the investigation material, 1.03 solid cu.m. for spruce and 0.86 for pine. The moving distance from stump to stump in extraction and splitting is 6 m and in unloading 40 m.

The daily output was markedly dependent on the size of the stump-root system. When the stump diameter increased from 25 to 40 cm, output increased by 50 % for pine and was doubled for spruce. The output was greater for spruce than pine.

The cost calculations are based on the target tariff, 52 marks/hour, of the RH 4-950 LC excavator in 1972 (Tie- ja vesirakennushallitus 1971). A lower hourly rental rate may be possible in continuous harvesting work. On the other

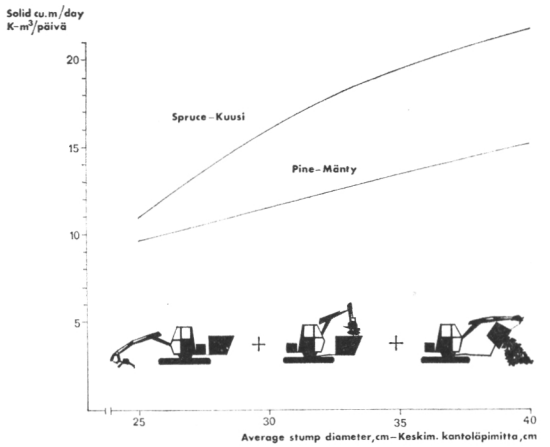


Figure 22. The average output of the Stumparvester in Sammallahti and Kettula swamps, in solid cubic metres per 8-hour day.

Kuva 22. Kantoharvesterin keskimääräinen tuotos kahdeksan tunnin työpäivänä Sammallahdenkorvessa ja Kettulansuolla.

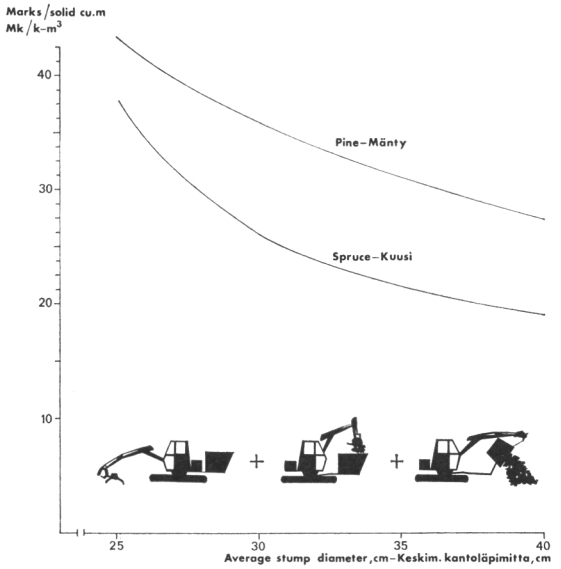


Figure 23. The harvesting costs of stump and root wood in Sammallahti and Kettula swamps, in Finnmarks per solid cubic metre in 1972. Forest transport distance 40 m.

Kuva 23. Kanto- ja juuripuun korjauskustannus markkoina kiintokuutiometriä kohti Sammallahdenkorvessa ja Kettulansuolla v. 1972. Lähikuljetusmatka 40 m.

hand, it is necessary to consider the moving costs which are included here in the hourly rental. If logging is extended to small work sites of short-term character, a separate fee must be charged for moving.

In this study, extraction, splitting and bunching over a distance of 40 m cost 26 marks/solid cu.m. for spruce and 36 marks/solid cu.m. for pine when the stump diameter was 30 cm. However, costs vary over a wide range depending on

Table 8. Time consumption, daily output and harvesting costs of the Pallari Stumparvester in Sammallahti and Kettula swamps. The proportion of interruptions is 10 % of the productive time. Forest transport distance 40 m

Taulukko 8. Pallarin kantoharvesterin ajankäyttö, päivätuotos ja korjuukustannukset Sammallahdenkorvessa ja Kettulansuolla. Keskeytysten osuus 10 % tehotyöajasta. Lähikuljetusmatka 40 m

Stump diameter cm *Kannon läpimitta cm*	Time consumption, min./load Ajankäyttö, min./kuorma		Output, cu.m./day *Tuotos, k-m³/päivä*		Cost, marks/cu.m. *Kustannus, mk/k-m³*	
	Spruce *Kuusi*	Pine *Mänty*	Spruce *Kuusi*	Pine *Mänty*	Spruce *Kuusi*	Pine *Mänty*
25	44	43	11.2	9.7	37.10	42.90
30	31	35	16.2	11.7	25.70	35.60
35	25	31	19.6	13.6	21.20	30.60
40	22	27	22.1	15.3	18.80	27.20

the properties of the stump-root system, stand and soil. In the following, only some of the most important cost factors are considered.

1. The tree species influences costs materially. The spruce stump-root system on swampy soil contains more wood than pine of the same stump diameter. The stump-root system of the spruce is more superficial and thus easier to extract, and spruce has fewer thin roots to interfere with cleaning and reduce the solid volume content. The costs of the Stumparvester per solid cubic metre are therefore 10—30 % dearer for pine than for spruce, depending on the size of the stump-root system. The difference is smaller per unit of weight, however, for the basic density of pine stump and root wood in the investigation material was 450 kg/solid cu.m., against only 395 kg/solid cu.m. for spruce.

2. When the size of the stump-root system increases costs decrease sharply (Table 6). The minimum size of the merchantable stump-root system depends in the last instance on the mill price of wood, but the cost of harvesting stumps under 25 cm in diameter is already distinctly too high. It is obvious that only the stump-root systems of saw timber trees come into question. The mean diameter of the stump must probably be at least 30 cm, which corresponds to a breast height diameter of 23 cm.

3. The per-hectare quantity of stump and root wood affects the harvesting costs to some extent. However, over two-thirds of the time consumption of the Stumparvester went solely to splitting, only 10 % to moving from stump to stump. This included also the return from the unloading site.

The amount of bole wood harvested per hectare was 181 solid cu.m. in experimental plot I and 135 solid cu.m. in plot II. The average yield of bole wood from clear cutting areas in Finland, however, is only 88 solid cu.m./hectare (Savolainen 1972), so the investigation conditions were more favourable than average.

The following table shows that stand density did not influence the costs very markedly with the work technique employed. The stump diameter was assumed to be 30 cm in the calculation. The average moving distance in experimental plot I was 6 and in II 7 m.

	Moving distance from stump to stump, m				
	3	6	9	12	15
	Harvesting cost excluding forest transport, marks/solid cu.m.				
Spruce	24.90	25.70	26.50	27.40	28.10
Pine	34.40	35.60	36.80	38.00	39.10

4. When the load size of the Stumparvester increases, costs decrease. The volume of the rear box used in the study was 4.6 cu.m. but the true amount of wood per load was 1.03 solid cu.m. for spruce and 0.86 for pine. The difference between the tree species was due to the better solid volume content of spruce wood. Pine has numerous thin roots which are not accepted as merchantable timber.

The solid volume content can be increased by careful cleaning and loading, but this adds to the splitting time. Another possibility might be a bigger rear box, but this was not tried in this connection. The most practical load size depends also on the forest transport arrangement. The following table shows the effect of load size on costs, assuming that increasing the size does not require lengthening the splitting time per solid cubic metre. The stump diameter was taken to be 30 cm.

	Load size, solid cu.m.				
	0.6	0.8	1.0	1.2	1.4
	Harvesting cost excluding forest transport, marks/solid cu.m.				
Spruce stumps	28.40	26.80	25.70	25.40	24.90
Pine stumps .	38.20	36.10	34.40	33.80	33.10

5. When the unloading distance lengthens harvester costs increase fast because of the low travel speed. The average unloading distance in the time studies was only 40 m. When the distance was 200 m for spruce and 150 m for pine the transport costs rose to 6 marks per solid cu.m. If the distance is lengthened further it is more economic to use a tractor for transport.

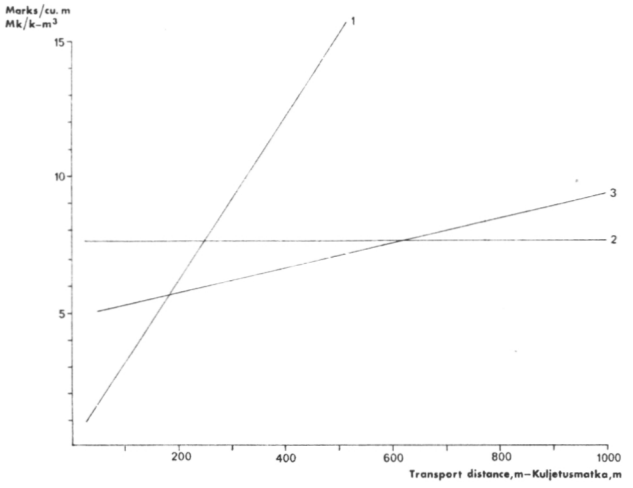


Figure 24. The forest transport costs of stump and root wood of spruce as a function of distance. 1 = transport with the Stumparvester; 2 = the Stumparvester unloads into a farm tractor trailer which is then used for transport; 3 = the Stumparvester unloads in the compartment and transport is done by a forest tractor equipped with grapple loader.

Kuva 24. Kuusen kanto- ja juuripuun lähikuljetuskustannus matkan funktiona. 1 = kuljetus kantoharvesterilla, 2 = harvesterin kuorma puretaan maataloustraktorin peräkärryyn, jolla kuljetus tapahtuu, 3 = harvesterin kuorma puretaan palstalle ja kuljetus tapahtuu kourakuormaajalla varustetulla metsätraktorilla.

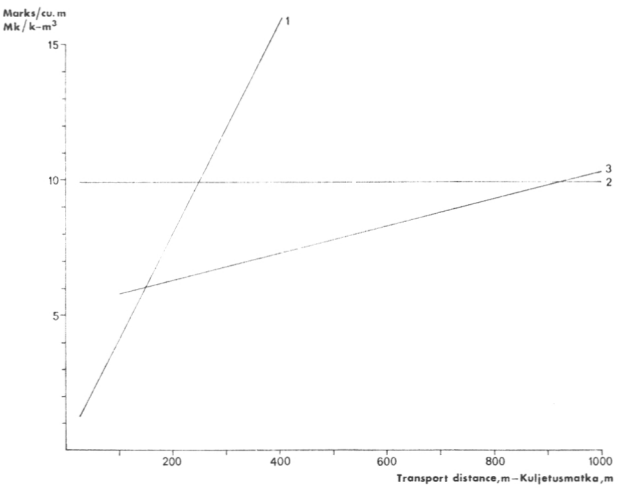


Figure 25. The forest transport cost of stump and root wood of pine as a function of distance. The explanations of curves 1, 2 and 3 are given in Figure 24.
Kuva 25. Männyn kanto- ja juuripuun kuljetuskustannus matkan funktiona. Käyrät 1, 2 ja 3 on selitetty kuvassa 24.

Figs. 24 and 25 show the costs of different alternatives as a function of the unloading distance. Forest transport can be performed by e.g. the following: Stumparvester (1), farm tractor equipped with tipping trailer (2) or forest tractor equipped with grapple loader (3).

The farm tractor alternative is tied up with the working rhythm of the harvester, for loading is done by tipping the harvester rear box contents directly into the trailer. As the harvester is an expensive unit it must not made to wait for the tractor. If the tractor capacity is not sufficient, two tractors must be used and the transport costs are then doubled. Depending on the terrain, one tractor can carry the load a distance of 500—2,000 m without endangering the working rhythm of the harvester.

A forest tractor with grapple loader has the advantage of being independent of the schedule of the rest of the harvesting operations. When the distance to be covered is over 600 m for spruce and 900 m for pine, the farm tractor of alternative 2 becomes the most economic solution. The prerequisite is, however, that the work can be done by a single tractor.

6. Harvester costs depend also on the s o i l. The main material for the study was collected from peatlands to which the costs mentioned above are also applicable. Indicative conclusions can be made from the small comparative material as to the costs of harvesting operations on mineral soil. Cost differences are coused primarily by the following factors:

— A narrow-track RH 4 excavator is used on mineral soil; its per-hour rental in 1972 was only 41 marks.
— The excavator moves more slowly on mineral soil if the soil is stony.
— Stoniness may make extraction difficult. Large pine stumps in particular stick very firmly in the ground because of their tap root.
— Cleaning the stump-root system is easier in mineral soil, for peatland stumps always contain abundant humus which adheres tenaciously to them. Stones may, however, interfere with splitting.
— If the stump diameter is the same, the stump-root system on mineral soil contains distinctly less wood than on swampy ground.

The harvester made an average of 2.3 loads per hour from 30 cm spruce stumps on mineral soil. The quantity of wood in the load may be assumed to be the same as for swamp pine, i.e. 0.86 solid cu.m. Even with spruce, numerous small roots are included in the load on mineral soil. With this assumption the daily output of the harvester is 16.1 solid cu.m. and costs 20.40 marks/solid cu.m., which is lower than on swampy ground.

8. SCARIFICATION AND PREPARATION OF THE SOIL

Different consequential effects are associated with the harvesting of stump and root wood. One of them is that the soil becomes scarified and broken. Scarification is beneficial for both natural and artificial regeneration of swamp forests (cf. K a u n i s t o 1971 and 1972). This was seen within the short period of the investigations in the appearance of profuse spontaneous young growth in experimental plot II on clean peat surface exposed by the Stumparvester.

The number of stump-root systems per hectare was great in Sammallahti and Kettula swamps. The earth was therefore broken up almost throughout, partly in connection with the extraction of the stump-root systems and partly by the tracks of the Stumparvester. However, holes formed in places and filled with water in the autumn (Fig. 26). But the stump-root system of the pine, too, is fairly superficial on peatlands and the holes are generally shallow.

Scarification must be taken into consideration when the profitability and expediency of utilizing stump and root wood are weighed. In the best case it may completely supersede the soil-preparation phase which precedes reforestation and the forest owner may then be ready to give the stump-root systems to the buyer



Figure 26. Kettula swamp after the harvesting of stump and root wood.
Kuva 26. Kettulansuo kanto- ja juuripuun korjuun jälkeen.



Figure 27. Air photo of Sammallahti swamp after the harvesting of stump and root wood.

Kuva 27. Ilmakuva Sammallahdenkorvesta kanto- ja juuripuun korjuun päätyttyä.



Figure 28. Air photo of Kettula swamp during the harvesting of stump and root wood. The right side of the swamp has already been treated, the middle part and left side are still untouched.

Kuva 28. Ilmakuva Kettulansuolta kanto- ja juuripuun korjuun alkuvaiheessa. Suon oikea reuna käsitelty, keskiosa ja vasen reuna vielä käsittelemättä.

without charging stumpage price. This in turn will lower the mill price of stump and root wood.

Fig. 27 gives a general idea of Sammallahti swamp at the end of the studies. Piles of stump and root wood are seen in various parts of the area, especially along the roadsides. The picture in Fig. 28 was taken of Kettulansuo in a phase when stump and root wood had been harvested only from right edge of the area. The experimental plots were handed over to the Department of Peatland Forestry, Finnish Forest Research Institute, which will continue the project with reforestation studies.

9. DISCUSSION

With the Pallari Stumparvester the most economic harvesting schedule depends primarily on the forest transport distance. Four harvesting schedule alternatives are presented in Fig. 29.

1. The simplest solution is based on the harvester alone which moves to the storage site to tip the rear box. The low travelling speed and the small volume of the transport box make the method unprofitable over long distances.

2. In harvesting schedule alternative 2 the rear box is replaced by a trailer, pulled by the harvester, into which the stumps are split. This method has not yet been tried out, but will be studied in summer 1973.

3. The third alternative comprises in addition to the Stumparvester a farm tractor equipped with a tipping trailer. The Stumparvester tips its load directly into the trailer and the tractor transports the wood to the storage site.

4. In harvesting schedule alternative 4 the harvester tips the pieces onto the ground. A forest tractor equipped with a grapple loader performs the forest

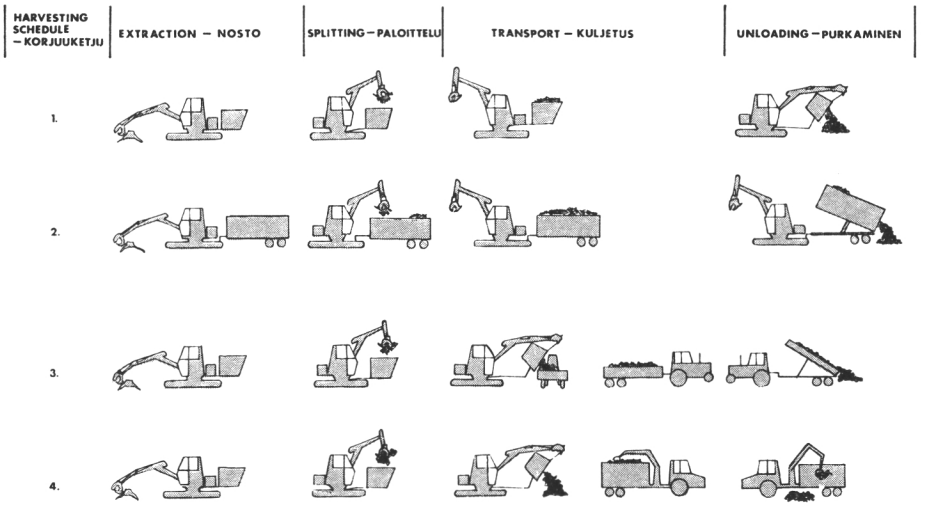


Figure 29. The Pallari Stumparvester in alternative harvesting schedules.
Kuva 29. Pallarin kantoharvesteri erilaisissa korjuuketjuvaihtoehdoissa.

transport. The advantage of the method is that tractor timetable and capacity need not be synchronised with the Stumparvester.

Table 9 gives the price of stump and root wood alongside the long-distance transport route for various forest transport distances and the most economic harvesting schedule. The figures do not include stumpage price or the overall costs of work supervision, purchasing activity, scaling, and other general costs.

Table 9. The harvesting costs of stump and root wood at the roadside, excluding general costs
Taulukko 9. Kanto- ja juuripuun korjuukustannukset kaukokuljetusreitin varrella ilman yleiskustannuksia

Stump diameter cm *Kannon läpimitta cm*	Forest transport distance, m — *Lähikuljetusmatka, m*				
	50	150	300	500	1 000
			Spruce — *Kuusi*		
25	37.70	40.80	42.20	43.30	43.60
30	25.90	29.50	31.10	32.00	32.30
35	21.50	25.10	26.70	27.60	27.90
40	19.00	22.60	24.20	25.10	25.40
			Pine — *Mänty*		
25	43.20	47.30	48.10	49.10	51.20
30	35.90	39.50	40.30	41.30	43.40
35	30.80	34.70	35.50	36.50	38.60
40	27.40	31.20	32.00	33.00	35.10

The long-distance transport costs were calculated on the basis of the target charges for the truck transport of dry softwood pulpwood (cf. Mäkelä 1972) and a solid volume content of 0.38. The transport of a piled cubic metre of stump and root wood has thus been assumed to cost as much as a piled cubic metre of pulpwood. In practice, however, lower costs may be possible for stump and root wood.

	Transport distance, km — *Kuljetusmatka, km*		
	20	50	100
Cost, marks/cu.m. — *Kustannus, mk/k-m*^{3}	9,90	13,10	17,40

The total costs of stump wood in an average case in which the stump diameter is 30 cm, forest transport distance 300 m and long-distance transport 50 km are as follows. The mill price is 44:20 marks/solid cu.m. for spruce and 53.40 marks/solid cu.m. for pine, excluding general costs. The calculations do not include stumpage price, for scarification of the soil may be compensation enough for the forest owner. The examples assume that the stumps are harvested on a swamp. The costs on mineral soil are probably lower than these figures, but utilization of stump and root wood from mineral soil involves greater difficulties at the mill because of stones.

The following features may be regarded as the advantages of Pallari Stumparvester:

1. The auxiliary apparatus of the basic machine is simple, reliable in operation and cheap. Installation in the excavator is fast and simple. The auxiliary apparatus increases the degree of employment of the basic machine.

2. It is economic from the standpoint of harvesting that one machine performs as many work phases as possible. This obviates difficulties in synchronising the expensive machines. The cost of transfer from one work site to another also diminishes along with the number of machine units. With the Pallari Stumparvester the harvester unit alone or with a forest transport vehicle are enough.

3. The productivity of human work is relatively high with the Stumparvester compared with the harvesting of bole wood. The human labour input of the harvester alone in an average case was 0.06 man-days for spruce and 0.08 for pine per solid cubic metre of stem and root wood at the roadside. When a farm tractor was used for forest transport the figures were 0.12 man-day per solid cubic metre for spruce and 0.16 for pine, and with the forest tractor harvesting schedule over a distance of 300 m they were 0.8 man-days per solid cubic metre for spruce and 0.10 for pine. According to Metsäteho's statistics, the average human labour input for logging and forest transport for the whole of Finland is 0.14 man-days per solid cu.m. for bole wood (Rysä and Savolainen 1972).

The Pallari Stumparvester seems to offer opportunities for harvesting of stump and root wood at such low cost that it may be profitable for the sulphate pulp industry to utilize stump and root wood as a supplementary raw material. Stone-free wood from swamps comes into question in the first phase as its utilization does not necessarily require a separate chipping line at the mill. The condition is, however, that the quantity of wood available is sufficient to make the additional investments in the requisite apparatus at the mill profitable.

10. SUMMARY

The Pallari Stumparvester is a multi-processing machine which extracts the stump-root system, removes most of the humus and mineral soil from it, splits it into pieces of desired size, collects them into piles of approximately one solid cubic metre and is also capable of forest transport over distances up to 150—200 m. The machine was developed in 1971—1972. The financing was supplied by the stump committee of the Central Association of Finnish Forest Industries.

The basic machine of the Stumparvester is an RH 4 excavator. The wide-track RH 4—950 LC type is used on swamps. Its technical data are given on p. 10 and in Fig. 1. The auxiliary apparatus consists of a hydraulic extraction-splitting device (Fig. 2 and colour plate 1) and a tipping 4.6 cu.m. rear box (Fig. 3).

The investigation phase that followed the development work is part of the joint Nordic research programme for the utilization of logging residues. The study was conducted in summer 1972 in the Vesijako experimental forest of the Finnish Forest Research Institute.

The most important goals of the investigation were to develop the work technique of the machine and to examine its operating reliability, the structure of the work time, output and costs. In addition, material was collected on the quantity of stump and root wood on swamps, and the nature of the product and the scarification of the soil were studied. The results obtained are applicable primarily to South-Finnish peatlands.

The main part of the study was conducted on two drained swamps which had been clear cut during the previous winter (Table 1, Figs. 4—7). The time study material comprised 1,419 stump-root systems. The mean diameter of the stumps was 30 cm and mean height 31 cm (Tables 2 and 3).

The work technique depends on the size of the stump-root system. Small stumps are extracted intact. Spruce stumps over 25 cm in diameter are extracted in pieces by twisting off the thickest lateral roots individually. A work technique in which the stump proper is split prior to extraction into two or more parts with a shearing device is suitable for pine stumps over 35 cm in diameter. Extraction and splitting are thus done partly simultaneously. Cleaning and loading of the pieces into the rear box are also combined with the splitting phase (Fig. 9). The rear box is emptied by tipping onto the ground or into the tractor rear box (Figs. 13—15, colour plates 1 and 2).

The time consumption of the Stumparvester is given partly per stump (Figs. 8, 10 and 11) and partly per load (Figs. 12 and 16). Preparing a load and carrying it a distance of 40 m took an average of 26 min. for spruce and 27 for pine, excluding interruptions. The total productive time for spruce was distributed as follows on peatland: Moving from stump to stump 8 %, extraction 5 %, splitting 75 % and unloading 12 % (Table 4). The proportion of delay time compared with productive time was 19 % during the investigation (Table 5). In the output and cost calculations, however, the share of interruptions was assumed to be 10 %.

The average output of the Stumparvester was calculated for the following conditions: mean diameter of the stump above bark 30 cm, load size 1.03 solid cu.m. for spruce and 0.86 for pine, average moving distance from stump to stump 6 m for spruce and 7 for pine, distance to unloading point 40 m, and share of interruptions 10 % of productive work time. Within these conditions, the output of the Stumparvester was 16.2 solid cu.m./8-hour work day for spruce and 11.7 for pine (Fig. 22). Costs in 1972 were correspondingly 26 and 36 marks/solid cu.m. (Table 8). Output and costs depend, however, on several factors.

The size of the stump-root system influences the costs markedly. If the stump diameter is 25 cm, harvesting one solid cubic metre in the conditions mentioned above costs 37 marks for spruce and 43 marks for pine. When the diameter increases to 40 cm the costs decrease correspondingly to 19 and 27 marks per solid cubic metre (Fig. 23).

Most of the time of the machine is consumed on splitting. The quantity of wood obtained from a unit of area therefore affects the costs relatively little. The amount of bole wood harvested in the experimental conditions was 181 solid cu.m./hectare in experimental plot I and 135 solid cu.m. in plot II. If the quantity of wood is one-half of the above, the harvesting costs of stump and root wood increase by about 2 marks per solid cubic metre.

The travelling speed of the Stumparvester is low and the transport distance thus affects the costs markedly. The transport distance was only 40 m in the example. Use of the Stumparvester for transport is profitable over distances of less than 200 m for spruce and less than 150 m for pine. The condition is, however, terrain with few stones. The cost of wood at the roadside is then 30 marks/solid cu.m. for spruce and 40 marks for pine.

Forest transport must be performed by tractor over longer distances. The cost of a forest tractor equipped with a grapple loader over a transport distance of 500 m is 7 marks/solid cu.m. for spruce and 8 marks for pine. The roadside price of wood is then 32 and 41 marks/solid cu.m., respectively, provided again that the average stump diameter is 30 cm. If the transport distance exceeds 600 m for spruce and 900 m for pine the use of farm tractor with a tipping trailer may be more economic. The Stumparvester then unloads directly into the tractor trailer (Figs. 24 and 25, Table 9).

The small comparative material collected from mineral soil indicates that harvesting costs are lower on mineral soil, at least in good conditions. But very stony soil slows the work of the Stumparvester. The cheaper narrow-track RH 4 excavator is the basic machine for mineral soil.

The solid volume content of stump and root wood in the Stumparvester rear box was only 0.19, against 0.38 in a manually packed truck load. The splitting result of the Stumparvester is satisfactory for sulphate pulp, although checking typical of the shear blade occurs. The timber is completely stone-free on swamps. Part of the peat and bark disappear with rain and frost during storage (Figs. 19—21). Studies on this aspect will be continued.

Soil scarification occurs in conjunction with the harvesting of stump and root wood, partly in the extraction of the stump-root systems and partly by the Stumparvester tracks. This facilitates reforestation work (Fig 26—28).

Stump and root wood over 5 cm in diameter totalled 79 solid cu.m./hectare in experimental plot I and 51 solid cu.m./hectare in plot II. 94—95 % of it was harvested. Compared with bole wood (unbarked bole = 100), the share of stump and root wood on a dry weight basis as 42 % for spruce and 37 % for pine (Table 6). Per-stump data on the quantity of stump and root wood are given in Figs. 17 and 18).

The investigation shows that, at least in certain conditions, the Pallari Stumparvester may be an economic solution for the harvesting of stump and root wood. The continued programme will pay special attention to the development of forest transport by exploring e.g. the possibilities of using a trailer with the Stumparvester (Fig. 29).

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LYHENNELMÄ

Kanto- ja juuripuun korjuu Pallarin kantoharvesterilla

Pallarin kantoharvesteri on monitoimikone, joka irrottaa juurakon maasta, poistaa pääosan humuksesta ja mineraalimaasta juurakosta, paloittelee sen halutun kokoisiksi kappaleiksi, kerää palat noin kiintokuutiometrin suuruisiin kasoihin ja voi suorittaa myös metsäkuljetuksen 150—200 metriä lyhyemmillä matkoilla. Kone on kehitetty vuosina 1971—72 Suomen Metsäteollisuuden Keskusliiton asettaman kantoryhmän rahoituksella.

Kantoharvesterin peruskoneena on RH 4 kaivukone. Suolla käytetään leveätelaista RH 4-950 LC tyyppiä, jonka tekniset ominaisuudet on esitetty sivulla 10 ja kuvassa 1. Lisävarusteina ovat irrottamis- ja pilkkomislaite (kuva 2, värikuvasivu 1) ja kipattava 4.6 m^3:n perälaatikko (kuva 3).

Kehitystyötä seurannut tutkimusvaihe kuuluu NSR:n alaiseen yhteispohjoismaiseen hakkuutähteitten hyväksikäyttöön tähtäävään projektiin. Tutkimus suoritettiin kesällä 1971 Metsäntutkimuslaitoksen Vesijaon kokeilualueessa.

Tutkimuksen tärkeimpinä tavoitteina oli kehittää koneelle eri olosuhteisiin soveltuva työtekniikka sekä selvittää kantoharvesterin toimintavarmuus, työajan rakenne, tuotos ja kustannukset. Lisäksi kerättiin aineistoa kanto- ja juuripuun määrästä suolla ja tutkittiin tuotteen laatua ja maan laikuttumista. Tulokset soveltuvat lähinnä Etelä-Suomen turvemaille.

Pääosa tutkimuksesta tapahtui kahdella ojitetulla suolla, jotka oli hakattu aukeiksi edellisenä talvena (taulukko 1, kuvat 4—7). Aikatutkimusaineisto sisälsi 1 419 juurakkoa. Kantojen keskiläpimitta oli 30 cm ja keskikorkeus 31 cm (taulukot 2 ja 3).

Työtekniikka riippuu juurakon koosta. Pienet kannot irrotetaan kokonaisina. Läpimitaltaan yli 25 cm:n kuusen kannot irrotetaan paloina siten, että paksuimmat sivujuuret repäistään irti yksitellen poikkisuuntaan vääntämällä. Yli 35 cm:n männynkannoille soveltuu työtekniikka, jossa kanto-osa ennen irrottamista halkaistaan leikkuulaitteella kahteen tai useampaan osaan. Irrottaminen ja paloittelu tapahtuvat siis osittain samanaikaisesti. Myös puhdistaminen ja palojen kerääminen perälaatikkoon yhdistyvät paloitteluvaiheeseen (kuva 9). Perälaatikko tyhjennetään kippaamalla lähikuljetusratkaisusta riippuen maahan tai traktorin peräkärryyn (kuvat 13—15, värikuvasivut 1 ja 2).

Kantoharvesterin ajankäyttö on esitetty osaksi kantokohtaisena (kuvat 8, 10 ja 11), osaksi kuormakohtaisena (kuvat 12 ja 16). Kuorman valmistaminen ja kuljettaminen 40 m:n matkan päähän vei kuusella keskimäärin 26 ja männyllä 27 minuttia ilman keskeytyksiä. Esimerkiksi kuusella tehotyöaika jakaantui suomaalla seuraavasti: Siirtyminen juurakolta toiselle 8 %, irrottaminen maasta 5 %, paloittelu 75 % ja purkaminen 12 % (taulukko 4). Tutkimuksen aikana keskeytysten osuus oli 19 % tehotyöajasta (taulukko 5). Tuotos- ja kustannuslaskelmissa on niitten osuudeksi oletettu kuitenkin 10 %.

Kantoharvesterin keskimääräinen tuotos laskettiin seuraavien edellytysten vallitessa: Kannon keskimääräinen läpimitta kuoren päällä 30 cm, kuorman koko kuusella 1.03 ja männyllä 0.86 k-m^3, siirtymisetäisyys juurakolta toiselle kuusella 6 ja männyllä 7 m, purkamisajomatka 40 m sekä keskeytysten osuus 10 % tehotyöajasta. Näissä puitteissa oli kantoharvesterin tuotos kuusella 16.2 ja männyllä 11.7 k-m^3 kahdeksan tunnin työpäivää kohti (kuva 22). Kustannukset olivat vuonna 1972 vastaavasti 26 ja 36 mk/k-m^3 (taulukko 8). Tuotos ja kustannukset riippuvat kuitenkin monista tekijöistä.

Juurakon koko vaikuttaa kustannuksiin voimakkaasti. Jos kantoläpimitta on 25 cm, maksaa kiintokuutiometrin korjuu edellä mainituissa oloissa kuusella 37 ja männyllä 43 mk. Läpimitan kasvaessa 40 cm:iin kustannus laskee vastaavasti 19 ja 27 mk:aan/k-m^3 (kuva 23).

Suurin osa koneen ajasta kuluu paloitteluun, joten pinta-alayksiköltä saatava puumäärä vaikuttaa kustannuksiin verraten vähän. Tutkimusoloissa kertyi koealalla I 181 k-m^3 ja koealalla II 135 k-m^3 runkopuuta hehtaarilta. Puumäärän supistuminen puoleen edellisestä nostaa kanto- ja juuripuun korjuukustannusta n. 2 mk/m^3.

Kantoharvesterin kulkunopeus on alhainen, joten purkausmatkan pituus vaikuttaa kustannuksiin jyrkästi. Esimerkkitapauksissa ajomatka on vain 40 m. Kantoharvesterin käyttö kuljetuksessa on kannattavaa kuusella 200 ja männyllä, jolla pinotiheys on alhaisempi, 150 m lyhyemmillä etäisyyksillä. Edellytyksenä on kuitenkin vähäkivinen maasto. Tavaran kustannus on tuolla kuljetusmatkalla tienvarressa kuusella 30 ja männyllä 40 mk/k-m^3.

Pidemmillä matkoilla lähikuljetus on suoritettava traktorilla. Kourakuormaajalla varustetun metsätraktorin kustannus on esimerkiksi 500 metrin ajomatkalla kuusella 7 ja männyllä 8 mk/k-m^3. Tavaran tienvarsihinta on silloin vastaavasti 32 ja 41 mk/k-m^3 edellyttäen jälleen keskimääräistä 30 cm:n kantoläpimittaa. Jos ajomatka ylittää kuusella 600 ja männyllä 900 m, saattaa edullisimmaksi tulla kipattavalla perävaunulla varustetun maataloustraktorin käyttö. Kantoharvesteri puretaan silloin suoraan traktorin peräkärryyn (kuvat 24 ja 25, taulukko 9).

Suppean vertailukoneiston perusteella korjuukustannukset näyttävät ainakin hyvissä oloissa jäävän mineraalimaalla edellä mainittuja alhaisemmiksi. Kustannusero aiheutuu huomattavalta osalta siitä, että mineraalimaalla voidaan käyttää hal-

vempaa kapeatelaista RH 4-kaivukonetta kantoharvesterin peruskoneena. Jos kiviä on runsaasti, työskentely kuitenkin hidastuu.

Kanto- ja juuripuun pinotiheys oli kantoharvesterin perälaatikossa vain 0.19. Käsin tiivistetyssä autokuormassa pinotiheys oli paljon korkeampi, 0.38. Leikkuujälki on sulfaattimassan raaka-aineelle tyydyttävä, joskin leikkuuterälle tyypillistä halkeilua tapahtuu. Puutavara on soilla täysin kivetöntä. Turve ja osa kuoresta poistuvat sateitten ja pakkasten vaikutuksesta varastoinnin aikana (kuvat 19—21). Tältä osin selvityksiä tullaan jatkamaan.

Kanto- ja juuripuun korjuun yhteydessä tapahtuu maan laikuttumista, osaksi juurakoitten irrotamisesta johtuen ja osaksi harvesterin telojen vaikutuksesta. Tämä helpottaa myöhempiä metsänviljelytöitä (kuvat 26—28).

Koealalla I oli yli 5 cm:n paksuista kanto- ja juuripuuta 79 ja koealalla II 51 k-m^3/ha. Siitä saatiin talteen 94—95 %. Runkopuuhun verrattuna (kuorellisen rungon kuivapaino = 100) kanto- ja juuripuun osuus oli ojitetulla suolla kuusella 42 ja männyllä 37 % (taulukko 6). Kantokohtaisia tietoja kanto- ja juuripuun määrästä on esitetty kuvissa 17 ja 18.

Tutkimus osoittaa, että Pallarin kantoharvesteri saattaa ainakin tietyissä oloissa tarjota kanto- ja juuripuun korjuuseen taloudellisen ratkaisun. Jatko-ohjelmassa tullaan kiinnittämään erityistä huomiota lähikuljetuksen kehittämiseen selvittämällä mm. peräkärryn käyttömahdollisuudet kantoharvesterin yhteydessä (kuva 29).