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PENTTI HAKKILA AND HANNU KALAJA

HARVESTING FUEL CHIPS WITH THE PALLARI SWATH HARVESTER

POLTTOPUUN KORJUU PALLARIN LEIKKUUHAKKURILLA

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Pentti Hakkila and Hannu Kalaja

HARVESTING FUEL CHIPS WITH THE PALLARI SWATH HARVESTER

Polttopuun korjuu Pallarin leikkuuhakkurilla

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A new fuel wood harvesting method which is based on a continuously moving Pallari swath harvester and chip sack system is described. The method is intended primarily for hardwood coppices in which the trees are unmerchantable because of their small size but in which the number of stems and the biomass volume per hectare may be great.

The swath harvester fells and chips small trees along its path of advance over a 2,3 m wide swath. It collects the chips into 1 m^3 sacks which are dropped off the rear of the machine. The sacks are transported by a forwarder of standard construction to the landing where they are emptied into a truck trailer or pallet. The forwarder returns the sacks to the swath harvester for re-filling.

Tests carried out in four stands show that the method is competitive in the clear-cutting of hardwood coppices. In contrast, the Pallari swath harvester mounted on the present prime mover is too large and clumsy in its movements for corridor thinning of softwood sapling stands.

Tutkimuksessa kuvataan uutta polttopuun korjuumenetelmää, joka perustuu jatkuvatoimiseen Pallarin leikkuuhakkuriin ja hakesäkkijärjestelmään. Menetelmä on tarkoitettu ensisijaisesti lehtipuuvesakoille, joissa puut ovat pienen kokonsa vuoksi markkinakelvottomia mutta joissa runkoluku ja biomassamäärä hehtaaria kohti saattavat olla suuria.

Leikkuuhakkuri kaataa ja hakettaa eteensä sattuvat pienet puut 2,3 m:n levyiseltä kaistalta. Kone kerää hakkeen 1 m^3:n säkkeihin, jotka pudotetaan koneen perästä maahan. Säkit kuljetetaan vakiorakenteisella kuormatraktorilla välivarastolle, missä ne tyhjennetään kuorma-auton perävaunuun tai vaihtolavalle. Kuormatraktori palauttaa säkit leikkuuhakkurille uudelleen käytettäviksi.

Neljässä leimikossa tehdyt kokeet osoittavat, että menetelmä on kilpailukykyinen lehtipuuvesakoitten avohakkuussa. Havupuutaimistojen käytäväharvennuksiin Pallarin leikkuuhakkuri sen sijaan on nykyiseen peruskoneeseen asennettuna liian suurikokoinen ja raskasliikkeinen. Tutkimuksen tulokset rohkaisevat jatkamaan kehitystyötä.

Helsinki 1980. Valtion painatuskeskus

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PREFACE

Mr Kyösti Pallari, a contractor, put forward a plan in autumn 1972 for the building of a continuously moving small-tree harvester. The aim was mechanized recovery as whole-tree chips of the biomass of under-sized hardwoods. The complete-tree concept was still new in those days and the project aroused no interest in the field of practical forestry.

The Finnish Forest Research Institute began in summer 1973 a research project on the production and utilization of short-rotation wood. The focal target was to find additional raw material for industry from the unmerchantable small-sized stands of existing forests and from the biomass to be produced in the future in short-rotation plantations. The project, financed by the National Fund for Research and Development, began to support the construction of a continuously moving harvester.

The first prototype was ready for a field test in autumn 1975. The working principle of the machine was found to be successful and it seemed to offer an attractive starting point for full mechanization of harvesting bush thickets and hardwoods less than 10 cm in diameter. The Finnish Forest Research Institute published the test results in Folia Forestalia 240 (Hakkila and Mäkelä 1975).

It was not until 1978 when the State began actively to further utilization of low-grade wood as a source of energy that the opportunity arose to continue the work. The second prototype, called here the Pallari swath harvester, was built in 1979 by Tervolan Konepaja Oy in cooperation with Kyösti Pallari. The Department of Forest Technology, Finnish Forest Research Institute, was responsible for the planning and implementation of the field tests as a part of the comprehensive PERA project. The results which are presented in this report give pointers for the further development of the machine. Svenska Traktor Ab, Kyösti Pallari and Tervolan Konepaja Oy will cooperate in the future development work.

In the organization of the field work of the study, assistance was given by Kajaani Oy, Veitsiluoto Oy, The Kannus Association of Forest Owners, the Regional Forestry Board for Central Ostrobothnia, the City of Kemi and Tervolan Konepaja Oy. The crew of the swath harvester consisted of Mr Juhani Leinonen, Mr Ilari Tulkki and Mr Olli Pallari. Mr Hannu Kalaja assisted by Mr Erkki Salo and Mr Veikko Salo led the field work on behalf of the Forest Research Institute.

The drawings for the report were made by Mrs Pirkko Hakkila. The colour photograph page is the work of Mr Matti Ruotsalainen and it was donated by Svenska Traktor Ab. The typing was done by Miss Raija Siekkinen. The translation from Finnish into English was done by Miss Päivikki Ojansuu and Mr. L.A. Keyworth.

We express our best thanks to all the participants in the work, especially to Mr Kyösti Pallari whose innovations led to the birth of the swath harvester.

Helsinki, January 1980

Pentti Hakkila *Hannu Kalaja*

1. INTRODUCTION

Tree size is the most important of the factors that affect the costs of mechanized timber harvesting. Output decreases abruptly when the tree DBH is under 10 cm. The minimum diamter at breast height of merchantable trees in Finnish conditions is 7—9 cm and it is essentially greater in many other countries.

When the requirement is the production of traditional raw material of bolt form, timber has to be handled singly. If the trees are small-sized, harvesting costs then exceed the economical limit and, furthermore, a great proportion of the biomass is lost in the delimbing process.

Harvesting of small-sized trees as fuel will therefore probably be based in the future on whole-tree logging methods in which delimbing is abandoned completely or at least partly. There are available already several alternative whole-tree chipping schedules with which more effective recovery of wood of smaller size is possible.

The economicalness of whole-tree chipping schedules as an alternative to the shortwood method is based on the mass handling of small-sized trees. But in the existing methods the trees are still handled singly in the felling and bunching phase and the costs of the present-day whole-tree chipping methods are also dependent on tree size. Stands in which most of the biomass is in trees with a diameter of under 6 cm are still unmerchantable despite the often high areal yield.

Large-scale harvesting of the smallest coppice trees for fuel requires a harvesting method in which small-sized trees are treated as a mass article in all stages of the schedule. Individual tree planning and handling must be abandoned already during felling. A continuously moving multipurpose machine is needed and its operation and output must be governed not by the individual tree but, rather, by the basal area of the growing stock confronting the machine or the area of the forest land that the advancing machine covers. The machine can perform any of the following combinations of operations:

— Felling and windrowing
— Felling, bunching (and binding)
— Felling and baling
— Felling and blocking
— Felling and chipping

Activity must be organized in each case in a way permitting flexible and undisturbed forest haulage. Biomass must be treated to the end as a mass article.

The chipping alternative was selected as the starting point for Finnish development work. As the tree DBH varies from, for example, 1 to 10 (15) cm, binding and baling are technically difficult to perform. Chipping is essentially simpler and there are ready component solutions for it. For fuel purposes, too, whole-tree chips are a more processed product than bundles or bales of small-sized wood.

However, the chipping method also has a weak link. It is in the organization and scheduling of chip transport that the difficulty lies. At least the following solutions are available for forest haulage:

— The continuously moving harvester blows the chips into a separate vehicle which travels alongside or behind the harvester. Two chip transport vehicles are required to enable the harvester to work without interruption. An example is the 27-ton mobile swath harvester prototype designed for large working sites in the southern states of the USA which recovers cull trees and logging residues (Koch and Nicholson 1978).
— The continuously moving harvester pulls its own trailer. When the trailer is filled it is replaced. A single tractor suffices for hauling the chips to the road unless the transport distances are exceptionally long.
— The continuously moving harvester is equipped with a tippable chip bin. The harvester unloads the bin onto a tractor in the terrain or onto a roadside pile, chip pallet or truck at the landing site. Examples are the 17-ton mobile swath harvester prototype Jaws 3 used in the southern United States (Forest Industries 1979) and the Finnish 18-ton forwarder-mounted terrain chipper TT 1000 F (Kalaja 1978).
— The continuously moving harvester sacks the chips and drops the sacks in the logging site. The forwarder moves the sacks to alongside the road.

The first alternative was experimented with at the beginning of this development project; the harvester blew the chips into the trailer of a tractor travelling alongside it (Hakkila and Mäkelä 1975). The method was found clumsy in Finnish stands which are small in size and irregular in shape.

In the second phase of the project, the use of chip sacks was adopted. The sacking system was considered to have the following advantages and drawbacks.

Advantages:

— The method gives the harvester the greatest possible manoeuvrability around obstacles, enables it to reverse, etc. This is a very important consideration in Finnish stand conditions.
— Transport of chips does not consume harvester working time.
— The sack system permits the formation of a small buffer storage in the forest and at the landing. This eases the scheduling problems.

Drawbacks:

— No ready-made sack solution is available. Development of sacks had therefore to be included in the project.
— A considerable investment in sacks is required and split sacks cause direct operating costs.
— Moving of sacks from one work site to another and within the work site causes costs.
— The sacking system requires at least for the present an extra hand for the harvester and another for unloading the sacks at the landing.

The second prototype of the Pallari swath harvester was evolved along this line of reasoning. It was designed originally for the preparation of fuel chips in Finnish conditions. In the long-term view, much broader use may be found for the machine in many other countries in which unproductive coppice forests of small-sized hardwoods are more common than in Finland.

2. TECHNICAL PROPERTIES OF THE PALLARI SWATH HARVESTER

21. Prime mover

The prime mover of the swath harvester is a Valmet 1502. It is a 6-wheel-drive bogie tractor with a high traction capacity and a moderately low ground pressure. The bogie halves the swing caused by the obstacles (cf. Hahlman and Ahokas 1978) and, thus, makes it easier to control the height of the stubble in the harvesting operation.

The weight of the prime mover is 7.5 tons. The total weight of the swath harvester, including the harvester device and the sacking system, is about 10 tons.

The transmission system is synchronized with 16 forward gears and 4 reverse gears. The speed of the first gear is 0,9 km/h (800 rpm) — 2,5 km/h (2 300 rpm). A hydrostatic crawling gear with a speed 0—3 km/h is available as an optional equipment. The crawling gear is necessary in the swath harvester.

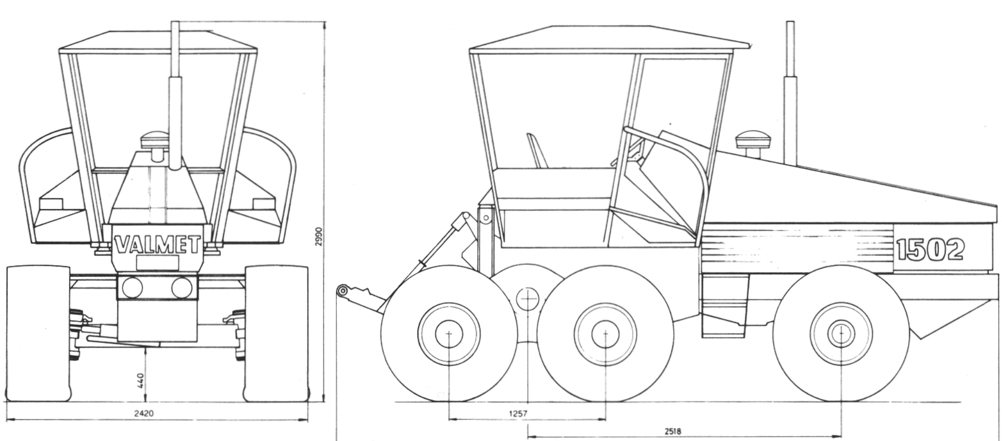

Figure 1. The prime mover of the swath harvester, a Valmet 1502 tractor.
Kuva 1. Leikkuuhakkurin peruskone, Valmet 1502 traktori.

The technical data of the prime mover are as follows:

Dimensions (Figure 1):

Maximum length	5 330 mm
Width	2 420 mm
Maximum height	2 990 mm
Wheel base	2 518 mm
Bogie wheel base	1 257 mm
Ground clearance	440 mm

Engine:
4-stroke Valmet 611 CS diesel with direct injection
Output 100 kW DIN/2 300 rpm
6 cylinders

Hydraulic system:
Tandem pump: capacity for the lift 26 dm^3/min (2 200 rpm) and for the power stearing 35 dm^3/min (2 200 rpm)
Lift force at link ends 35 000 N
Lift independent of drive clutch and power take-off clutch
Lift functions: position control, draft control, pressure control and lowering speed control
Three-point linkage category II

22. Harvester device and sacking equipment

The harvester part weighs 3 000 kg. It is mounted at the back of a Valmet 1502. The original moving direction of the machine has been reversed and the harvester part is in actual fact before the multipurpose machine. The height and tilt of the harvester device are regulated by a hydraulic lifting device.

The sacking part consists of a chip conveyor, sack holder and sacks. They are placed in what is now the rear section of the swath harvester from which the full sacks are dropped by tilting the holder.

In addition to the prime mover, the swath harvester has the following parts (Fig. 2).

1. A pusher frame which bends the tree forward and prevents it from falling to the side of the machine. The pushing height is 2,3 m.
2. Two cutting plates which rotate in the horizontal plane. Each plate has three sickle blades for felling the tree. The plate diameter is 110 mm and thickness 20 mm. Each plate is rotated by a separate hydraulic pump.
3. A base plate along which the trees pass butt foremost to the chipper.
4. Two rotating feeding cylinders with triangular plates that strike the tree towards the drum chipper. The cylinders are on the same axles as the cutting plates. Their diameter is 520 mm and height 400 mm. The 150 mm wide triangular plates — nine in each cylinder — are arranged in three layers.
5. A hydraulic drum chipper which chips the tree and throws the chips into the pipe. The drum diameter is 420 mm and width 440 mm. Originally, the drum has 24 55 mm knives arranged stepwise in three series around its surface. The knife arrangement was changed after the second sample stand and there are now 12 with a width of 110 mm. The stepwise position of the knives is otherwise unchanged.
6. A chip pipe along which the chips move up to the conveyor. The pipe is in two parts so that it shortens or lengthens telescopically to suit the change in the height of the harvester part. The cross section of the rectangular pipe is 200×400 mm.

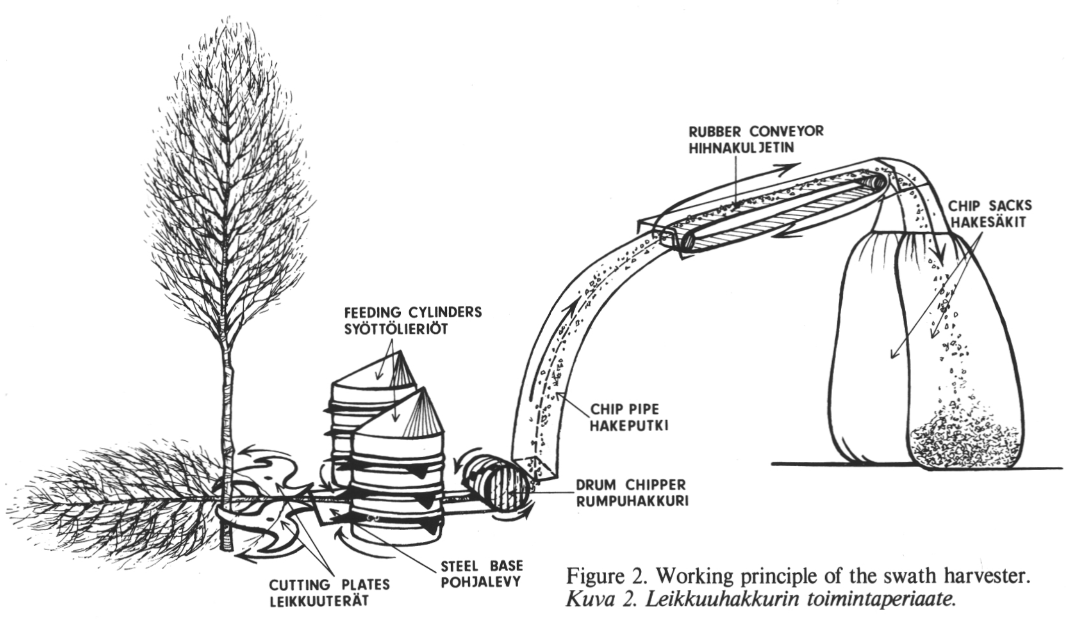

Figure 2. Working principle of the swath harvester.
Kuva 2. Leikkuuhakkurin toimintaperiaate.

7. A rubber-coated belt conveyor which moves the chips into the sacks at the back of the machine. The width of the conveyor is 400 mm and length 3,7 m.
8. A holder for two 1,5 m^3 chip sacks. The chips from the conveyor are directed into the desired sack by means of a closing flap. The holder has room for extra empty sacks.

23. Chip sacks

The chip sack system frees the swath harvester from having to carry or pull a heavy load of chips. The harvester is able to move more flexibly and its power requirement is smaller.

Sacks will occasionally be dropped onto sharp stumps and other obstacles. Moreover, the sacks are moved by the grapple of the forwarder. As the weight of a full chip sack may be several hundred kilos, it has to be very strong. This places high quality requirements on the material. The sack price inevitably becomes so high that it must be possible to use it several times.

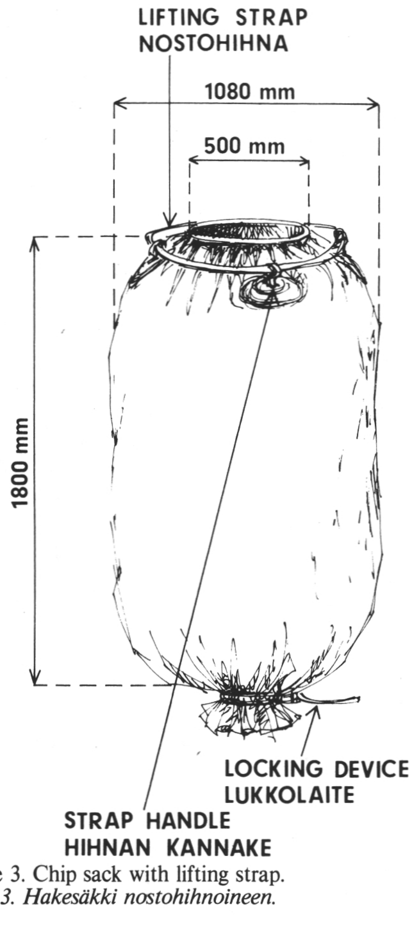

Figure 3. Chip sack with lifting strap.
Kuva 3. Hakesäkki nostohihnoineen.

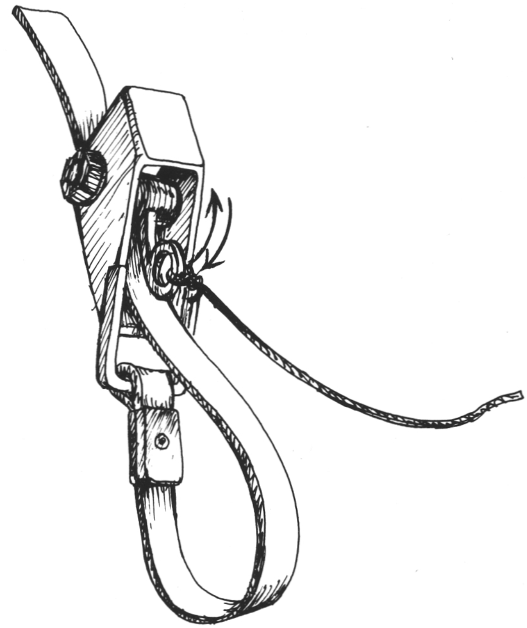

Figure 4. The chip sack locking device.
Kuva 4. Hakesäkin lukkolaite.

The most economical sack size depends primarily on the strength and price of the material and the power of the machines handling the sacks. The sacks in this development project can take 1 m^3 (loose volume) of chips. Their nominal size is slightly larger.

The mouth of the sack has a reinforced edge from which it can be suspended in the holder of the swath harvester (Fig. 3). The mouth of a full sack need not be closed by tightening. The upper edge also has straps by which the sack is lifted in the emptying phase.

The lower end of the sack is closed with a tightening strap equipped with an eccentric locking device (Fig. 4). The locking device is opened by pulling the string attached to it when the sack is hanging by the lifting straps. The locking device was made by Tervolan Konepaja.

Several sack materials were experimented with during the project. The manufacturers supplied the following data on them:

Sack type 1. The material is knotted mesh woven of nylon yarn. The tensile strength of the yarn is 800 N. The eye of the mesh is rectangular, side length 25 mm. The sack is reinforced with nylon ropes. The mouth is closed with a throttle rope. The sack weighs 5,5 kg. Manufactured by Oy Aino Lindeman Ab Vaasan Verkkotehdas.

Sack type 2. The sack is made of Trevira spunbond polyester fabric intended originally for road and waterway construction work. It weighs 305 g/m^2, its thickness is 3 mm, tearing strength 750 N and tearing extension 65 %. Manufactured by Turo Oy.

Sack type 3. The sack is made of Vinyplan fabric. Its bonding material is polyamide yarn woven with 2 mm×2 mm spacing and coated with frost-proof, fire-resistant PVC plastic. The sack material weighs 250 g/m^2, its tearing strength is 300 N, tensile strength in the direction of the warp 1350 N/5 cm and 1200 N/5 cm in that of the weft. The tensile strength of the lifting strap is 10 000 N. The weight of the sack including the straps but without the locking device is 6,6 kg. The sack can be repaired by heat sealing or Vinstick glue. Manufactured by Turo Oy. Price without the locking device is 245 marks.

Sack type 4. The material is fabric woven of polypropene plastic; its weight is 180 g/m^2, tensile strength in the direction of the warp 1810 N/5 cm and of the weft 1240 N/5 cm. The fabric is protected against ultraviolet radiation. The tensile strength of the lifting strap is 31 400 N. The sack without the locking device weighs 2,5 kg. Manufactured by Oy Rukka-Products Ab. The price without the locking device is 135 marks.

Sack types 3 and 4 were chosen for the final field tests on the basis of strength and price.

3. APPLICATION RANGE OF THE PALLARI SWATH HARVESTER

The working requirements of the swath harvester depend on the later use of the area. There are two alternatives:

— Alternative 1. The under-productive small-sized trees are clear-cut and utilized as fuel. After that the aim is primarily the establishment of a softwood plantation as raw material for the forest industry. It is to be hoped that the trees to be felled do not produce sprouts.
— Alternative 2. Only fuel wood is to be produced in the area. After clear-cutting the hardwood trees, a new dense hardwood coppice is to be produced and its biomass yield also used as fuel in the future. Vigorous sprouting is the aim (cf. Säll 1979).

The Pallari swath harvester is suitable for the first alternative (Figures 5 and 6). The latter alternative is still an exceptional case in current Finnish forestry conditions. No attempt has been made so far in developing the machine and working method to keep the stump-root systems undamaged. However, the development of energy prices is changing the targets. This possibility may become topical in the next few years in alder and white birch stands of certain types.

The Pallari swath harvester is intended for the harvesting of dense hardwood thickets. The smaller the trees the more competitive is the swath harvester compared with the other alternatives. When the tree size grows the operation of the machine becomes more difficult tehnically and its competitiveness vis-à-vis other alternatives weakens. The maximum diameter depends on the tree species and the basic density of wood. The wood basic density of young trees generally varies between the following limits for Finnish tree species:

	Basic density, kg/m^3
Small-sized softwoods	330—390
Small-sized alder	350—370
Small-sized birch	440—480

The machine is capable of operating in stands in which the stump diameter of the trees is 1—10 cm. It can be used temporarily to harvest larger-sized trees, 10-15 cm, but this slows the work and strains the machine heavily. Tree species with denser wood have higher power requirements.

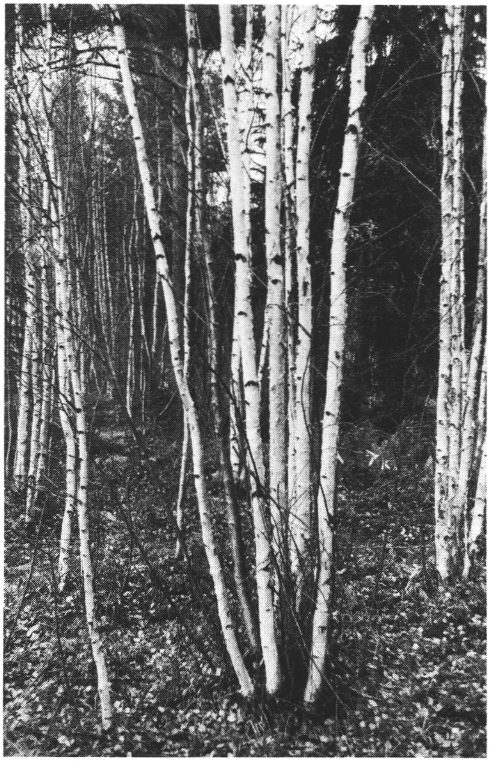

Figure 5. Small-sized hardwood trees for which the swath harvester was designed (Photo by Matti K ä r k- k ä i n e n).
Kuva 5. Pienikokoista lehtipuustoa, jonka talteenottoon leikkuuhakkuri on suunniteltu (kuva Matti K ä r k- k ä i n e n).

The 2,3-m wide swath places relatively strict limitations on the terrain. If the machine begins to sway the strain on the cutting plates increases and the trees may fall also in the lateral direction. To prevent the cutting plates from coming into contact with the soil surface, stones and large stumps, the cutting height must be raised in uneven terrain. The machine thus operates most effectively over even terrain with few stones.

The prime mover of the harvester, the Valmet 1502 tractor, has six driving wheels. Its manoeuvrability is satisfactory provided that the terrain has a good carrying capacity. A wheel tractor can be used in swamp forests only in the winter when the soil is frozen. As it is impossible to use the swath harvester in deep snow the machine is serviceable in swamps for only a short time of the year. It can be equipped with tracks but they were not tried in this investigation.

The range of application of the Pallari swath harvester is determined by the limitations mentioned in the foregoing. It is mostly a question of clear-cutting a hardwood coppice to prepare the area for regeneration of softwoods or to clear it for other than forestry use. The main potential targets in Finnish conditions are:

— Abandoned farm lands on which low grade hardwoods have originated naturally. These coppice forests are classified as unproductive from the forest point of view. The stands are of small size and often of indeterminate shape. The growing stock is frequently concentrated on the edges of open ditches which makes harvesting difficult. The area of such regions is estimated to be 200 000 hectares.
— Grey alder stands which have arisen on former burn-beating lands and pasture lands; these are concentrated especially in East Finland. Some of them are suitable for harvesting by clear-cutting, but in several cases spruce has already been planted under alder shelter trees and the use of the swath harvester is impossible. The total area of the grey alder stands is 160 000 hectares.
— White birch stands that have originated naturally on drained swamps. The areas are generally sufficiently large and uniform for effective harvesting. The even topography and the absence of stones facilitate harvesting. One difficulty, however, is the poor carrying capacity of peatland and the ditches at intervals of about 50 m. The swath harvester can be used only during a limited period of the year when the peat is frozen. Such swamps covered in white birch total hundreds of thousands of hectares and more will originate as draining activity progresses.
— Growing stock arising along power transmission lines which must be felled at the latest when they reach a height of 4—5 m. As the number of stems may amount to 30 000—50 000 per hectare and the work must be repeated at 5-year intervals, just the clearing costs rise to rather high figures. The largest power company, Imatran Voima Oy, has to keep open 26 000 hectares of areas under the main power lines.
— Softwood sapling stands which have to be thinned at an early age before the trees reach the minimum dimensions for industrial wood (cf. H e i n o and R u o t s a l a i n e n 1976). Precommercial thinning should be selective with a view to the later yield of the stand. However, to save labour costs mechanized methods and corridor thinning may have to be resorted to. The machine should be as narrow as possible, preferably less than 2 m wide. As far as terrain is concerned, it is primarily the young pine stands on dry mineral soils and swamps that are suitable for the swath harvester.

Removal of small-sized trees is necessary in all these cases for silvicultural or other reasons. As the number of trees per hectare is great the costs of the clearing work with traditional methods is high. These points should be considered in calculating the costs of fuelwood recovery by the swath harvester.

Figure 6. The swath harvester offers a new solution for the recovery of small-sized hardwood from abandoned farm land (Photo by Matti K ä r k k ä i n e n).
Kuva 6. Leikkuuhakkuri tarjoaa uuden ratkaisun hylätylle peltomaalle syntyneen lehtipuuston talteenottamiseksi (kuva Matti K ä r k k ä i n e n).

4. WORKING TECHNIQUES

The working principle of the Pallari swath harvester is continuous advance. The 242 cm wide machine fells and chips the trees in a 230 cm swath along its path. The chips are collected in sacks at the back of the machine. Full sacks are dropped to the ground by tilting the sack holder and the forwarder transports them to alongside the road. The sacks are emptied into the chip truck and the empties are returned to the swath harvester for re-use (Fig. 7.).

When advancing in a coppice the harvester's pusher frame first touches the tree at a height of 2.3 m; the frame bends the tree forwards in the travelling direction of the machine to prevent it from falling back onto the harvester.

In the front of the machine 10—30 cm above ground level are two horizontal cutting plates each with three sickle-like knives which rotate to cut the tree. A small tree is felled with a single stroke, but thicker trees need several strokes. The rotational velocity of the cutting plates is 60 rpm. Because of the slow speed the knives do not hurl pieces of wood around, which increases work safety.

Seen from the front, the cutting plates rotate from the outer edge of the machine towards the centre. The sickle knives throw the falling tree butt foremost onto the smooth steel bottom in the centre behind the cutting plates. If the butt of the tree falls to the ground it must be cut again or, in the worst case, it may remain under the machine and be lost.

The forward movement of the machine causes the butt of the tree to glide along the steel bottom to the drum chipper. The transfer of the tree to the chipper is assisted by two vertical side-feed cylinders which have a speed of 60 rpm. Each cylinder has in three levels a total of nine triangular plates which push the tree towards the chipper. The side-feed cylinders are spaced 54 cm apart and thus do not compress the tree.

The advancing movement of the feeding cylinders and the machine brings the tree butt within reach of the 1900-2000 rpm drum

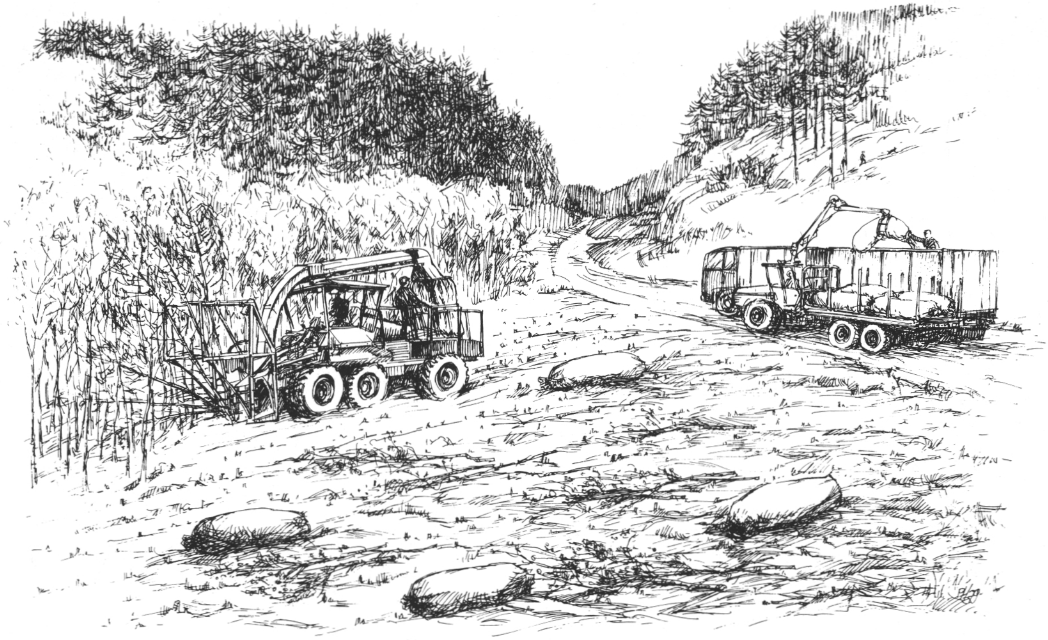

Figure 7. Harvesting schedule based on the Pallari swath harvester and chip sack system.
Kuva 7. Pallarin leikkuuhakkuriin ja hakesäkkijärjestelmään perustuva korjuuketju.

chipper. The drum is after this self-feeding in principle, but in practice the drum chipper knives often lose their grip of the tree. The tree is then re-introduced into the drum knives as described above.

The air current caused by the rotating drum raises the chips along the pipe to a height of 3,0 m from where they drop onto the rubber conveyor. The conveyor moves the chips at 1.8 m/s into a sack.

The holder at the back of the machine takes two sacks simultaneously. When the first sack is filled the chips dropping from the conveyor are directed by a closing flap into the other sack and the full sack is dropped to the ground from the back of the machine without closing its mouth. A new empty sack is suspended in the holder. This work requires a sack hand who can also assist the machine operator with maintenance jobs.

The sacks are transported to the road side by a forwarder or a farm tractor equipped with a knuckle boom loader. The load space has a wooden bottom. The grapple grasps the sack in the middle and places it in the load space horizontally in the manner of pulpwood boles. A full Turo sack is 108 cm in diameter and 180 cm long.

At the landing, the sacks can be left in a pile to await truck transport. Since the aim is to manage with the smallest possible number of sacks, however, the forwarder prefers to empty the sacks straight into a chip pallet or truck.

To empty the sacks the forwarder operator grasps with the grapple the lifting strap at the upper end of the sack and moves the sack over the load space of the truck. When the helper pulls the cord the eccentric locking device opens and the sack empties instantly. The forwarder returns the empty sacks to the harvester.

It is possible to separate completely the operations of the harvester, forwarder and chip truck, but this requires great numbers of sacks. As the sacks are relatively expensive at present, this alternative is not recommended. However, it is possible to work fairly flexibly with, say, 200 sacks, reducing the scheduling problems of successive machines significantly. This number of sacks corresponds to 10—15 forwarder loads and 2—3 truck and full-trailer loads. It is also possible to empty the sacks onto the ground at the landing and stockpile chips in dumps to eliminate the need to synchronize forest haulage and trucking.



5. RESEARCH MATERIAL

The Finnish Forest Research Institute tested the Pallari swath harvester at four work sites in autumn 1979. The trees were still in leaf during the first test, but later the hardwoods had shed their leaves. The soil was unfrozen in all the cases.

When the experimental series began the crew was completely inexperienced in the use of the machine. The working technique progressed somewhat in the course of the investigations. Furthermore, certain changes to influence the work output were made in the machine; the most important of these alterations was the knife arrangement of the drum chipper. These factors make it difficult to compare the sample plots and interpret the results.

The investigation was concerned in each case with the harvesting schedule as a whole: felling, chipping and sacking whith the Pallari swath harvester, and forest haulage and unloading of chip sacks with a forwarder. The investigation consisted of the following parts:

- Measurement of tree and stand data
- Time study of the swath harvester
- Time study of the forwarder
- Weighing a part of the chip sacks whith a 500 kg dynamometer, weighing a part of the chip loads with a truck scale and measurement of the loose volume of chips in truck loads.
- Surveying the logging waste, including the trees lost by the swath harvester and the stubble, that is the above-ground portion of the stumps.
- Measurement of the fuel comsumption of the harvester
- Recording the machine and system failures
- Measurement of the moisture content of chips
- Hole and slot screening of chips.

The experimental stands included the main stand types for the harvesting of which the Pallari swath harvester is primarily intended in Finnish conditions. The terrain of all the sample plots was fairly even and easy to negotiate. Tree data for the sample plots are presented in Tables 1 and 2.

Experimental stand 1 was located on company-owned abandoned farm land at Vaala. The drained peatland was partly soft,

Table 1. The diameter distribution of the trees at stump height in the experimental areas.
Taulukko 1. Puuston kantoläpimitan jakauma koealoilla.

Stump diameter, cm *Kantoläpimitta, cm*	Experimental area — *Koeala*			
	1	2	3	4
	Number of trees per ha — *Puita, kpl/ha*			
— 2	3704	4348	2640	1136
2— 4	10789	6159	10559	4167
4— 6	3221	4710	11646	3788
6— 8	2415	2174	9317	3220
8—10	1449	1087	3106	1705
10—12	886	1449	2329	379
12+	644	—	1708	379
Total — *Yhteensä*	23108	19927	41305	14774

but this did not impede the working of the machines. The area was covered by 15—25-year-old dense growing stock of hardwoods which was partly too large-sized for purposeful use of the swath harvester. 80 % of the volume of the growing stock was birch, 15 % was aspen and alder and 5 % low-grade pine. The trees were straight-stemmed and had small branches. The area was cut clear.

Experimental stand 2 was owned by the local congregation of Kannus. The site was mineral soil of Vaccinium type; its dominant tree species were large seed tree pines which had grown sparsely. Underneath them there were numerous small-sized hardwood trees aged 5—15 years. This prevented the natural regeneration of the pine. Of the small-sized growing stock, 5 % was birch, 85 % aspen and 10 % alder. The stem form of the trees was straight.

The target was to restock the area with pine. To implement this the following measures had been decided upon: removal of all small-sized trees for fuel with the swath harvester, chemical treatment of hardwood stumps, harvesting of saw timber trees as a separate operation, soil preparation and planting of pine.

Experimental stand 3 was privately owned abandoned farm land in the City of Kemi. The soil was fairly soft in places as a result of autumn rains. The area grew hardwood

Table 2. Data of the trees and the amount of chips harvested from the experimental areas.
Taulukko 2. Tietoja koealojen puustosta ja kokeissa korjatun hakkeen määrästä.

Variable — *Muuttuja*	Experimental area — *Koeala*			
	1	2	3	4
Area, m^2 — *Pinta-ala,* m^2	4090	4745	3420	5300
Trees per ha — *Puita kpl/ha*	23108	19927	41305	14774
Stump diameter, mm — *Kantoläpimitta, mm*	39	39	50	51
Height, dm — *Pituus, dm*	62	65	71	53
Chips harvested — *Haketta korjattu:*				
Number of sacks — *Säkkejä, kpl*	105	73	101	49
Loose m^3 — *i-*m^3	86,1	69,4	105,0	55,4
Solid m^3 — *k-*m^3	29,3	25,3	38,8	19,9
Green tons — *Tuoretonnia*	24,8	19,1	28,3	17,9
Dry tons — *Kuivatonnia*	13,6	10,3	14,9	7,4

aged 15—25 years of which 10 % consisted of birch, 5 % of alder and 85 % of willow. In some places the trees had been bowed almost against the ground by snow during previous winters and this hampered harvesting. The main part of the growing stock was straight-stemmed, however.

The area was to be cleared to make an industrial plot. The small-sized growing stock was removed, but groups of straight-stemmed birches were left standing.

Experimental area 4 was a 15—20-year-old pine sapling stand owned by the City of Kemi. The site was dry mineral soil of Vaccinium type. There were some stones restricting the movements of the machines, but the area was in the easiest terrain class for forwarders. The growing stock consisted almost exclusively of pine.

The original object was selective thinning of the pine sapling stand and recovery of the raw material as whole-treee chips. The use of the swath harvester for systematic thinning was experimented with as an alternative: parallel corridors were driven in the forest. As the machine was too wide (2,42 m) for the purpose as regards silvicultural practice, corridors were driven in this experiment at a spacing of only approx. 10 m. The study did not thus aim at true systematic thinning but proposed only to find out whether the principle of the swath harvester was applicable to the opening of corridors. It was possible at the same time to study the collection of chip sacks by forwarder from the corridors.

6. RESULTS OF THE FIELD TESTS

61. Output of the harvester

The swath harvester is designed for continuous, slow advance. However, it must repeatedly stop for a while, especially when the stump diameter of the trees begins to approach 10 cm and when the density of the coppice to be felled is high. The machine often has to reverse to make the cross-cut trees fall in the horizontal plane and move on to the drum chipper. The machine actually advances in practice for only a third of its working time. The true speed of advance in the different experimental stands was thus only 0,3—0,5 km/h.

Cross-cutting of trees created no difficulties for the harvester. With thick trees it did have to stop and strike the tree with its cutting plates several time, but the felling operation was otherwise eminently successful. The cutting plates functioned faultlessly in all the experiments. The duration of the experiments was too short, however, to warrant conclusions about the strength of the cutting plates in continuous use.

Most of the difficulties in the experiments conducted with the first prototype in 1975 lay perhaps in directing the trees from the cutting plates to the chipper. Re-shaping the feed cylinders and doubling the diameter of the chipper drum helped to ease this problem significantly. When the coppice is so dense that several trees tend to crowd into the chipper simultaneously and the standing trees ahead prevent the cut trees from falling in the horizontal plane, the feeding opening still tends to become blocked. In order to force the jammed trees towards the chipper the operator must tilt the harvester part or move the machine forward and backward. Blocking of the feeding opening was not especially serious in the tests, however. The situation was always corrected in this way, but it naturally lowered the work output.

The drum chipper with its originally unsatisfactory knife arrangement appeared to constitute a real bottleneck. As the knife width was only 55 mm the space below the blades rapidly filled with wood shavings and the chipper lost some of its efficiency. It took an immoderately long time to clean the knives. The output in experimental stand 1 was 5,0 and in experimental stand 2 6,4 m^3 per effective hour (Table 3).

When the width of the drum chipper knives was doubled to 110 mm no blocking occurred. The new knife arrangement was tried for the first time in experimental stand 3. Although the conditions were otherwise comparable with stands 1 and 2, output now rose to 9,1 m^3 per effective hour. The increase was no less than 60 %.

In the last experiment the swath harvester was used to open systematic corridors in a young pine stand. This work was considerably slower than clear-cutting. Although the system itself functioned, the prime mover was much too heavy and clumsy for the job. Especially turning round and moving to a new corridor were difficult and caused damage to standing trees. In spite of the improved cutter knives, the output in driving down a straight corridor, excluding the time spent on turning round at the end of the corridor, was only 4,9 m^3 per effective hour.

Table 3 also shows the energy value in tons of oil equivalent (toe) of the chips made by the machine in an effective hour. The result for pine is burdened by an exceptionally high moisture content, 59 % on a green weight basis.

It is impossible to compare the results achieved in the individual stands. Differing conditions, accumulation of experience by the crew and the improvement of the chipper knives after experimental stand 2 complicate interpretation. The authors are of the opinion that the result, 9,1 m^3 per effective hour, in stand 3 is possible to achieve generally in practical work provided that the terrain does not restrict and retard the movements of the machine. Output does not seem to depend closely on the density of the coppice for a lower density is compensated by a higher driving speed.

The result for stand 3 promises well for the further development of the machine and the method. In contrast, the output when opening corridors in experimental stand 4 excluding the time spent on turning round at the end of the corridors is not satisfactory.

Table 3. The output of the swath harvester per effective working hour, excluding the delay time in clear-cutting of hardwood coppice (stands 1—3) and corridoor thinning of pine (stand 4).

Taulukko 3. Leikkuuhakkurin tuotos tehotuntia kohti lehtipuuvesakon avohakkuussa (koealat 1, 2 ja 3) ja männyn käytäväharvennuksessa (koeala 4).

Stand *Koeala*	Speed *Nopeus* km/h	Output per effective hour — *Tuotos tehotunnissa* Loose m^3 *l-m^3*	Solid m^3 *K-m^3*	Green tons *Tuoretonnia*	Dry tons *Kuivatonnia*	Toe *Toe*	Ha *Ha*
1	0,30	14,6	5,0	4,2	2,3	0,98	0,07
2	0,47	16,1	6,4	4,8	2,6	1,07	0,11
3	0,33	24,7	9,1	6,7	3,5	1,40	0,08
4	0,51	13,1	4,9	4,2	1,7	0,68	0,12

62. Observations on chip sacks

The swath harvester stores the chips in sacks. When the sack is filled it is dropped to the ground from the back of the harvester. The sacks are collected by farm tractor or forwarder and taken alongside the road.

Fifty chip sacks were available for the study. As a total of 361 sacks of chips were made in all four experimental areas, each sack was filled 7,2 times on average. No wear or weakening caused by repeated use was observed in the sacks. On the other hand, several sacks were torn in the different phases of work for the following reasons:

- — The tractor grapple pressed the sack too hard.
- — The tractor grapple tore the adjacent sack during unloading.
- — The sharp parts of the load space of the tractor tore the sack.
- — The swath harvester ran into a full sack on the ground.
- — The sack was caught in the drive roll between the wheels of the tractor trailer.

In all, 5,5 % of the sacks were damaged. As no actual wear-and-tear was observed, the average life of a sack would appear to be 18 times of use.

Experimental stand	Number of sacks used	Number of sacks torn	Per cent of sacks torn
1	119	3	2,5
2	73	4	5,5
3	115	8	7,0
4	54	5	9,3
All	361	20	5,5

Most of the damage occurred when the sacks were being handled by the grapple. The result depends both on the shape of the grapple and the operator's skill. Although all the operators were experienced in working with a forwarder they were beginners in this type of work.

It is obvious that the useful life of sacks can be increased essentially merely by restructuring the tractor grapple, by covering the bottom of the load space and by increasing the operator's experience. The cost calculations in Chapter 64 assume in fact that the life of the sacks is 30 times of use.

Twigs and slivers reduce the solid volume content of the sacks. Sack filling improved with the chip quality after experimental stand 2. The average sack weight was subsequently 280 kg for hardwood and as great as 365 kg for pine. The heavy weight of the pine sacks was due to the high moisture content of the wood. The sack volume exceeded 1 m^3 and its wood content was around 0,4 m^3 (solid volume).

The locking device for the sack bottom functioned satisfactorily. The release mechanism for emptying generally functioned well. However, releasing was difficult in the last experimental stand where the weight of the sacks was greatest. It also appeared that if the locking device of an empty sack is not closed carefully it may open when the sack is being moved by the grapple.

63. Output in forwarding

The swath harvester leaves the chip sacks scattered in the terrain. It may be possible to speed up the loading phase of haulage by dropping the sacks in groups, but this was not attempted in the present study.

Either a farm tractor or a forwarder may be used for transport (Figures 8,9 and 10). The machine must be equipped with a loader which is capable of handling 350—450 kg sacks. The following tractors were used for forest haulage in the present work:

- — Experimental stand 1 Ford County 754
- — Experimental stand 2 Valmet 920 Jehu
- — Experimental stand 3 Hemeg
- — Experimental stand 4 Ford County 754

Chip sacks are easy to transport in clear-

Table 4. The weight and volume of the chip sacks.
Taulukko 4. Hakesäkkien paino ja tilavuus.

Stand *Koeala*	Main species *Pääpuulaji*	Loose volume, m^3 *Irtotilavuus, m^3*	Solid volume, m^3 *Kiintotilavuus, m^3*	Green weight, kg *Tuorepaino, kg*	Dry matter, kg *Kuiva-ainetta, kg*
1	Birch — *Koivu*	0,82	0,28	236	130
2	Aspen — *Haapa*	0,95	0,35	282	152
3	Willow — *Paju*	1,04	0,38	280	147
4	Pine — *Mänty*	1,13	0,41	365	151

Figure 8. Loading of chips sacks.
Kuva 8. Hakesäkkien kuormaus.

cutting conditions. Loading proceeds speedily and the load size is adequate.

In contrast, it is difficult to work with a forwarder in corridor thinning of pine. The forwarder width must be smaller than that of the swath harvester. As the forwarder must move the sacks in a narrow corridor from in front into its load space the risk of damage to the growing stock is great. In fact, it is only possible to work in stands where the trees are so short that the forwarder can lift the sacks above the crown layer. Otherwise the sacks must be dropped from the swath harvester within reach of the strip roads running across the corridors.

The time consumption and output of haulage depends on the number of sacks per unit of area. The density of chip sacks in the terrain prior to forwarding was as follows:

Stand	Number of sacks per ha
1	257
2	154
3	295
4	94

The differences in time consumption between the stands may be attributable equally much to the operators as to stand differences. The results are fairly definite as to loading and unloading. In forwarding,

Table 5. The time consumption in forwarding the chip sacks. Hauling distance 200 m.
Taulukko 5. Hakesäkkien kuormatraktorikuljetuksen ajankäyttö. Matka 200 m.

Work element *Työvaihe*	Stand — *Metsikkö*							
	1	2	3	4	1	2	3	4
	Effective time, cmin/m³ *Tehoaika, cmin/m³*				Time distribution, % *Ajan jakauma, %*			
Moving — *Siirtyminen:*	265	238	365	358	24	31	40	40
Unloaded — *Tyhjänä*	55	37	147	55	5	5	16	6
During loading — *Kuormauksen aikana*	155	155	62	253	14	20	7	28
Loaded — *Kuormattuna*	55	46	156	50	5	6	17	6
Loading — *Kuormaus*	253	217	167	194	24	28	18	22
Unloading — *Purkaminen*	554	322	393	340	52	41	42	38
Total — *Yhteensä*	1072	777	925	892	100	100	100	100

Figure 9. Transport of chip sacks.
Kuva 9. Hakesäkkien kuljetus.

on the other hand, time distribution varies greatly with the terrain and organization of the work. It must be borne in mind that in Table 5 unloading includes the emptying of the sacks into the truck trailer, onto a pallet or a chip pile. If the sacks are stacked as such at the landing the work is accelerated essentially. The unloading time is then roughly the same as the time spent on making a load.

As the studies were short and the quantities of timber harvested small the tractor load was often inadequate. Hauling a short load reduces the work output. The following schedule shows the largest load and the size of an average load measured at the different work sites.

	Average load	Maximum load at a work site
Number of sacks	12,3	17,0
Loose m^3	12,2	16,5
Solid m^3	4,4	5,9
Green tons	3,6	4,8

Output in the forwarding of sacks was an average of 7,4 m^3 per effective hour. This is smaller than in the transport of cordwood, but greater than for the transport of undelimbed small-sized trees.

Stand	Output in forwarding m^3 per effective hour
1	8,8
2	7,7
3	6,5
4	6,7
All	7,4

Output is burdened by the lack of the operators' experience in the handling of sacks, the short loads and the open base structure of the forwarders. Allowing for this, the output was fairly satisfactory. It is evident that this output level will be achieved easily in the future also per gross effective hour which includes short delays of less than 15 min. This figure is used in the cost calculations of Chapter 64.

64. Harvesting costs

As the swath harvester is still in the prototype stage no final price has been fixed for it. In this calculation its price is assumed to be 700 000 Finnish marks.

The per-hour cost of the machine is increased by the helper needed for sacking and the relatively short (7—8 months) period

Figure 10. Unloading of chip sacks.
Kuva 10. Hakesäkkien purkaminen.

of use. It is impossible to use the harvester in the winter when the snow cover is thick or during the thawing period when the roads are impassable and the carrying capasity of the terrain is weak. The per-hour cost is assumed here to be 290 marks. The output of the machine per gross effective hour (including delay times shorter than 15 min.) in the calculation is 80 % of the output per effective hour in the hardwood stand 3, i.e. 7,3 m^3/h.

Sacks mean a considerable additional expenditure. The Rukka sack which cost 135 marks was the most economical in price. Adding to this the cost of the locking device, 15 marks, the total cost of the sack is 150 marks. As mentioned in Chapter 62, it is assumed that the sacks can be used 30 times. If full sacks contain an average of 0,38 m^3 (solid volume) of chips a total of 11,4 m^3 (solid volume) of chips is carried in one sack during its useful life.

Sacks are transported by a standard model forwarder or farm tractor. The minor alterations that may have to be made in the grapple and the covering of the bottom of the load space are not significant cost factors. However, additional costs are caused by the helper needed to empty the chip sacks into the truck trailer or onto a pallet. The per-hour cost, including the helper, of a forwarder is 135 marks in the calculation and the output in accordance with Chapter 63 is 7,4 m^3/h.

Given these premisses, the cost of chips at the landing loaded into truck is as follows. It should be noted that the calculation does not include overheads and stumpage price.

	Cost of chips, Fmk*/solid m^3
Cutting, chipping, sacking	40
Sacks	13
Forwarding, unloading	18
Total	71

*At the end of 1979 the Finnish mark (Fmk) equalled 0,266 U.S. dollars or 1,121 Swedish krona.

The consumption of energy compared with the energy of the fuel recovered in the harvesting of a hardwood coppice is shown by the following figures. They include only the energy required for actual harvesting and ignore the energy input of the manufacture of the machines, their maintenance and movements from one work site to another.

	Consumption of fuel dm^3/ton of wood	% of the energy content of wood
Swath harvester	11,6	2,4
Forwarding	2,7	0,6
Truck transport (70 km)	4,8	1,0
Total	19,1	4,0

The calculations give an idea of the cost and energy level at which the method described operates in hardwood coppices. A precondition, of course, is that the swath harvester is as readily available as most multi-purpose machines. The calculation contains many factors of uncertainty, but follows conservative principles. It must be remembered that the growing stock was of exceptionally small size, but that the terrain was easy to negotiate.

65. Work quality

651. Accuracy of biomass recovery

As all parts of a tree are of almost the same value as fuel the aim is recovery of the entire above-ground part of a coppice. The exception is foliage the removal of which from the site may be detrimental to the nutrient balance of the soil. Attention must thus be paid in assessing the efficiency of the method also to the accuracy of biomass recovery. Biomass losses arise primarily for three reasons:

- The wood left in over-long stumps, i.e. stubble
- Trees and tops that have fallen to the ground from the swath harvester
- Chips that fall in the different phases of the harvesting schedule.

Stubble is the most significant source of logging waste. The shorter the trees harvested, the greater the proportion of the wood that remains in stumps. The stubble height depens primarily on the terrain. Stones, stumps of large trees and other unevennesses increase the height of the stump. On the other hand, the diameter of coppice trees hardly affects the stump height. The following results were obtained in the experimental stands.

Stand	Stubble height, cm	Tree height, m	Proportion of stubble of the above-ground biomass, %
1	21,7	6,2	8,6
2	26,2	6,5	9,8
3	21,0	7,1	7,3
4	25,1	5,3	11,3

The proportion of stubble in the three hardwood stands was 7—10 % of the above-ground biomass of the growing stock. 11 % of the biomass remained in the stubble in the pine stand in which the trees tapered more steeply.

Cutting plates and machine wheels damage stumps. The stump cross-section is uneven and the stump may lose part of its bark. If the stump bends the roots are damaged. It may be assumed for these reasons that a coppice harvested by the Pallari swath harvester sprouts more slowly than one cut by a chain saw, circular saw or brush hook.

If the harvester drops an entire tree or top it is difficult to re-gain it. Some biomass is lost in this way. When the trees are straight the losses are relatively small. Bushy stumps that sag escape the machine more readily. The share of trees and tops that had fallen in all the biomass above the stump cross-section was 1 % on average in the experimental areas. Over a half of the losses originated because the tree fell past the pusher frame to the side of the machine. Other causes were the fall of a tree or top to the ground in front of the machine or the tree being overrun by the harvester's wheels.

When a full sack is dropped from the harvester's sack holder its mouth is partly open. Chips are lost in the dropping and when the sack is moved by the tractor grapple. The chips lost in this way account for about 1 % of all the above-ground biomass of the growing stock.

The biomass yield in harvesting in experimental hardwood stands was an average of 89 % of the above-ground part of the coppice excluding foliage. Reducing the amount of logging waste requires above all lowering the stubble height.

	Per cent of the above-ground biomass of the stand
Logging waste:	
Stubble	9
Trees and tops	1
Chips	1
Total waste	11
Biomass recovered	89
Total	100

Figure 11. Fuel chips made by the Pallari swath harvester (Photo by Matti R u o t s a l a i n e n).
Kuva 11. Pallarin leikkuuhakkurin tekemää polttohaketta (kuva Matti R u o t s a l a i n e n).

652. Properties of chips

The Pallari swath harvester is intended in the current economic situation for the harvesting of fuel chips. Chip properties are therefore assessed only with regard to burning as fuel.

As the tree is chipped immediately after felling the *moisture content* of the chips is high. However, the moisture content on the green weight basis is generally under 50 % for hardwood and the chips are thus suitable for burning in most boiler types. In contrast, small-sized pine has such a high moisture content because of its abundant foliage that burning of green chips poses problems.

Stand	Main species	Moisture content, %
1	Birch	45,1
2	Aspen	46,2
3	Willow	47,5
4	Pine	58,7

Another factor affecting the value of chips is the *dry-matter content of a loose cubic metre of chips* when the sacks have been unloaded into a truck trailer or onto a pallet. The solid volume content of chips made by swath harvester is relatively low, 0,34—0,37, before the beginning of truck transport (Table 6). The low solid volume content is at least partly the consequence of the high proportion of over-sized particles and twigs (Tables 7 and 8).

Table 6. The weight and the solid volume content of chips in a truck load before transport.
Taulukko 6. Hakkeen paino ja tiiviys autokuormassa ennen kuljetusta.

Stand *Koeala*	Green weight kg/loose m³ *Tuorepaino kg/i-m³*	Dry weight kg/loose m³ *Kuivapaino kg/i-m³*	Solid volume content *Tiiviys*
1	288	158	0,34
2	275	148	0,37
3	270	142	0,37
4	323	134	0,36

Table 7. The particle size distribution of chips in hole screening.
Taulukko 7. Hakkeen palakokojakauma reikäseulonnassa.

Stand *Koeala*	Fraction, mm — *Palakoko, mm*							Total *Yhteensä*
	—3	3—6	6—13	13—19	19—25	25—32	32+	
	Distribution, % — *Jakauma, %*							
1	5	9	21	21	17	14	13	100
2	3	11	28	21	15	12	10	100
3	3	6	22	25	22	15	7	100
4a*	6	15	27	22	14	8	8	100
4b*	6	12	26	23	14	10	9	100

*4a short (2—4 m) pines, 4b taller (5—8 m) pines —
**4a lyhyt (2—4 m) mänty, 4b pitempi (5—8 m) mänty*

Table 8. The particle size distribution of chips in slot screening.
Taulukko 8. Hakkeen palakokojakauma rakoseulonnassa.

Stand *Koeala*	Fraction, mm — *Palakoko, mm*						Total *Yhteensä*
	—2	2—4	4—6	6—8	8—10	10+	
	Distribution, % — *Jakauma, %*						
1	14	15	12	20	19	20	100
2	15	18	18	16	15	18	100
3	9	12	16	15	19	29	100
4a*	24	18	19	15	12	12	100
4b*	16	13	19	16	17	19	100

*See Table 7 — *Selitys taulukossa 7.*

The *particle size distribution* (Fig. 11) of the chips is satisfactory as regards burning. However, the abundance of twigs and other long particles causes difficulties in emptying the chip silos and the automatic feeding of chips onto stoker conveyors. The chips are acceptable for many large furnace units, but for use in smaller boilers the quantity of long particles must be reduced. This may call for a new knife arrangement in the chipper.

7. DISCUSSION

The experimental series with the Pallari swath harvester was so short that it is difficult to make a final estimate of the suitability of the method for regular practical use. The correct working technique was still being sought in the investigation phase and thus the planning of the work sites left something to be desired. Interpretation of the time study results is complicated by the lack of experience of the harvester crew.

The authors have no doubts that the method is technically applicable to the harvesting of fuel chips from hardwood coppices. The chip sack system is serviceable and flexible. The output of the swath harvester and the forwarder is already so great in good conditions that the preparation of fuel chips from coppice trees seems feasible. However, the operation of the machines and the working method still require fine-tuning. Further development work must be done to increase reliability and allow practical activity on a major scale. The following points at least require attention:

The power of *the prime mover* is low. The engine overheated during the experiments.

The cutting plates fuction well. But the short duration of the experiments does not warrant conclusions on their durability.

The feeding cylinders function faultlessly. The feeding opening becomes blocked if too many trees are fed into it simultaneously. Movement of the trees to the chipper requires that they fall almost flat. The feeding procedure would be more efficient and the work would be speeded up if the trees entered the chipper at an even more vertical position than they do at present.

The drum chipper was the principal limiting factor on output in the first two experiments. The main reason was jamming of the knives. With the knife arrangement changed, output increased essentially in the third experimental stand. It will probably be possible to develop the chipper further. A spiral-head chipper may enter into question as an alternative to the drum chipper. In developing the chipper attention should be paid also to the particle size distribution of the chips. At present, the chips contain too many unbroken thin twigs and slivers.

The location of *the chip pipe* in the middle of the operator's field of vision makes it difficult to see the cutting knives. This forces the operator to leave the stubble higher than would perhaps be necessary otherwise. When large trees are chipped the chip pipe may become blocked. It may also be blocked by a large volume of foliage and by rain. The blowing power of the chipper should therefore be increased. It should be possible for the operator to notice immediately a blockage in the chip pipe.

The chip conveyor functions faultlessly as long as the chip quality is satisfactory. An abundance of twigs and over-sized chips, however, may choke the conveyor. The height of the conveyor hampers road transport and work along power lines.

The sacking device functions well. The sack hand has, however, to assist the filling by swinging and kicking the sack. This is strenuous work, especially if there are great quantities of chips. It is important for the filling process that the dimensions of the sacks accord exactly with the holder. The filling of the sacks could perhaps be furthered by means of a vibration apparatus.

Sack costs must be reduced by lowering the price or lengthening the useful life of the sacks. As the majority of sack tears are caused by the loader grapple, special attention must be paid to solving this problem by improving the sack materials, the shape of the grapple and the handling technique.

The Pallari swath harvester is a promising solution for the recovery of small-sized coppice trees. The fuel chip harvesting schedule based on it and on the chip sack system is a fully realistic future alternative in coppices in which the stump-root systems are not desired to sprout vigorously. However, achieving the operative reliability foreseen by practical harvesting work demands the finalization of certain details and larger experimental work sites. The experiences of this research project strongly encourage continuation of the development work.

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