METSÄNTUTKIMUSLAITOKSEN
TIEDONANTOJA 302

# CO-OPERATION IN FORESTRY RESEARCH BETWEEN THE FINNISH FOREST RESEARCH INSTITUTE AND THE FEDERAL UNIVERSITY OF PARANÁ (CURITIBA, BRAZIL)

RESULTS OF THE JOINT RESEARCH PROJECTS

EDITED BY
JARI PARVIAINEN AND JOSE GERALDO DE ARAUJO CARNEIRO



HELSINKI — JOENSUU 1988

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In 1985 the Finnish Forest Research Institute and the Federal University of Parana (Curitiba, Brazil) signed an agreement concerning co-operation in forestry research. The goal of the co-operation programme has been to promote forestry research in subjects of mutual interest, to establish collaboration contacts and to increase, in general, the dissemination of information about forestry. Forestry research has formed a channel for the promotion of economic and technological co-operation between Finland and Brazil.

The following joint studies of the co-operation project are included in this publication:

**Carneiro, J.G.A. & Parviainen, J.** 1988. Comparison of production methods for containerized pine (Pinus elliottii) seedlings in Southern Brazil: 6-24.

*Abstract: The suitability of six different Finnish and Brazilian containerized seedling methods for raising pine seedlings in southern Brazil were studied in the nursery of the University of Parana (Curitiba). The raising period lasted eight months. The total number of seedlings in the experiment was over 5500.*

*The morphological characteristics of the containerized seedlings did not differ from those of bare-rooted ones. The mean height of the tallest seedlings was 13-14 cm. Seedling development was especially poor in containers with a small volume. This Finnish paperpot and VAPO methods at least are suitable for the mass production of seedlings under South Brazilian conditions. However, more extensive raising experiments are needed before the methods can be adopted on a wide scale.*

**Kanninen, M. & Seitz, R.A.** 1988. Dendrochronology of Araucaria angustifolia in Southern Brazil: Preliminary results: 25-35.

*Abstract: Tree-ring analysis of Araucaria angustifolia trees grown at the forest research station Sao Joao do Triunfo of the University of Parana has been carried out.*

*The tree ring data consisted of cross sections (discs) taken from 9 trees at the height of 2 m. On each disc, eight radii were defined, from where the width of annual rings was measured with a digital positiometer. Calculation of the tree ring index for each radius involved the removal of trend by fitted theoretical growth curves. Subsequently, tree average and stand average chronologies were computed.*

*The preliminary results indicate that there exists high degree of variation within the tree. The mean intracorrelation coefficient for the ring widths between the radii varied between 0.57 and 0.89.*

*Mean correlation coefficient of 0.60 for all pairs of trees was obtained indicating consistency between the trees in the index series. The estimated autocorrelation functions indicated persistence in index series.*

**Harstela, P. & Malinovski, J.** 1988. Productivity and strain of workers in clear-cutting of eucalyptus plantations in South Brazil: 36-53.

*Abstract:* *Productivity, physical strain, working capasity and energy expenditure of workers were studied when using short wood cutting methods. A new work method with "simplified" piling was developed. Productivity for two-men team varied from 4.5 to 6.7 $m^3$/h being higher for the new work method. Degree of strain was in average 40.2 % for the new method and 61.5 % for the old one. Work capasity of workers according to max. $O_2$-uptake ability was rather good, in average 53.3 ml/min.kg and energy expenditure 14 400 kJ per 8 h shift. These last mentioned figures based on sub-maximal tests and reliability of them is not very good. Further development of work methods and need of studies were discussed.*

**Soares, R.V. & Hakkila, P.** 1988. Energy potential of thinning residue from loblolly pine (Pinus taeda) plantations in the state of Parana, Brazil: 54-78.

*Abstract:* *The objective of the joint study was to evaluate the amount and energy potential of residual crown mass left on site as residue after thinning operations in loblolly pine (Pinus taeda) plantations in the state of Parana in southern Brazil. A sample of 115 trees was collected from 7-, 10-, and 14-years-old stand of loblolly pine that would be submitted to the 1st, 2nd, and 3rd thinnings. The residual crown mass was classified into the following categories: needles, branches less than 0.7 cm diameter, branches 0.7-2.5 cm diameter, and large branch sections and unmerchantable top 2.5-7.0 cm diameter.*

*For most crown component and stand type combinations, dry mass was estimated best by a simple logarithmic function based on the use of the breast height diameter as the explaining variable. The total residual dry crown mass in the 1st, 2nd, and 3 rd thinnings, was 8.3, 15.0 and 14.0 tons/ha. The energy potential of this residue, including needles, was 3.9, 7.1, and 6.6 toe/ha. When needles were excluded, the energy potential was reduced by one fourth.*

# PREFACE

In 1985 the Finnish Forest Research Institute and the Federal University of Paraná (Curitiba, Brazil) signed an agreement concerning co-operation in forestry research. The goal of the co-operation programme has been to promote forestry research in subjects of mutual interest, to establish collaboration contacts and to increase, in general, the dissemination of information about forestry. Forestry research has formed a channel for the promotion of economic and technological co-operation between Finland and Brazil.

The results of the joint research undertakings have been summarized in this publication. The studies has been directed expressly at regeneration, silviculture and harvesting questions associated with Brazilian plantation forestry. The Brazilian plantation programme is one of the most extensive of its kind in the world. Brazil has been the trail-blazer for the tropical forest zone in this field. The fact that forestry practice in Finland is similar to that adopted in the establishment of plantations in Brazil, means that there is excellent potential for collaboration between the two countries.

The importance of forestry co-operation was emphasized in the technical and economic co-operation discussions held between Finland and Brazil in 1984 and 1986. It was agreed at the meetings held in Brazil in October 1986 that two separate forestry seminars would be held in Brazil and Finland in order to strengthen collaboration and to outline, in detail, the fields and themes of co-operation. The first forestry seminar, with associated field excursion, was held in Finland in August 1987 (Bulletin of the Finnish Forest Research Institute, No 273). A corresponding seminar will be held in Brazil in October 1988. The main starting point in the planning of further co-operation has been to implement forest research co-operation between the Finnish Forest Research Institute and the University of Parana.

As the Finnish coordinator I would like to extend my warmest thanks to all those who have participated and assisted in the co-operation programme. In particular I would like to thank the coordinator of the Brazilian side, Professor Jose Geraldo de Araujo Carneiro, for his excellent collaboration in arranging the research and various events throughout the duration of the co-operation programme, and Ambassador Pekka J. Korvenheimo for his wide support. My sincere thanks also go to the funding body for the co-operation programme, the Commercial Policy Department of the Finnish Ministry for Foreign Affairs.

Jari Parviainen

Jari Parviainen
Coordinator of the co-operation in forestry research between the Finnish Forest Research Institute and the University of Paraná

# CONTENTS

# COMPARISION OF PRODUCTION METHODS FOR CONTAINERIZED PINE (*PINUS ELLIOTTII*) SEEDLINGS IN SOUTHERN BRAZIL

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Abstract

The suitability of six different Finnish and Brazilian containerized seedling methods for raising pine seedlings in southern Brazil were studied in the nursery of the University of Paraná (Curitiba). The raising period lasted eight months. The total number of seedlings in the experiment was over 5500.

The morphological characteristics of the containerized seedlings did not differ from those of bare-rooted ones. The mean height of the tallest seedlings was 13-14 cm. Seedling development was especially poor in containers with a small volume. The Finnish paperpot and VAPO methods at least are suitable for the mass production of seedlings under South Brazilian conditions. However, more extensive raising experiments are needed before the methods can be adopted on a wide scale.

CONTENTS

# 1. INTRODUCTION

The artificial forestation programme in Brazil is one of the most extensive of its kind in the world. So far, about 6 million hectares of forest plantation have been established in Brazil during the last twenty years. According to the longterm plan, Brazil will be self-sufficient in pulp and paper production by the year 2000. In addition, pulp and paper are to be produced for export. In 1986 Brazil was the eleventh largest producer of paper and the eighth largest producer of pulp in the world. In order to be able to meet the domestic demand and export targets, Brazil will have to establish 16.3 million hectares of forest by the year 2000. Thus one third of the target had been reached in 1987 (see Kengen 1987, Murakami 1987).

The main emphasis in the plantation establisment has been on exotic species. The majority of the plantations - over 60 % - have been established with eucalyptus species originating from Australia. The eucalyptus plantations are being established for pulp and energy wood production. The fast-growing eucalyptus species are followed in importance by pine species (*Pinus taeda*, *Pinus elliottii*) from the southern and southeastern states of the USA.

Large-scale planting work presupposes rationalized production of forest tree seedlings. The present rate of plantation establishment corresponds to an annual seedling production of over 500 million seedlings. Up to now, the production of pine seedlings in southern Brazil has been based on bare-rooted seedlings. However, eucalyptus seedlings are being raised as containerized on an ever-increasing scale. The seedling production methods are very mixed. This has resulted in great variations in the quality of the seedlings. The quality variation of bare-rooted seedlings especially, may result in considerable losses during planting and establishment. Up to now, very little research has been carried out in Brazil into production methods and quality of seedlings (see Carneiro 1976, 1984).

Intensive plantation forestry has been practiced in Finland for over 30 years. The area of artificially regenerated forests totals 3,6 million hectares. This is equivalent to c. 18 % of the whole area of forest in Finland. New techniques for the production of Scots pine (*Pinus sylvestris* L.) seedlings especially have been developed during this period. The methods have received international attention, and many of the production solutions have been adopted in different parts of the world.

Plastic greenhouses have been introduced owing to the short growing season and need to speed up seedling production. The first fully automated production line for containerized forest tree seedlings (based on the paperpot method) was developed in the 1960's. Since then, production lines have been developed for the raising of a number of other corresponding types of both small and large, containerized seedlings. At the present time, annual production of tree seedlings in Finland is around 250 million, of which 60 % are containerized. The reforestation area totals 140 000 hectares annually. The experiences gained so far with plantations established using containerized seedlings have been favourable, and hence their proportion is continuously increasing (see Parviainen 1984, 1986).

The aim of this study is to compare different containerized seedling production methods for pine under South-Brazilian conditions. One subsidiary goal is to determine whether Finnish containerized seedling methods are applicable to Brazilian conditions. We have had to assume that the same basic solutions for containerized seedling production are applicable to different conditions and to different tree species. However, before the experiences gained under different conditions can be transferred as such from one country to another, large-scale practical planting work will have to be started to test the results of the research.

## 2. FACTORS AFFECTING THE CHOICE OF SEEDLING PRODUCTION METHOD IN TROPICAL CONDITIONS

Biological, technical and economic factors affect the choice of seedling production method (see Tinus & McDonald 1979). The basic solution consists of a choice between the production of containerized seedlings or bare-rooted ones. Since the production of bare-rooted seedlings is highly suitable for mechanization, it has been possible to develop this approach into large-scale mass production. Economic considerations in Finland and the other Nordic Countries have forced these countries to develop production lines for containerized seedlings that are as rationalized, mechanized and automated as possible. Thus, in a way, containerized seedlings have become a product of a biological conveyor belt system (see Parviainen 1986).

The factors which the seedling producer takes into account when deciding which production method to adopt can include easy handling, transport and planting of the seedlings, rationalization of the nursery work, being able to lengthen the planting season, and the unit price of the seedlings. However, the most important criterion when choosing which type of seedling to use is the success of planting in the field. The person responsible for the regeneration should know which factors will promote the subsequent success of the seedlings in the field. A central factor is the quality of the seedlings.

The following factors at least have to be taken into account when choosing seedling production methods under tropical conditions (see e.g. Owston & Stein 1972, Meskimen 1973, Stein & Owston 1975, Carneiro 1976, Abbott 1981, Hahn 1981, Harris 1981, Elam et al. 1981, Amidon et al. 1981, Guldion 1982a, 1982b, Evans 1982, Silander 1984, Carneiro 1984):

Biological factors:

- The survival of containerized seedlings in plantings is usually good. Containerized seedlings permit the planting season to be extended. The use of containerized seedlings is safer under especially dry conditions than that of bare-rooted ones. Containerized seedlings also permit replanting to be done during the same growing season.

- Bare-rooted seedlings require careful timing of the lifting and planting work, as well as favourable weather conditions after planting, if survival is to be ensured. Bare-rooted seedlings give poor results under difficult climatic conditions.
- The seed requirements can be precisely estimated in the production of containerized seedlings. The production of some species of tree seedling is only possible through the use of containers.

Technical factors:

- Containerized seedlings are difficult to handle and heavy to transport. The transport costs are high over long distances.
- The transport of bare-rooted seedlings is easiest when the distances are long.
- Containerized seedlings require as many containers as seedlings. The material used as the substrate in the containers should be of as uniform quality as possible.
- Arranging the production of bare-rooted seedlings often requires certain mechanization investments. Machines are required for site preparation, harrowing, forming the sowing beds, sowing, cutting and lifting (e.g. tractor - mounted equipment).

Economic factors:

- The production of containerized seedlings is usually more labour-intensive than that of bare-rooted ones. This often raises the production costs of seedling production above those of bare-rooted ones. However, the development of containerized seedling methods has reduced costs.

When making a choice about the type of container, the following criteria should be taken into account:

- extent of damage to root system, if any;
- distribution of the root system of seedlings;
- dimensions (height and diameter);
- possibility of re-use;
- cost;
- ease of handling (whether it decomposes during the seedling production phase or not);

- ease of transport to the plantation field;
- availability on the market;
- toxicity for the seedlings;

Some authors like Barnett (1974, 1981), Mattei (1980), Barnett & McGilvray (1981) and Kinghorn (1981) have classified containers into the three types: a) tubes; b) moulds and c) blocks. The tubes have an external wall, have to be filled with substrate and planted with the seedlings. Paperpot, peatpot, veneer, jacatron, etc, could be mentioned as examples. The plastic bag is the one exception which cannot be planted with the seedling. The rigidity of the wall allows for easy handling and transport and, to a certain extent, can help to decrease desiccation in dry soils. The disadvantage on dry soils is that the contact surface between the root system and the soil is limited, if the container wall does not decay quickly. The roots sometimes come out through the bottom of the container.

Moulds also require filling with substrate. The soil blocks are removed from the moulds before planting out. These seedlings, however, must be kept in the moulds long enough for the root mass to penetrate the block completely in order to facilitate extraction. This period varies with tree species and the dimensions of the cavity of the moulds. The walls are not normally perforated by the roots unless they have been specially designed for this purpose, the moulds having gaps between the cavities through which the roots can penetrate. This avoids deformed development of the root system. Styrofoam moulds, Ensopot and multipot can be mentioned as examples.

Blocks incorporate the advantages of the two previous types: they are the container and the substrate at the same time. They are planted with the seedlings, are normally hard and permit fast development of the roots. It should be pointed out that a long production period causes the roots to penetrate the root space of adjacent seedlings. In Brazil the "torrao paulista" (Sao Paulo block) can be mentioned as an example. In other countries some other blocks are being used, in Finland a new promising method based on pressed and dryed peat sheets (VAPO method) is developed.

Various studies are being carried out on containerized seedling production like conditions in southern Brazil. Moron & Gonzales Pino (1961) came to the conclusion that plastic containers can be used with Eucalyptus tereticornis and Pinus radiata, having the advantage over containers made of oven-dried mud, "torroes paulistas" or bituminized paper cylinders if the time at the nursery is limited.

Bertolani et al. (1976) obtained better development of root collar diameter and height with seedlings of Pinus caribaea var. hondurensis in veneer. Sturion's work (1980) made this container more suitable for seedlings of Schizolobium parahyba, allowing them to develop better in height, root collar diameter and dry weight compared to those produced in plastic containers of the same dimensions.

McGilvray & Barnett (1981) found correlation between some parameters of containerized seedlings and their performance after planting out. They found the height to be of major importance. According to their conclusions, a comparison of height and other features is desirable when seedlings are produced in various containers under different environmental conditions.

In a study on the effect of soil blocks on the root system, Barnett (1981) found that the cavity of styrofoam moulds may provoke the formation of spiral roots if these cavities do not bear vertical bands in high relief which force the roots to grow downwards. He also found that the roots of seedlings of *Pinus palustris* are more sensitive to spiral growth than those of *Pinus taeda*.

In his investigation of the influence of containers on the development of seedlings of *Mimosa scabrella*, Sturion (1981) came to the conclusion that the diameter of the root collar and the dry weight of the aerial part and root system were larger in containers with a bigger diameter. In the case of "torronetes" (soil blocks), Barnett & McGilvray (1981) found that the majority of the variation in the performance of seedlings after planting out depends on the volume of the cavity of the moulds. In their studies on *Quercus falcata* var. *pagodifolia*, *Q. mutalli*, *Q. shumardii* and *Q. nigra*, Elam et al. (1981) concluded that, on the one hand, the stem height and the shoot-root ratio are influenced by the size of containers and, on other, that the folial surface depends on the type of substrate used. Goodwin et al. (1981) also found better responses of survival and development with *Juglans nigra*, *Fraxinus americana* and *Liriondendron tulipifera* when the seedlings were produced in containers of 45 cubic feet if compared to 21 cubic feet.

The size of the container brings about technical and economic consideration, the optimal ones being those which balance the cost of production and the possibility of obtaining the maximum number of seedlings per square meter, while keeping quality high. The diameter of containers seems to be more important than the height. Boudox (1970) and Brazil et al. (1972) and Sturion (1980), respectively obtained first class seedlings of *Picea mariana* and *Eucalyptus saligna* in containers with a bigger diameter. However, Cozzo (1976) pointed out that the height of containers is more important than the side dimensions. Simoes (1968) observed that seedlings of *Eucalyptus saligna*, *E. alba*, *E. grandis* and *E. citriodora* developed better in plastic containers of 5.5 cm in diameter and 11.0 cm high compared to those of 18 cm in height. According to Gomes et al. (1978), both the height and the diameter of the containers influenced the height growth of *Eucalyptus grandis* seedlings.

## 3. MATERIAL

The seedlings were raised in the seedling nursery of Paraná University, Curitiba, during 14.11.1986 - 22.6.1987. There were seven experimental treatments:

| Treatments | Container dimension (mm) | Volume (ml) | Number of seedlings in experiment |
|---|---|---|---|
| 1. Paperpot (Fh 5010) | 51 x 100 | 125 | 1040 |
| 2. Paperpot (Fh 5015) | 51 x 150 | 185 | 1040 |
| 3. Peatpot (FP 620) | 75 x 70 | 90 | 480 |
| 4. VAPO, 5 x 5 cm | 50 x 85 | 200 | 768 |
| 5. Tubete | 30 x 125 | 60 | 768 |
| 6. Bare-rooted | 50 x 150 | - | 800 |
| 7. Taquara (Bamboo) | 25 x 150 | 75 | 800 |

Treatments 1-4 are Finnish seedling production methods, and 5-7 Brazilian ones (Fig. 1).

The containers were filled with a substrate consisting of vermicullite (25 %), pine bark (well composted 25 %) and organic soil (50 %). The VAPO-method is based on the use of a peat block, made of dried and compressed Spaghnum peat. On watering, the blocks swell up to a final size of 8 cm thick. The seedling density in the blocks was 5 x 5 cm. The blocks used in the trial were supplied from Finland.

Two seeds were sown in each container on 14.10.1986 (seed supplied by Klabin Co. Ltd., Telemaco Borba). After germination, the second germling was cut away with scissors on 21.12.1986.

The growing units were arranged in a completely random experimental design in the nursery. There were four replications for each treatment (Fig. 2).

The same growing programme (watering) was given to all types of seedling. However, the seedlings were not watered at the weekend. The seedlings were not fertilized in the nursery. The roots and peat blocks of the VAPO seedlings were cut with a saw at the end of the growing period.

The growing stage in the nursery was terminated a good eight months after sowing on 22.6.1987. A planting field trial was then arranged on the experimental farm (Canquiri) of Paraná University. Planting was done on 22.-25.6.1987. The aim of the trial was to follow the survival and development of the seedlings under field conditions. This stage will last for a number of years. The field trial is being used to study, for instance, the root development of the seedlings.

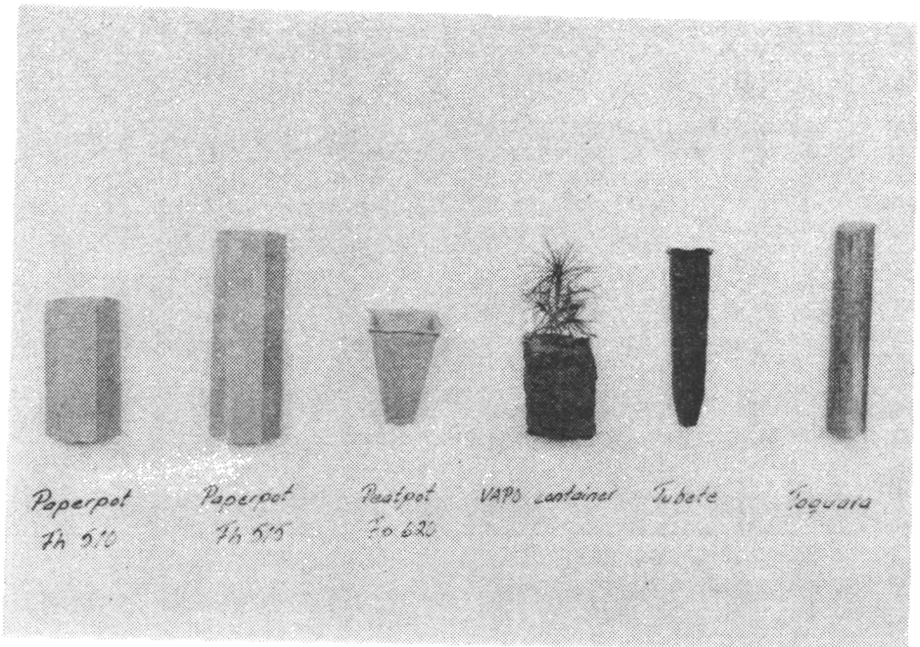


Fig. 1. The container methods to be compared in the experiment

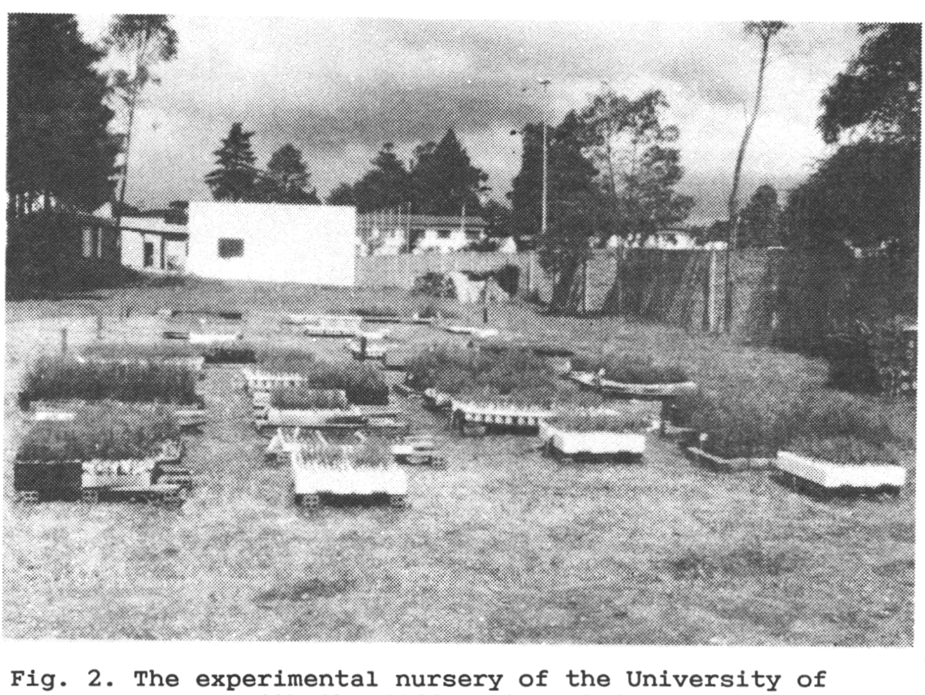

Fig. 2. The experimental nursery of the University of Parana with the different container methods

Sample seedlings were taken from each seedling lot at the end of the growing period. 25 seedlings/treatment were measured in each replication, making 100 seedlings/treatment. The height and root-collar diameter were measured on each sample seedling, and the height/root-collar diameter ratio calculated. The fresh and dry weights of the seedlings were measured in 25-seedlings groups. The root system and stem were separated by cutting through the stem collar, and stored in separate paper bags. The bags were weighed before and after drying at a temperature of 75°C /24 h.

# 4. RESULTS

## 41. Observations on the seedling production phase

Germination was recorded two months after sowing (16.12.1986). The mean germination percentages were as follows:

| Treatment | Germination |
|---|---|
| 1. Paperpot, Fh 5010 | 70 % |
| 2. Paperpot, Fh 5015 | 61 % |
| 3. Peatpot, FP 620 | 60 % |
| 4. VAPO | 44 % |
| 5. Tubete | 46 % |
| 6. Bare-rooted | 67 % |
| 7. Taquara | 49 % |

The following observations were made on each type of seedling during raising:

<u>3th MONTH</u>

Peatpot:
- The most vigorous roots showed the first signs of perforation of the container wall.
- As during the first and second months, the substrate did not maintain a high moisture content.
- Complete desiccation of some seedlings (up to 10 %).

Vapo: Very high moisture retention capacity.

Paperpots: No root perforation signs.

Tubete: Ability to maintain a high moisture content of the substrate.

Taquara: Very resistent to degradation, although a change occurred in the colour of its underground part.

Obs: Except for peatpots, relatively good mycorrhiza formation was observed in all treatments (including the bare-rooted ones).

4th MONTH

Peatpot: Increase in the perforation of the container walls was verified.

Vapo: Seedlings showed a chlorotic discolouration

Paperpots: - The first perforation signs.
- Resistant to manipulation (not decomposed)

Tubete: The internal friezes lead the roots in to the bottom of the containers.

Taquara: Same observations as in the 3th moth.

Obs: Increase in mycorrhiza formation in all treatments.

5th MONTH

Paperpots: These types of container did not show much resistance in the manual individualization. Separation tears the bottom part of the container wall. The 10-cm high container did not show this characteristic.

Tubete: Survival rate was low.

6th MONTH

Paperpots: Both types had the same problems - sereparation of the containers tears the wall, specially the 15 cm-high ones.

GENERAL OBSERVATIONS:

- From the 3th month the survival rate decreased, in containers with smaller volumes, specially in the tubetes.
- An increase in mycorrhiza formation was observed throughout the seedling production period. In other words, a higher number of thin roots was observed during this period.
- No sanitary problem occurred during the period.
- The Vapo-system proved to be a practical and reasonable solution for producing seedlings. The observed chlorotic colour can be avoided. This colour may be due to a nutrient deficiency which has still to be determined (no fertilization during the raising period).

42. Morphological characteristics at the end of the raising

The paperpot seedling grew the tallest (Fig. 3). Their height was twice that of the shortest types of seedling (Tubete and peatpot). Bare-rooted, VAPO and Taquara seedlings were about 2 cm shorter than the paperpot ones. The mean height of the seedlings differed, to a statistically highly significant degree (F-value in variance analysis 19.4***), between the seedling types. According to the Tukey test, the Tubete containerized seedlings differed significantly from all the other types, and the peatpot seedlings from the paperpot ones.

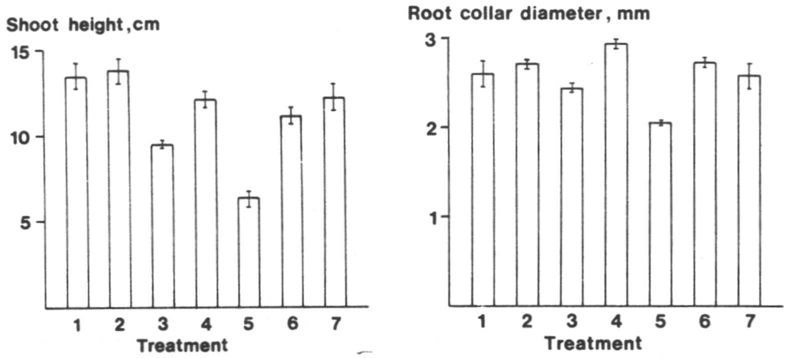


Fig. 3. Mean height and mean root-collar diameter (with standard deviation) of the seedlings.
Treatments:

1. Paperpot, Fh 5010
2. Paperpot, Fh 5015
3. Peatpot, FP 620
4. VAPO
5. Tubete
6. Bare-rooted
7. Taquara

The differences between the root-collar diameters of the different types of containerized seedlings were relatively small (Fig. 3). The VAPO seedlings were the sturdiest, and the Tubete and peatpot seedlings the slenderest. The mean values of the root-collar diameter of the different types of seedlings differed statistically significantly (F-value 6.4*) from each other. According to the Tukey-test, the Tubete seedlings differed significantly from all the others.

The height growth was especially poor in containers with a small volume (Fig. 4).

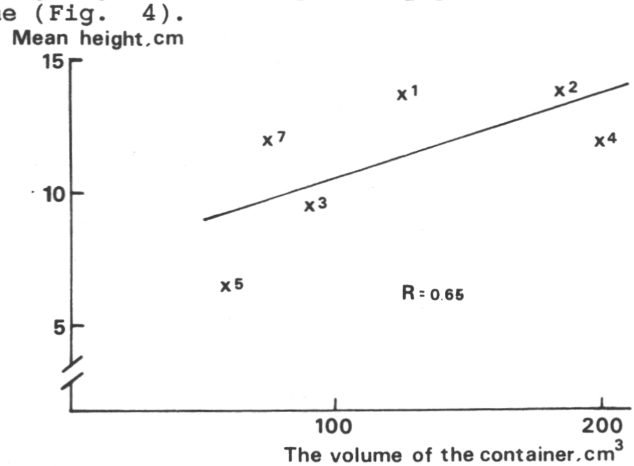


Fig. 4. The correlation between the volume of the container and the mean height of seedlings.
Treatments:

1. Paperpot, Fh 5010
2. Paperpot, Fh 5015
3. Peatpot, FP 620
4. VAPO
5. Tubete
6. Bare-rooted
7. Taquara

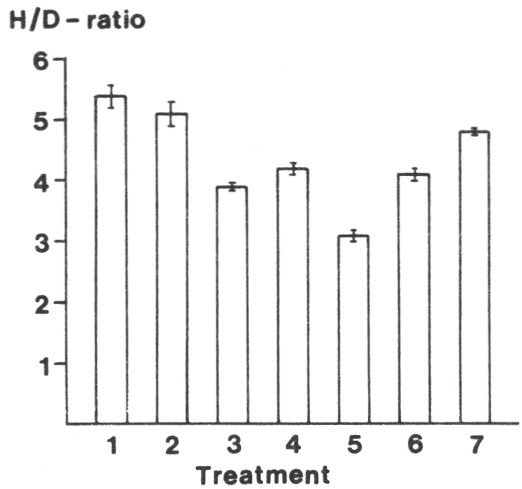


Fig. 5. The height/root-collar diameter ratio of the seedlings (H/D ratio).
Treatments:

1. Paperpot, Fh 5010
2. Paperpot, Fh 5015
3. Peatpot, FP 620
4. VAPO
5. Tubete
6. Bare-rooted
7. Taquara

It can be seen from the H/D ratio that the sturdiness of the VAPO and bare-rooted seedlings are similar (Fig. 5). The seedlings have grown in sparse conditions and hence their H/D ratio corresponds to that found under natural conditions. The differences between the H/D ratios of the different types of seedling were statistically significant.

The differences in the fresh and dry-weights of the different types of seedling showed the same trend as for the height and root-collar diameter values, i.e. the Tubete seedlings differed significantly from the other types (Fig. 6).

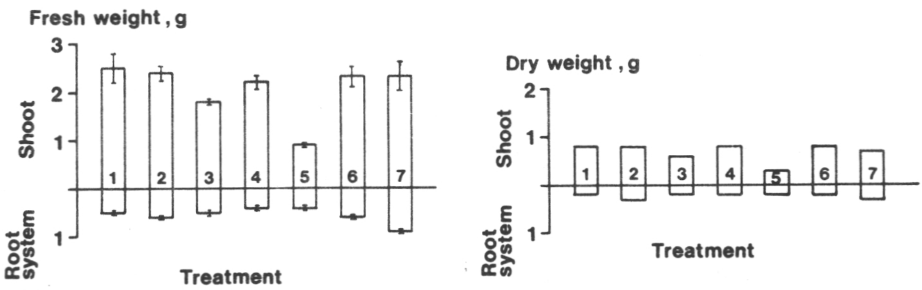


Fig. 6. Mean fresh and dry weights of the seedlings.
Treatments:

1. Paperpot, Fh 5010
2. Paperpot, Fh 5015
3. Peatpot, FP 620
4. VAPO
5. Tubete
6. Bare-rooted
7. Taquara

## 5. DISCUSSION AND CONCLUSIONS

At the end of the growing period the seedlings met the size norms which are used in pine planting under South Brazilian conditions (see Carneiro 1976, 1984). Since this is the first comparison trial of pine seedling types, there are no corresponding bench marks to which these results could be compared. Thus the main emphasis has to be placed on the differences in size between the different types of seedling.

According to the results, the morphological characteristics of the containerized seedlings did not differ from those of bare-rooted ones. This shows that, at the planting time, containerized seedlings are comparable to bare-rooted seedlings as regards their external characteristics. The clearest differences were found between certain types of containerized seedling. Seedling development was especially poor in containers with a small volume or where, owing to the properties of the container wall, they easily dried out. The properties of such containerized seedlings were cleary reflected in the poor growth because it was not possible to arrange regular watering. Regular watering could only be done on workdays, and not at the weekends. It can thus be assumed that those seedlings where the substrate easily becomes uniformly moistened, or which have a large container volume, are more resistant to variations in the moisture. Owing to the watering regime used in the experiment, the different types of containerized seedling were thus not grown under their own optimum conditions. The growth results would probably have been different if the watering of all the types of seedling had corresponded to their optimum. On the other hand, the results clearly illustrate the typical differences of containerized seedlings (see Parviainen 1984b).

The experiment showed that the raising of containerized pine seedlings in paperpots, VAPO and Taquara methods is possible in the South Brazilian conditions. Certain colour defect symptoms were observed in the needles of the seedlings, but these are probably caused by the fact that the seedlings were not fertilized. When necessary, fertilization of the VAPO seedlings can, however, be done beforehand in the peat blocks. Refertilization during raising will prevent the nutrient deficiency symptoms. Cutting up the roots of the VAPO seedlings did not present any problems, and it was possible to carry it out, as instructed, with a saw at the end of the raising period. The method is capable of producing very even seedling lots because the movement of nutrients and water takes place without hindrance throughout any container walls. The method can also be used for other tree species and for raising different-sized seedlings because the blocks can be produced in different thicknesses and the distance between the seedlings regulated.

One of the most serious problems which has been encountered in containerized seedling production is the danger of malformation of the root system (see Carneiro 1984, Parviainen 1986). This is especially the case if the sidewalls of the containers are not permeable to the lateral roots. When they come up against the walls, the lateral roots start to grow spiral, resulting in root system deformation. No such serious root deformations have been observed in the test seedlings. What is essential, however, is that the container walls does not form an obstacle to root growth at the planting site. An accurate picture of the root system development will be obtained as the field experiments progress.

In conclusion, we can state that the Finnish paperpot and VAPO methods at least are suitable for the massproduction of seedlings under South-Brazilian conditions. However, more extensive raising experiments are needed before the methods can be adopted on a wide scale. What especially must be investigated is how practical and rational are the different methods in large-scale seedling production. After this it will be possible to see clearly which method proves to be biologically, technically and economically the most workable under South-Brazilian conditions.

Summary

The artificial forestation programme in Brazil is one of the most extensive of its kind in the world. In order to be able to meet the domestic demand and export targets Brazil will have to establish 16.3 million hectares of forest by the year 2000. mmLarge-scale plantation establishment presupposes rationalized production of forest tree seedlings. Up to now, the production of pine seedlings in Southern Brazil has been based on bare-rooted seedlings.

The aim of this study was to compare different seedling production methods for pine under South Brazilian conditions. In the study there were included following seven methods: the Finnish ones; paperpot (type Fh 5010), paperpot (type Fh 5015), peatpot (FP-620) and Vapo, the Brazilian ones; Tubete, Taquara (Bamboo) and bare rooted seedlings. The containers were filled with a substrate consisting of vermicullite (25 %), pine bark (25 %) and organic soil (50 %). The VAPO-method is based on the use of Spaghnum peat. The raising of seedlings took place in the nursery of the University of Paraná (Curitiba). The raising period lasted eight months after sowing on 14.10.1986. The total number of seedlings in the experiment was over 5 500.

The morphological characteristics of the containerized seedlings did not differ from those of bare-rooted seedlings. The paperpot seedlings grew the highest and the VAPO-seedlings were the sturdiest. The mean height of the tallest seedlings was 13-14 cm in average and the root collar diameter 2.5 mm. Seedling development was especially poor in containers with a small volume or where, owing to the properties of the container wall, they early dried out. A planting field trial was then arranged on the experimental farm of the Paraná University in order to follow up the survival and height development of the seedlings under field conditions.

In conclusion, we can state that the Finnish paperpot and VAPO methods at least are suitable for the massproduction of seedlings under South-Brazilian conditions. However, more extensive raising experiments are needed before the methods can be adopted on a wide scale.

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# DENDROCHRONOLOGY OF *ARAUCARIA ANGUSTIFOLIA* IN SOUTHERN BRAZIL: PRELIMINARY RESULTS

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## Abstract

Tree-ring analysis of Araucaria angustifolia trees grown at the forest research station Sao Joao do Triunfo of the University of Paraná in South Brazil has been carried out.

The tree ring data consisted of cross sections (discs) taken from 9 trees at the height of 2 m. On each disc, eight radii were defined, from where the width of annual rings was measured with a digital positiometer.

Calculation of the tree ring index for each radius involved the removal of trend by fitted theoretical growth curves. Subsequently, tree average and stand average chronologies were computed.

The preliminary results indicate that there exists high degree of variation within the tree. The mean intracorrelation coefficient for the ring widths between the radii varied between 0.57 and 0.89.

Mean correlation coefficient of 0.60 for all pairs of trees was obtained indicating consistency between the trees in the index series. The estimated autocorrelation functions indicated persistence in index series.

CONTENTS

## 1. INTRODUCTION

Tree-ring studies in the South America have lagged behind those in Northern Hemisphere. For the genus Araucaria, only one species, i.e. A. araucana (Mol.) Koch. growing in the Andean region, has been subject to quantitative tree-ring studies (LaMarche et al. 1979a,b).

Araucaria angustifolia (Bert.) O. Ktze. is the most important native coniferous species in Southern America. It covers an area of app. 300 000 $km^2$ at the altitude between 400 and 1400 meters above sea level, mainly in Southern Brazil. However, no attempts to analyze its dendrochronology or relationship between climate and diameter growth are known. These studies could be used to increase the understanding of the tree growth in a natural forest, also providing knowledge for the management of both natural and man-made forests.

The objective of this paper is to describe the methodology used in the tree-ring study of Araucaria angustifolia trees growing in Southern Brazil. In addition to descriptive methods, variations within and between the trees are studied.

## 2. MATERIALS AND METHODS

### 2.1. Data collection and tree-ring measurements

The study area is located at the Forest Research Station of Sao Joao do Triunfo of the University of Paraná ($25^{o}34'S$, $50^{o}05'W$; 780 m a.s.l.) (Fig.1.). The stand forms a part of a natural forest, dominated by Araucaria angustifolia associated with an understorey of various broadleaved species. The tree age varied between 55 and 90 years. The stand mean diameter (DBH) was 30.1 cm, and the dominant height 19 m.

Nine trees of the dominating crown class were selected and felled. After felling, cross sections were taken at the height of 2 meters. At that height, the mean age of the felled trees was 65 years, and the mean diameter 45 cm. The cross sections were dried and prepared by smoothing one surface with a sand paper until it was polished. The sections allowed the indentification of single cells, giving the best condition for the identification and measurement of the rings. Therefore no staining was necessary (Fig. 2).

On each cross section, 8 radii were marked beginning with the greatest, the next turning clockwise $45^{o}$ and so on. From each radius the width of each annual ring was then measured with a digital positiometer to an accuracy of 0.01 mm. All the measured tree-ring sequences were cross-dated according to the procedure described by Fritts (1976).

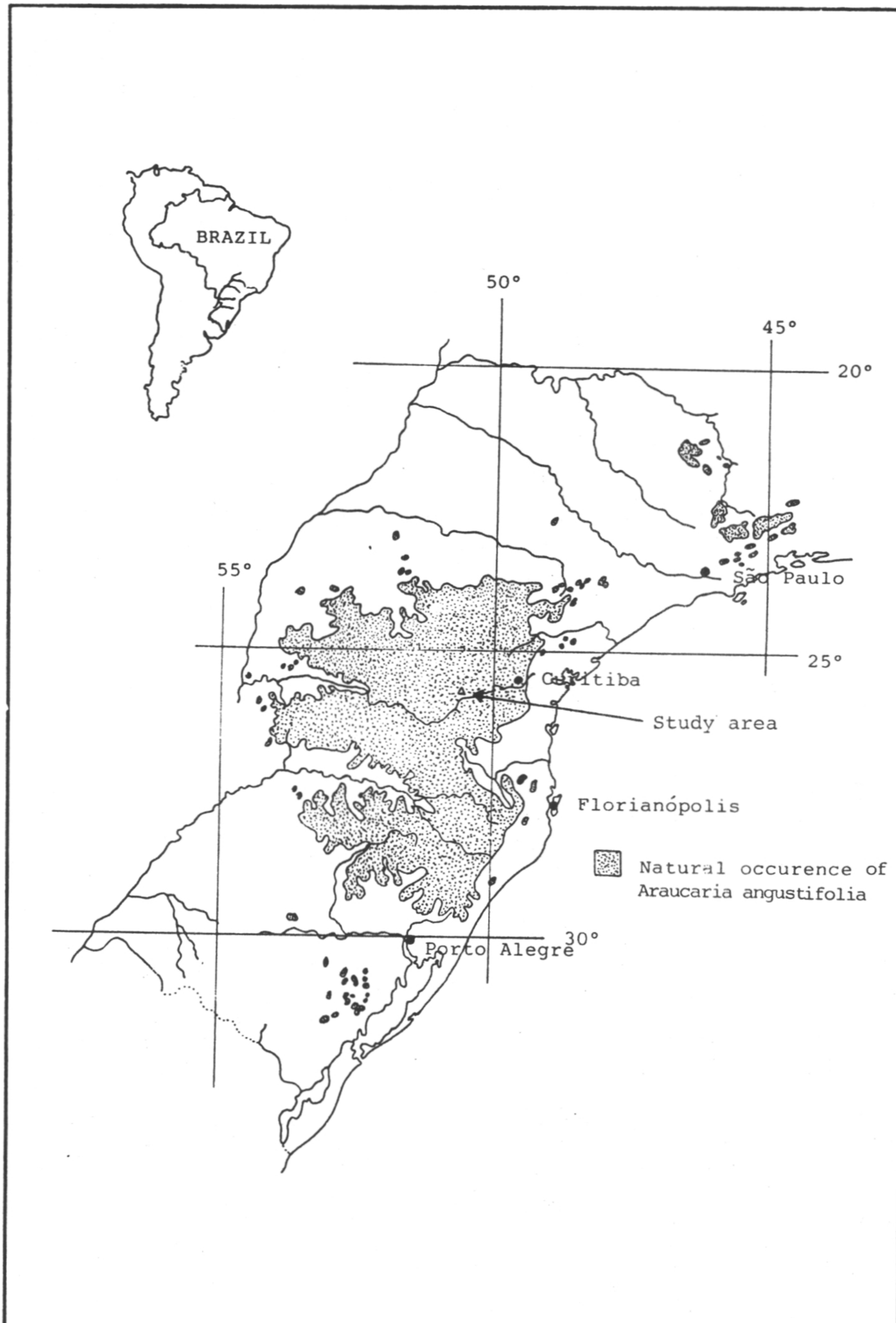


Fig. 1. Natural occurrence of Araucaria angustifolia and location of the study area.

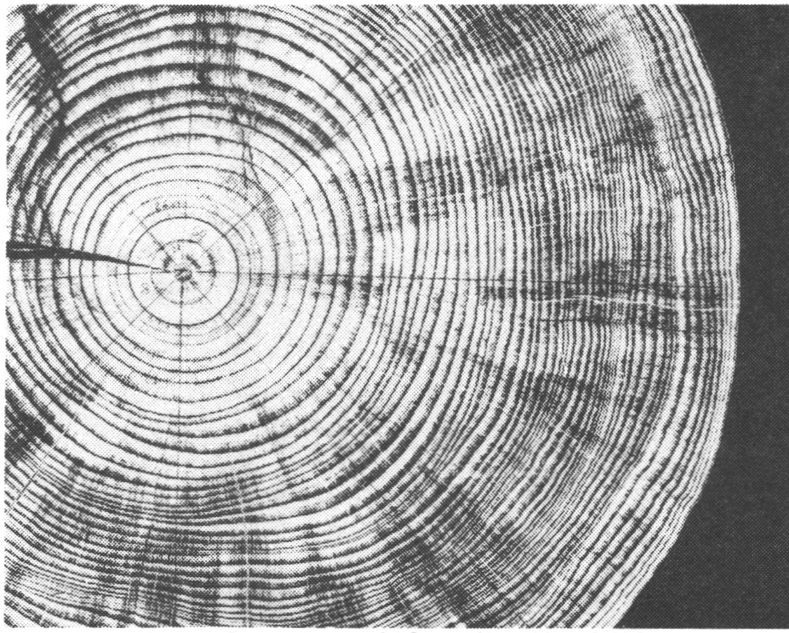

Fig. 2. Cross section from tree 912. Note the high variation in the ring pattern in different sides of the tree.

## 2.2. Standardizing

The tree-ring series can be considered as time series with certain frequency domain properties. This domain is composed of four different kinds of signals that are recognizable. Let $R_t$ be the measured ring width in year t, then

$$R_t = C_t + B_t + D_t + a_t, \qquad (1)$$

where $C_t$ is the micro- and macroclimatic signal common to all trees at a site, $B_t$ is the biological growth curve as a function of increasing tree age, $D_t$ is the tree disturbance signal, i.e. due to individual or common random effects, and $a_t$ is the white noise (error) term (Graybill 1982).

In order to remove growth trend effects, $B_t$, and to allow the detection of common variation in ring-width sequence, individual tree-ring sequences were standardized by fitting negative exponential or straight line with negative slope through each series of ring widths. This was performed for each radius separately. When each ring width, $R_t$, is divided by the value of the fitted curve, $F_t$, the tree-ring index, $Y_t$, for each radius is obtained, i.e.

$$Y_t = R_t/F_t, \qquad (2)$$

where $F_t$ is the expected annual growth determined from the fitted growth model.

In the first phase, the ring series of each radius was detrended and an index calculated. Subsequently, the mean indices for the trees and for the stand were computed.

## 2.3. Descriptive statistics

As a first phase of analysis, three basic statistical parameters were computed: standard deviation, mean sensitivity, and autocorrelation.

Mean sensitivity, $ms_y$, is a measure of the relative change in the ring-width index, $Y_t$, from one year to the next, and reflets the proportion of high-frequency variance in the ring-series. It is calculated as

$$ms_y = \frac{1}{n-1} \sum_{t=1}^{t=n-1} \left| \frac{2(y_{t+1}-y_t)}{y_{t+1}+y_t} \right| . \qquad (3)$$

Auto-correlation function gives a measure of persistence between the adjacent observations in a time series. It describes the non-randomness and reflects thus the proportion of low-frequency variance in the ring-series, $Y_t$. The estimate of the auto-correlation function, $r_{yy}(k)$, of a series $Y_t$ at lag k is

$$r_{yy}(k) = \frac{c_{yy}(k)}{c_{yy}(0)}, \qquad (4)$$

where $C_{yy}(k)$ is the estimate of the auto-covariance function at lag k given by

$$C_{yy}(k) = (1/n) \quad (y_t-y)(y_{t+k}-y), \quad k = 0,1,2\ldots . \qquad (5)$$

The consistency of the tree-ring sequence within the trees was studied by means of the estimated correlation coefficients between the widths of annual rings of individual radii. The mean value for all pairs of radii in each tree was computed, too.

For between-the-tree analysis, correlation coefficients of the index series for all pairs of trees were calculated using the data from the years 1930 to 1980. In addition, an overall mean correlation coeficient was computed.

# 3. RESULTS AND DISCUSSION

Figure 3 shows the removal of growth trend effects by fitted negative exponential growth curve. For the trees 910 and 913, only 5 and 7 radii, respectively, were identified due to wood defects.

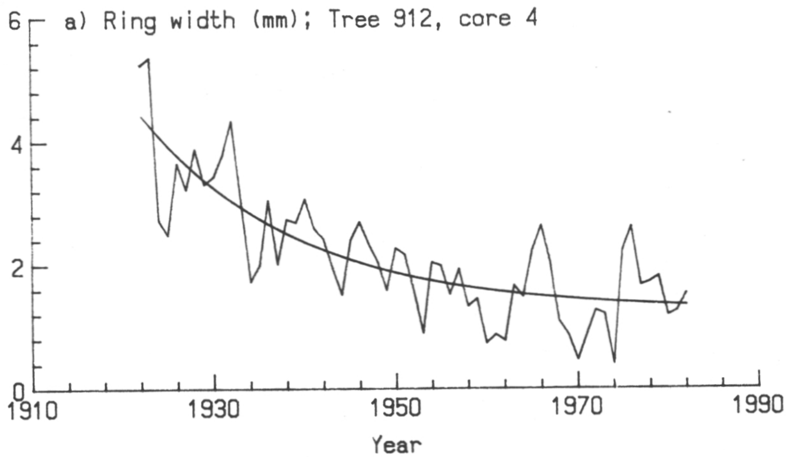


Fig. 3a. Measured ring widths (mm) of tree 912, core 4, and fitted negative exponential growth curve.

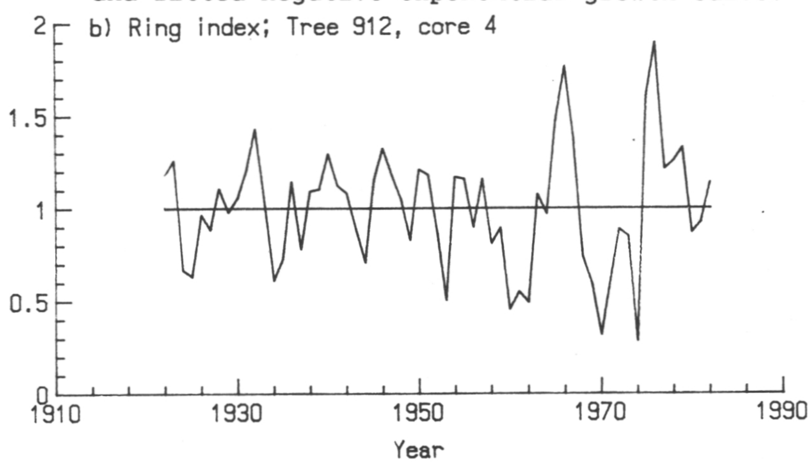


Fig. 3b. Ring index for tree 912, core 4.

The calculated correlation coefficients of the ring width series between the radii of individual trees revealed that within the tree variation may be large in some cases (Table 1). The mean intracorrelation coefficient calculated for each tree varied between 0.577 and 0.891. Although there are trees with high intracorrelations (e.g. tree 914; r=0.891), others show low values (e.g. tree 802; r=0.577) as a consequence of even lower values between the paired radii (e.g. radii 1 x 6, r=0.173; radii 4 x 6, r=0.365). For visual comparison, Fig. 4 shows the index series of the eight radii of trees 802 and 914.

The observed variation is apparently due to variations in the gambial activity at different sides of the stem (see also Fig. 2). Usually, such behaviour is detected with trees having irregular crowns or injuries (Fritts 1976). In the case of Araucaria angustifolia, it may also reflect variations in the development of the tree crown, causing abrupt changes in the flow of carbohydrates to the growing tissue.

Table 1. Correlation coefficients of the widths of annual rings between the paired radii of the sample trees.

| Radii | Tree | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 801 | 802 | 905 | 909 | 910 | 911 | 912 | 913 | 914 |
| 1 x 2 | .740 | .475 | .768 | .742 | .341 | .900 | .565 | .576 | .892 |
| 1 x 3 | .734 | .505 | .717 | .621 | .241 | .891 | .605 | .574 | .858 |
| 1 x 4 | .731 | .655 | .737 | .652 | .353 | .792 | .650 | .428 | .876 |
| 1 x 5 | .646 | .499 | .709 | .604 | .459 | .770 | .658 | .438 | .797 |
| 1 x 6 | .726 | .173 | .707 | .359 | - | .630 | .458 | .559 | .806 |
| 1 x 7 | .697 | .542 | .674 | .451 | - | .847 | .401 | .582 | .869 |
| 1 x 8 | .872 | .707 | .800 | .690 | - | .862 | .668 | - | .927 |
| 2 x 3 | .677 | .642 | .842 | .786 | .648 | .927 | .773 | .870 | .920 |
| 2 x 4 | .727 | .488 | .821 | .644 | .678 | .678 | .546 | .721 | .917 |
| 2 x 5 | .609 | .529 | .744 | .690 | .778 | .695 | .678 | .696 | .907 |
| 2 x 6 | .666 | .666 | .773 | .540 | - | .812 | .813 | .670 | .880 |
| 2 x 7 | .640 | .597 | .763 | .588 | - | .899 | .669 | .588 | .921 |
| 2 x 8 | .648 | .491 | .771 | .583 | - | .850 | .521 | - | .861 |
| 3 x 4 | .712 | .684 | .894 | .749 | .944 | .775 | .784 | .866 | .936 |
| 3 x 5 | .609 | .584 | .818 | .696 | .891 | .776 | .655 | .833 | .888 |
| 3 x 6 | .693 | .554 | .876 | .499 | - | .838 | .727 | .799 | .860 |
| 3 x 7 | .719 | .750 | .755 | .664 | - | .907 | .628 | .674 | .914 |
| 3 x 8 | .722 | .735 | .695 | .665 | - | .885 | .673 | - | .883 |
| 4 x 5 | .721 | .722 | .890 | .882 | .957 | .941 | .771 | .906 | .932 |
| 4 x 6 | .696 | .365 | .905 | .512 | - | .821 | .542 | .806 | .900 |
| 4 x 7 | .709 | .580 | .808 | .577 | - | .747 | .491 | .657 | .917 |
| 4 x 8 | .780 | .742 | .755 | .588 | - | .838 | .703 | - | .901 |
| 5 x 6 | .661 | .575 | .863 | .640 | - | .897 | .636 | .865 | .954 |
| 5 x 7 | .730 | .496 | .685 | .582 | - | .790 | .476 | .768 | .915 |
| 5 x 8 | .694 | .651 | .738 | .556 | - | .828 | .551 | - | .836 |
| 6 x 7 | .749 | .620 | .771 | .684 | - | .913 | .704 | .868 | .947 |
| 6 x 8 | .700 | .397 | .723 | .357 | - | .851 | .576 | - | .833 |
| 7 x 8 | .718 | .740 | .716 | .453 | - | .910 | .515 | - | .896 |
| Mean | .704 | .577 | .776 | .609 | .629 | .836 | .623 | .711 | .891 |

The mean index series of the nine trees showed similarity in their pattern (Fig. 5). However, differences in their statistical properties were observed (Table 2), e.g. tree 910 showed pronounced variation in comparison to other trees or the stand mean. The estimated autocorrelation coefficients at lag 1 were significant and varied between 0.30 and 0.69 except for tree 914, which differed from the rest of the studied trees.

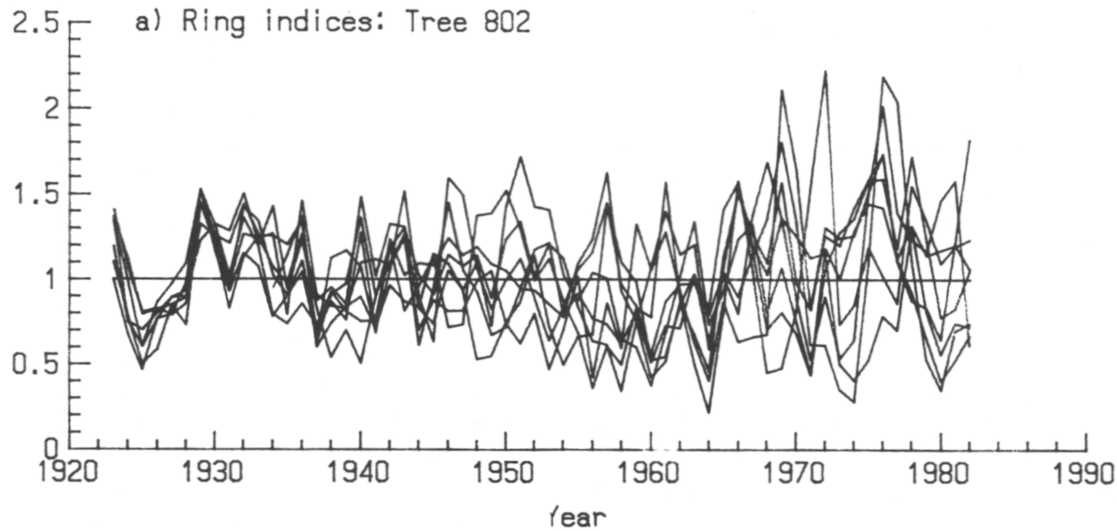


Fig. 4a. Ring indices of the eight radii (r1-r8) for the trees 802.

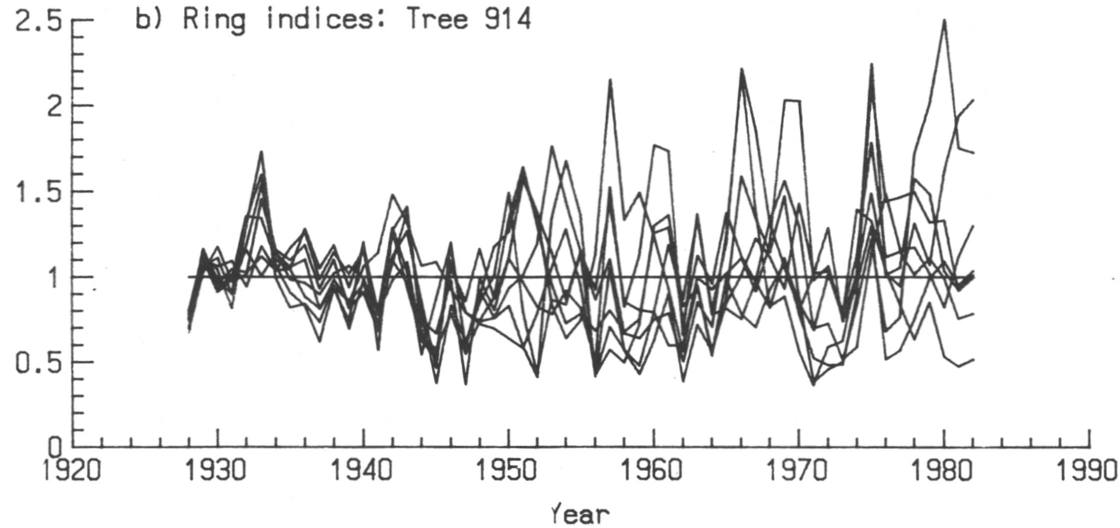


Fig. 4b. Ring indices of the eight radii (r1-r8) for the trees 914.

The correlation coefficient of the index series between the trees varied from 0.24 to 0.78 (Table 3). The mean correlation coefficient for all pairs of trees was 0.56 indicating consistency between the trees.

Table 2. General statistics of ring width and index series.

| Statistic | Tree | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 801 | 802 | 905 | 909 | 910 | 911 | 912 | 913 | 914 |
| General: | | | | | | | | | |
| Number of years | 86 | 60 | 62 | 65 | 81 | 65 | 61 | 51 | 55 |
| Number of radii measured | 8 | 8 | 8 | 8 | 5 | 8 | 8 | 7 | 8 |
| Ring width: | | | | | | | | | |
| Mean ring width, mm | 3.15 | 2.43 | 3.56 | 2.55 | 2.55 | 1.93 | 2.09 | 2.71 | 2.19 |
| Std. deviation, mm | 0.14 | 0.48 | 0.31 | 0.41 | 0.30 | 0.23 | 0.15 | 0.24 | 0.21 |
| Coefficient of variation | 0.04 | 0.20 | 0.09 | 0.16 | 0.12 | 0.12 | 0.07 | 0.09 | 0.10 |
| Mean sensitivity | 0.33 | 0.31 | 0.25 | 0.29 | 0.34 | 0.29 | 0.37 | 0.27 | 0.32 |
| Ring index: | | | | | | | | | |
| Mean index | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Standard deviation | 0.24 | 0.19 | 0.18 | 0.19 | 0.36 | 0.22 | 0.23 | 0.16 | 0.20 |
| Autocorrelation coefficient at lag 1 | 0.46 | 0.30 | 0.48 | 0.47 | 0.69 | 0.50 | 0.41 | 0.51 | 0.16 |

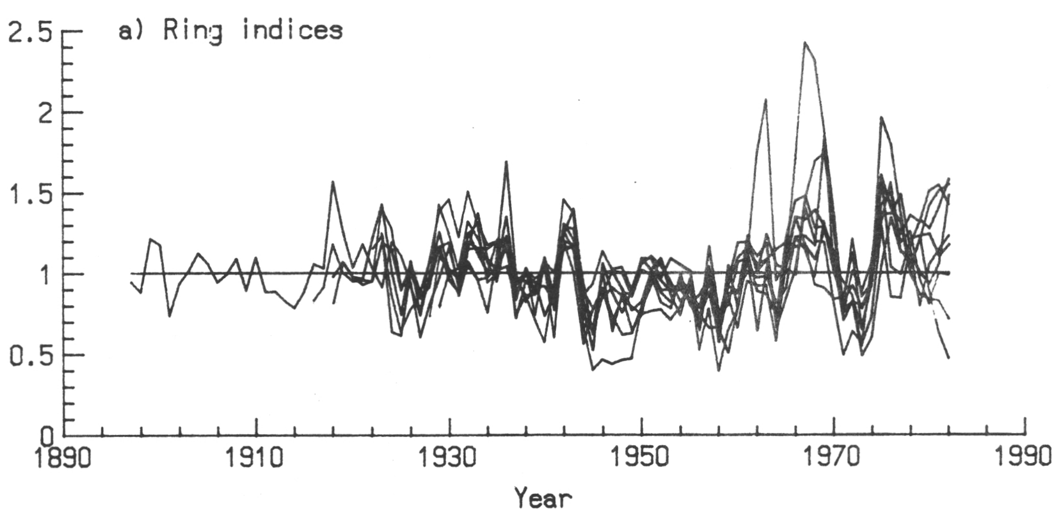


**Fig. 5a. Ring indices for all the individual trees studied.**

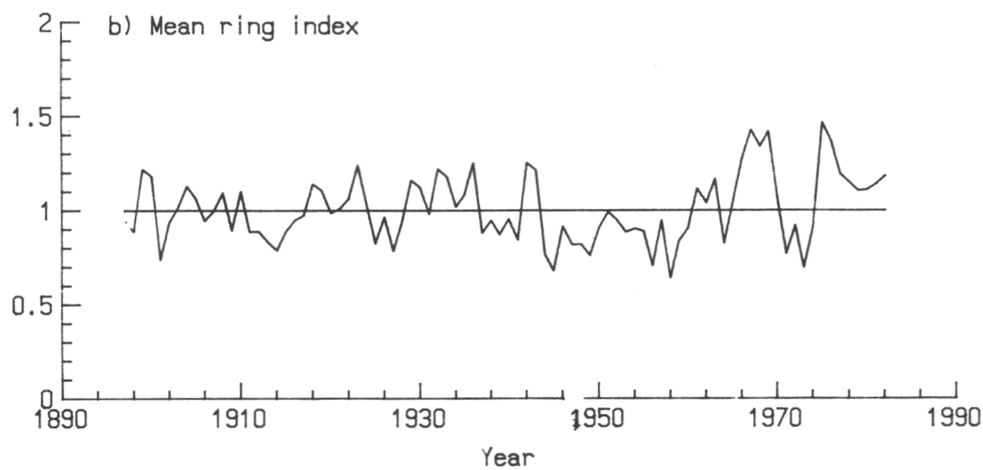


Fig. 5b. Mean index for the study stand.

The estimated autocorrelation function for the mean index of the stand had a significant value at lag 1 (Fig. 6), indicating persistence in the series, which is probably due to the role of stored carbohydrates in the gambial activity (e.g. Fritts 1976).

Table 3. Correlation coefficients between the tree mean indices for period 1920-1980.

| Tree | 801 | 802 | 905 | 909 | 910 | 911 | 912 | 913 |
|---|---|---|---|---|---|---|---|---|
| 802 | .60 | | | | | | | |
| 905 | .78 | .68 | | | | | | |
| 909 | .63 | .61 | .77 | | | | | |
| 910 | .50 | .42 | .56 | .74 | | | | |
| 911 | .48 | .49 | .52 | .67 | .74 | | | |
| 912 | .24 | .38 | .33 | .53 | .60 | .61 | | |
| 913 | .30 | .35 | .33 | .63 | .55 | .45 | .61 | |
| 914 | .47 | .54 | .56 | .62 | .56 | .57 | .71 | .58 |

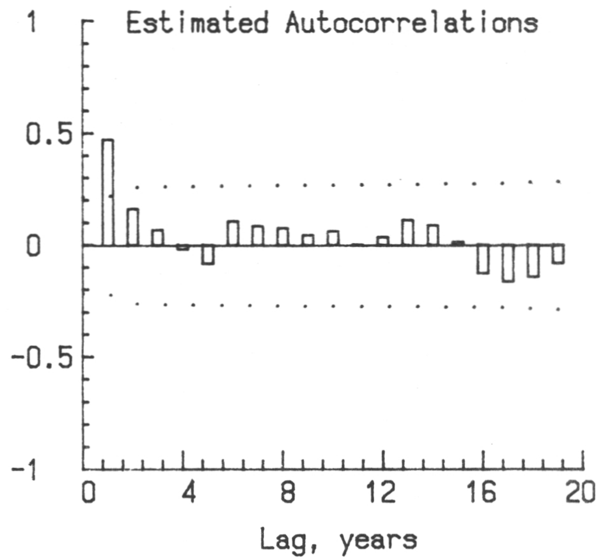


Fig. 6. Autocorrelation function for mean ring index series. Dotted lines represent two standard error limits.

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Total of 4 references

# PRODUCTIVITY AND STRAIN OF WORKERS IN CLEAR-CUTTING OF *EUCALYPTUS* PLANTATIONS IN SOUTH BRAZIL

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## Abstract

Productivity, physical strain, working capasity and energy expenditure of workers were studied when using short wood cutting methods. A new work method with "simplified" piling was developed. Productivity for two-men team varied from 4.5 to 6.7 $m^3/h$ being higher for the new work method. Degree of strain was in average 40.2 % for the new method and 61.5 % for the old one. Work capasity of workers according to max. $O_2$-uptake ability was rather good, in average 53.3 ml/min.kg and energy expenditure 14 400 kJ per 8 h shift. These last mentioned figures based on sub-maximal tests and reliability of them is not very good. Further development of work methods and need of studies were discussed.

CONTENTS

# 1. INTRODUCTION

Scandinavian type of short-wood cutting methods have been introduced in logging of plantations in Brazil. At the same time when productivity has increased, ergonomical problems have arised as a result of the way of applying these methods. Manual piling seems to be one of the main problems because of the weight of the Eucalyptus logs. Therefore, it was chosen to be the first work method for ergonomical and productivity analyses.

The ergonomics may be seen as a scientific study of the relationship between man and work including working conditions, work methods, machines and tools, material to be handled and work organization. Relations and information between people is also an important factor. Work capasity of workers is a basic information which is insufficiently known. The size, power, weight, motivation, skill and psycho-physiological work capasity are all influencing on productivity and strain of worker. Earlier in Nordic forest work studies the maximum oxygen uptake capasity has correlated quite well with productivity of cutting work and strain of worker (Hansson 1965, Harstela 1975).

In this study productivity, physical strain of worker, physical work capasity and energy expenditure of workers were studied and work methods were tried to develop ergonomically. Future activities in the field of work studies and in developing the logging of Eucalyptus plantations are recommended.

# 2. METHODS AND MATERIAL

## 2.1. Research methods

A time study was made manually by stop-watch method (uninterrupted method) separating different time elements according to the system descriped in the next sub-chapter. At the same time a heart rate was measured by the Sport Tester PE-2000 equipment. This based on sampling after every 5 minutes. The observation of heart rate was recorded for the work element just going on.

Teams of a motor saw operator and a helper were studied. Every worker was under studying at least for one day. Then all activities belonging to the work were registered. The productivity was calculated for a team and for getting productivity per person, one has to devide figures presented in this study into two parts.

The maximum oxygen uptake was determined by a step test using the bench height of 40 cm and 22 and 25 steps per minute. For estimating the maximum $O_2$-uptake nomograms presented by Åstrand and Ryhming (1954) were used. The energy consumption during the work day was determined by the average heart rate using the regression between heart rate and work load in the step test as a bases. Calories-consumption was estimated according to the nomogram presented by Margaria et al. (1965).

## 2.2. Work and time elements

Because of the variation in work conditions, methods and ways of working of individual worker, it is not easy to standardize the description of work for forest works. Often the following work elements however are defined:

Motor-saw operator:

- Clearing the butt of a tree, taking down epiphytes and clearing the way back.
- Felling; motor-saw Husqvarna 162 s, stump height 0,0-0,3 m (for normal trees).
- Lowering the stump, the stand where coppice system is practiced. Then, lowering into 0,0 m stump height is required.
- Delimbing by axe and clearing of removals for later cross-cutting
- Cross-cutting after delimbing into 2,40 m bolts up to minimum diameter by motor-saw.
- Piling into piles, where ends of bolts are at the same line (work method one) or by straightening them away from the strip road (work method two).
- Moving during the work in the stand.
- By-times: work times which do not influence direct on the object of the work such as maintenance of motor-saw, sharpening of chain, etc.
- Delay times (unavoidable delay times such as personal times).

Helper:

- Clearing the butt together with the motor-saw operator
- Delimbing " "
- Piling " "
- Moving during the work in the stand "
- Helping the felling: directing the trees manually or by the special tool
- By-times
- Delay times

When recording, the work time was devided into time elements according to the above descriped work elements. The total time also was devided into two main categories:

- Effective main time, which directly influences on the object of the work. During the effective main time the work ability of a worker can be fully utilized.
- General times which do not influence directly on the object of the work. They include by times and delay times.

## 2.3. Working conditions and research material

The data was collected from the four different work sites during the years 1985-1986. The main characteristics of the sites are presented in Table 1.

Table 1. Working conditions

| Work site | Cutt-ing method | Planting distances, m | Stand density trees/ha | D1,3 cm | Volume $m^3$/tree | $m^3$/ha | Terrain and coppice features |
|---|---|---|---|---|---|---|---|
| 1 | 1 | | | | | | Soil surface: eaven Medium steep terrain (0-10%). Single trees |
| 2 | 2 | 2,5x1,7 | 200 | 15,2 | 0,222 | 444 | Soil surface: eaven Medium steep terrain Single trees |
| 3 | 2 | 2,5x1,7 | 1249 | 16,1 | 0,221 | 276 | From medium to steep terrain |
| 4 | 2 | 3,0x1,6 | 1327 | 16,0 | 0,217 | 288 | Rather even terrain Coppice, 1-5 stems/stump |

These <u>Eucalyptus grandis</u> stands were planted in 1974/75 or in 1975. A good lunch was served by the employer for the workers, which guaranteeded a reasonable energy intake. The peace rate payment system was used.

The main characteristics of workers can be seen in Table 3. A material of a working team consisted of 236-483 trees.

## 2.4. Work methods

Work method one was composed of the work elements mentioned in chapter 2.2. Piling was done according to the Fig. 1 into piles on both sides of the strip road; All butts in the same line and piles just parallel with the direction of a strip road.

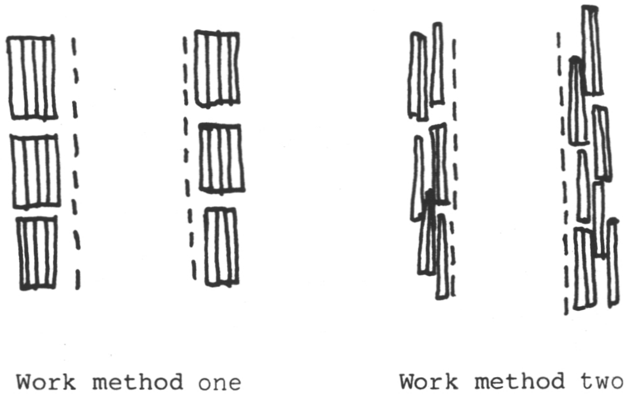


**Fig. 1. Piling in work method one and two.**

As seen in chapter 3.3. the piling in work method one was very heavy work and distinctively heavier than the other work elements (Fig. 2). Therefore an attempt was made to make it easier by simplifying the piling in work method two. According to the Figure 1 all bolts were only moved and straightened on both sides of the strip road, but no actual piling was done. It was assumed that this does not affect harmfully on manual loading. The effect on mechanized loading should be studied and if needed, a new way of piling should be planed, which leads into the minimum costs in satisfactory level of ergonomical features (Fig. 3).

Fig. 2. Lifting of bolts is very heavy work element and it is needed especially in work method one.

Fig. 3. In work method two rolling often is adequate mean to move bolts.

## 3. RESULTS AND DISCUSSION

### 3.1. Productivity

Share of time elements and productivity are presented in Table 2. Productivity was calculated for two-men team and per work site time (effective and delay times). Because no rating was made and different workers worked by different methods and in different working sites no reliable comparision can be done between work methods and work conditions. However mean productivity for two men team 4,6 $m^3$/h in work method one was lower than that of work method two 4,8 $m^3$/h. According to the share of effective main time, the piling has required 15 %-units more of the working time in work method one than in work method two. According to this, difference in productivity probably is bigger than productivity figures indicate.

Table 2. Productivity and share of working time.

| Works nr. | Work site | Effective main time in per cent | | | | | Delay time and by-time % 1) | Productivity, m /h |
|---|---|---|---|---|---|---|---|---|
| | | Felling | Cross-Cutting/ 2) Delimbing 2) | Moving | Piling | Total | | |
| | | Work method one, work site 1 | | | | | | |
| 1 | 1 | 25,6 | 26,7 | 3,1 | 44,6 | 100 | 16,2 | 4,56 |
| 2 | 1 | 31,0 | 37,2 | 6,0 | 25,8 | 100 | 23,7 | 4,55 |
| $\bar{x}$ | | 28,3 | 32,9 | 4,6 | 35,2 | 100 | 20,0 | 4,56 |
| | | Work method two, | | | | | | |
| 3 | 3 | 22,6 | 48,2 | 11,3 | 17,8 | 100 | 25,9 | 4,77 |
| 4 | 2 | 23,5 | 51,6 | 6,1 | 18,7 | 100 | 13,2 | 5,77 |
| 5 | 4 | 47,9 | 44,5 | 7,9 | - | 100 | 21,7 | 5,33 |
| 6 | 4 | 18,6 | 33,6 | 3,2 | 44,6 | 100 | 14,6 | 5,09 |
| 7 | 4 | 34,0 | 42,3 | 11,2 | 12,5 | 100 | 26,5 | 6,25 |
| 8 | 4 | 20,4 | 45,5 | 3,4 | 30,7 | 100 | 14,1 | 5,65 |
| 9 | 3 | 19,7 | 48,9 | 15,4 | 16,1 | 100 | 29,7 | 5,36 |
| 10 | 3 | 18,8 | 55,0 | 4,8 | 21,4 | 100 | 26,0 | 5,15 |
| 11 | 3 | 24,8 | 49,4 | 9,4 | 16,4 | 100 | 32,1 | 6,67 |
| 12 | 3 | 16,8 | 48,7 | 7,5 | 27,1 | 100 | 20,9 | 3,45 |
| 13 | 3 | 31,5 | 50,9 | 13,8 | 3,9 | 100 | 34,0 | 3,26 |
| 14 | 3 | 14,3 | 60,0 | 3,2 | 22,5 | 100 | 22,6 | 3,90 |
| 15 | 4 | 38,0 | 46,8 | 14,0 | 1,3 | 100 | 38,8 | 5,33 |
| 16 | 4 | 10,4 | 45,8 | 5,2 | 38,6 | 100 | 24,1 | - |
| 17 | 3 | 26,0 | 51,1 | 14,8 | 8,1 | 100 | 26,6 | 6,65 |
| 18 | 3 | 11,2 | 32,8 | 11,4 | 44,7 | 100 | 14,2 | 4,72 |
| 19 | 4 | 24,7 | 45,5 | 7,0 | 22,9 | 100 | 24,0 | 4,79 |
| 20 | 4 | 23,4 | 53,3 | 0,5 | 22,8 | 100 | 24,4 | 5,13 |
| $\bar{x}$ | | 23,7 | 47,4 | 8,3 | 20,6 | 100 | 24,1 | 4,79 |

1) per cent of the total work site time      h = work-site time
2) cross-cutting for a operator
   delimbing for a helper

According to the Fig. 4 the variation of productivity is quite big, but no significantly dependent variables were found in regression analyses. The main reason for variation may be the skill of workers, but age seems also to have some influence (Fig. 5). All workers with the productivity above 6 $m^3$/h are young peoples (under 30). On the other hand, variation of the productivity is quite big even in this age class and this may be due to the skill of workers. Exceptionally from Scandinavian studies a physical work capasity did not explain the productivity.

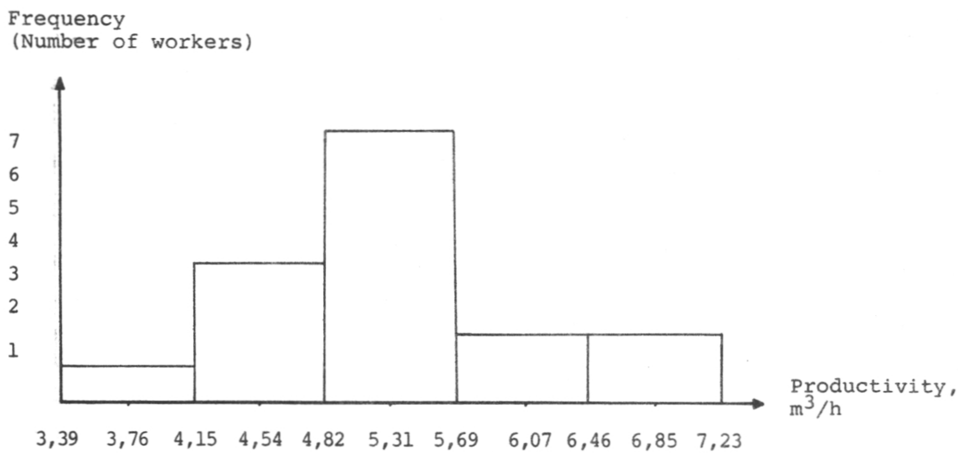


**Fig. 4. The share of productivity.**

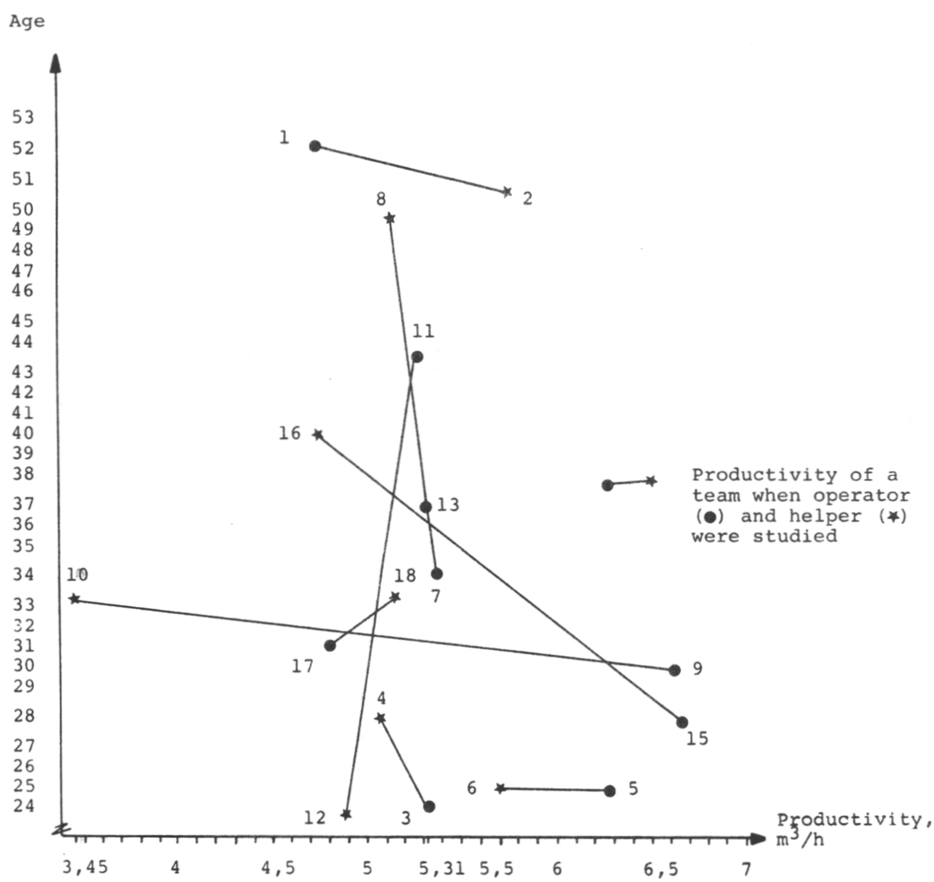


**Fig. 5. Relation between productivity and age of workers.**

Because of the variation of conditions, work methods, work organization and composition of teams, it is not easy to compare the productivity with other studies. But in average it is inside the variation limits of the FAO report for trained workers (Fåhraeus 1974).

## 3.2. Working capasity and energy expenditure of workers

Main charateristics of workers are given in Table 3. Both age and weight vary very widely. The variation of weight from 53 kg to 82 kg indicates the heterogenity of the Brazilian population. An average of maximum oxygen uptake ($VO_2$ max.) 54 ml/min kg is rather high. As a comparision $VO_2$ max. of 'normal' forest worker has been in Sweden ca. 44 ml/min kg and that of 'top men' 8 ml higher (Hansson 1965). In Finland and in Norway $VO_2$ max. of forest workers have been in same level as in Sweden (Samset et al. 1969, Harstela 1975). In India they found the work capasity between 43 and 49 ml/min kg and in Chile as a mean 53 ml/min kg (Hansson et al. 1966, Abud and Valdes 1986).

Although sub-maximal test is not very reliable, because nomograms to be used base on the data of the population from another part of the world, the figures indicate rather good oxygen uptake capasity. A big amount of subjects is in itself good bases for using sub-maximal tests. $VO_2$ max. have had a good correlation with productivity (Hansson 1965, Harstela 1975), although in this study this kind of correlation has not been found. This may be due to the small variation in average $VO_2$ max. of work teams and to big variation of the skill. Because productivity is a sum of output of two men, the $VO_2$ max. has to be looked as an average of these two men, too.

The method to estimate the energy expenditure was also rather rough. Therefore these results have to be studied by way of reserve. An average energy consumption of 14 300-17 100 kJ (3400-4100 kcal) per 8 hours shift is rather high. In Finland the energy expenditure per time unit during the work has been even higher (ca. 13 000 kJ/shift), but the lenght of the shift was only 6 hours (Kukkonen-Harjula and Rauramaa 1984). On the other hand in Central-Europe and in Tanzania energy expenditures have been clearly lower (Buchnerger 1978, Scholz and Wilhelmi 1975, Saarilahti and Ole-Meiludie 1986). In Chile energy expenditure of cutting and planting works was even higher per minute, but expenditure per shift lower (9 700-10 800 kJ) (Abud and Valdes 1986). This may be due to that in Chile bigger part of the shift is used for rest pauses or for some lighter activities.

Table 3. Working capasity and strain of workers.

| Worker nr. | Work | Age | Weight, kg | Step test, heart rate Rest | steps/minute 22 | 25 | Heart rate, in work, mean | Energy output kJ/work day (8h) | Kcal/8h | $VO_2$max. ml/min kg | Degree of strain, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Work method one | | | | | | | |
| 1 | o | 38 | 56 | - | 128 | 135 | 136,5 | 18 483 | 4 422 | 51,6 | 63 |
| 2 | h | 35 | 61 | - | 148 | 162 | 132,1 | 15 666 | 3 748 | 41,4 | 60 |
| $\bar{x}$ | | | | | | | | 17 075 | 4 085 | 46,5 | 61,5 |
| | | | | Work method two | | | | | | | |
| 3 | o | 52 | 79 | 64 | 118 | 127 | 109,4 | 19 592 | 4 687 | - | 46 |
| 4 | h | 50 | 59 | 56 | 101 | 113 | 109,7 | 17 303 | 4 139 | - | - |
| 5 | o | 24 | 62 | 62 | 138 | 133 | 119,2 | 15 612 | 3 735 | 51,6 | 47 |
| 6 | h | 28 | 63 | 75 | 142 | 161 | 134,1 | 17 569 | 4 203 | 47,6 | 57 |
| 7 | o | 25 | 58 | 66 | 138 | 143 | 119,9 | 10 473 | 2 506 | 51,7 | 37 |
| 8 | h | 25 | 62,5 | 71 | 145 | 160 | 102,9 | 11 032 | 2 639 | 46,4 | 38 |
| 9 | o | 34 | 82 | 68 | 116 | 125 | 106,6 | 19 950 | 4 773 | 62,2 | 37 |
| 10 | h | 49 | 67 | 76 | 124 | 134 | 116,3 | 17 946 | 4 293 | 47,8 | 53 |
| 11 | o | 30 | 56 | 68 | 128 | 141 | 102,4 | 11 031 | 2 639 | 55,4 | 35 |
| 12 | h | 33 | 58 | 68 | 151 | 171 | 133,1 | 15 303 | 3 661 | 44,8 | 50 |
| 13 | o | 43 | 64 | 54 | 116 | 129 | 99,4 | 16 244 | 3 886 | 64,1 | 32 |
| 14 | h | 24 | 56 | 54 | 136 | 156 | 112,0 | 13 466 | 3 222 | 51,8 | 45 |
| 15 | o | 37 | 51 | 52 | 126 | 159 | 95,1 | 11 394 | 2 726 | 54,9 | 39 |
| 16 | h | 36 | 65 | 64 | 119 | 134 | 104,3 | 14 522 | 3 474 | 63,1 | 37 |
| 17 | o | 28 | 69 | 64 | 133 | 142 | 101,2 | 10 885 | 2 604 | 50,7 | 31 |
| 18 | h | 40 | 59 | 70 | 120 | 135 | 109,5 | 15 022 | 3 594 | 59,3 | 40 |
| 19 | o | 31 | 66,5 | 55 | 126 | 137 | 95,2 | 11 681 | 2 795 | 57,1 | 29 |
| 20 | h | 33 | 61 | 54 | 145 | 157 | 102,6 | 9 571 | 2 289 | 44,3 | 33 |
| $\bar{x}$ | | 33,7 | 63,5 | 63,7 | 130,7 | 144,9 | 109,6 | 14 366 | 3 437 | 53,3 | 40,2 |

The energy expenditure was explained by a regression analyses and the following equation with statistically significant variables was achieved:

$$y = -9{,}55+0{,}26x_1^{**}+0{,}20x_2^{**} \qquad R=0{,}66 \qquad (1)$$

when $y$ = energy expenditure, kJ
$x_1$ = weight of worker, kg
$x_2$ = degree of strain, %

The weight of worker and degree of strain have influenced on energy expenditure, but the productivity did not. Again, it may be due to the variation of skill.

## 3.3. Strain of workers

An average heart rate of workers was 134 in work method one and 110 in work method two (see Table 3). In these numbers also short rest pauses, maintenance of tools and delay times were included. Therefore figures for effective work should be higher. A degree of strain calculated in per cent of the $VO_2$ max. was 61,5 % in work method one and 40,2 % in work method two. This indicator in work method one exceeds recommendations made for eight hours work day. According to a regression analyses only maximum oxygen uptake ability explained the degree of strain:

$$y = 89{,}9-0{,}65x_1^{*} \qquad R=0{,}12 \qquad (2)$$

$y$ = degree of strain, %
$x_1$ = max. $O_2$-uptake, ml/min kg

The correlation was rather weak, but the results suits to the theory that physical capasity is the main factor, which influence on the strain of worker in cutting work. However, workers have not used this higher work capasity for bigger productivity as seems to be in Scandinavian logging when using piece rate payment system.

The strain of workers in work method two seems to be just in the upper limit of the recommendation. Different researchers have presented 35-50% as an upper limit for 8 h shift. Andersen et al. (1970) came into the opinion that 40 % should be a suitable limit for forest workers. Situation has been much a like for instance in Finland where piece rate payment system maintains quite high work motivation. In different Finnish studies degree of strain has been varied from 39 to 69 % (e.g. Harstela 1975, Harstela and Vuorinen 1977). On the other hand, work shift has been only 6-7 hours. In Norway degree of strain has varied much a like in Finland, but for instance in Tanzanian study it was between 34-37 % (Samset et al. 1969, Saarilahti and Ole-Meiludie 1986). In Tanzania the daily task payment system was used.

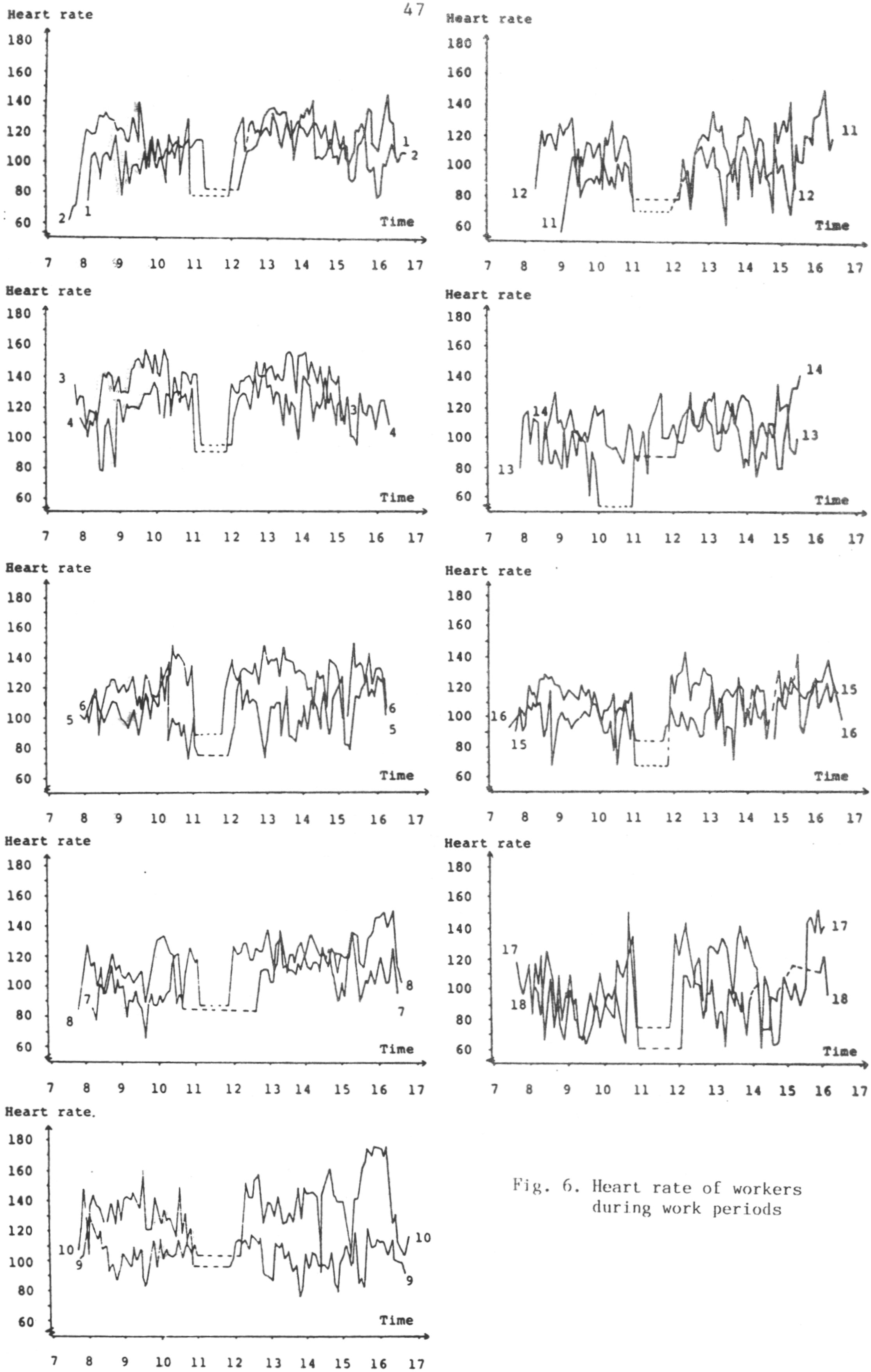


Fig. 6. Heart rate of workers during work periods

Differency between work methods can be seen in the share of heart rate by work elements as an average of all workers:

| | Work method one | | Work method two | |
|---|---|---|---|---|
| | Operator | Helper | Operator | Helper |
| Moving | 131,9 | 125,0 | - | - |
| Felling | 139,1 | 113,5 | 110,8 | 104,9 |
| Delimbing | - | 137,1 | - | 119,2 |
| Cross-cutting | 121,9 | - | 108,7 | - |
| Piling | 156,3 | 139,9 | 121,8 | 125,1 |

The piling is the heaviest work element in both methods and it influences also on other work elements, because recovery does not fully happen because of the "oxygen depth". Because different workers worked with different work methods, the comparision of work methods is not very reliable. However the figures of piling are relatively higher in work method one than in work method two compared with the other work elements. Bigger degree of strain in work method one confirms this conclusion.

This result suits very well with the former Scandinavian studies. The piling has always been the heaviest work element, and "simplifying" of it by reducing the moving distances of bolts has decreased the strain of workers remarkably (e.g. Harstela 1977).

The heart rate measures mainly the strain of circulatory system and it has strong correlation with the energy consumption. A heavy work may cause another kind of strain, too. One very important factor is the strain of skeletal system, especially strain of the back. Because piling contains of the heavy lifting, pulling and carrying, the strain of skeletal system is high: The lifting is the most harmful phase of carrying, which can be seen in the EMG of the back muscles (e.g. Harstela 1978). On the other hand carrying distance has a clear influence on energy consumption (Harstela 1977). When piling is simplified the carrying distance decreases. At the same time most bolts may stay in their felling place or can be only straightened or rolled instead of lifting and carrying, and strain of skeletal system decreases.

In this study no symptoms of over strain in circulatory system were measured. The level of heart rate in different part of work period may indicate the physiological state of the body (Fig 6). For instance, Lungren (1946) found out that heart rate of forest workers was in higher level at the end of the working day than in the beginning with the same level of work load. A work rate may change during the work period but such a hypotheses is presented that decreasing tendency of a heart rate after increasing one could indicate fatigue (Harstela and Vuorinen 1977). In any case great individual variation exists in this respect (Harstela 1975, Harstela and Vuorinen 1977).

In this study changes in heart rate during the work period seem also to be rather individual. In most cases in the later part of the work period a descending phase exists after a ascending one, and all workers with high degree of strain have this kind of tendency. Reliable tests should be needed to ascertain if this is over-strain phenomen or not.

### 3.4. Further development of the work

Work method two is more profitable method, if one looks at only the cutting work. It was assumed that it has no influence on manual loading of tractors or trucks. This however should be studied. Also an influence on mechanized loading should be studied. So it is possible to calculate if the benefits in the cutting phase are bigger or smaller than disadvantages in the loading.

It has also to be remembered that "simplifying" of piling can be done by several ways. Some kind of optimal solution for mechanized loading could be such a piling, where only small heaps are made (Fig. 7). Biggest bolts may be stay on it's place or rolled away from strip road. The medium size of bolts can be straightened and pulled side by side the bigger bolts and smallest one can be carryied on the bigger bolts. So small heaps are formed, which are big enough to be a optimal burden for a grapple loader (compare: Harstela 1978). In Eucalyptus plantations amount of timber may be quite big and most bolts are rather heavy ones. So, some difficulties may exist in applying this, but without studies one is not able to make it sure.

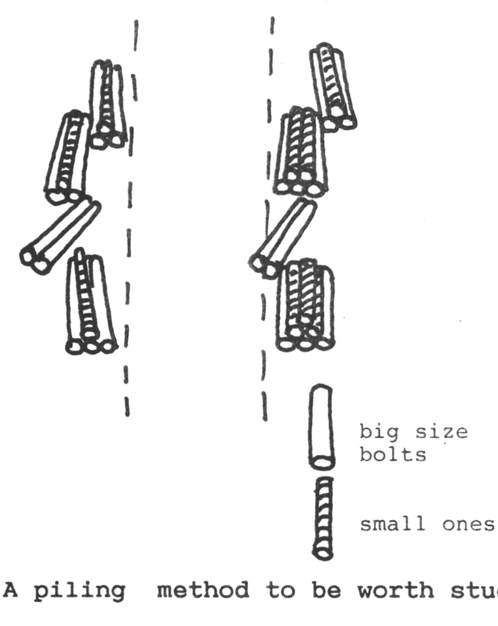


Fig. 7. A piling method to be worth studying.

## 4. CONCLUSIONS

The main ergonomic problem in the cutting of Eucalyptus plantations is heavy piling. Method two in this study solves the problem, when manual loading of further transport is used. How to solve this problem is connection with the mechanized loading, needs more studies.

On the other hand, piling creates more variation to the work. Especially motor saw operator requires other kind of work in order to prevent problems of sawing e.g. static muscular load. But piling must be designed to be moderate as to the strain.

Although this is only a hypotheses, the main source for big variation in productivity is the skill of workers. Therefore training probably would improve productivity and at the same time decrease the strain of workers, if ergonomical principles are taken into account. According to the visual observations for instance dangerous work habits existed in felling, wrong lifting techniques were used and some uneconomical piling techniques were practiced.

Physical fitness of workers to the heavy work was very good according to the submaximal step-test. Degree of strain and energy expenditure were however rather high and this indicates good work motivation and high work rate. The degree of strain was above the common upper limit (40 %) in work method one and just in the limit in work method two. Because no regular rest pauces were practiced over strain may be possible. Short pauses after every hour should be needed and this may influence positively even on productivity, because it hinders fatigue.

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## SUMMARY

After applying short wood cutting methods in Brazil, ergonomical problems have arosen among forest workers. These seemed to be most severe in cutting of Eucalyptus plantations. Therefore it was choosen as an object of this study. Productivity was studied by time studies. The physical strain of workers by heart rate measurements and workers' work capasity and energy expenditure on the bases of sub-maximal step test.

In the former cutting method timber was piled into heaps alongside the strip road. A new method was developed basing on a "simplified" piling by straightening the bolts. Both methods were studied but because different workers worked with different methods and no rating was done, comparisions of these methods are not very reliable.

Productivity of two-men team was in average 4.6 $m^3$/h for the old method and 4.8 $m^3$/h for the new one. According to the share of working time difference should be bigger, ca. 15 %. Degree of strain of workers was in average 61.5 % for the old method and 40.2 % for the new one. Maximum oxygen uptake ability of workers was rather high 53.3 ml/min kg and energy expenditure 14 400 kJ per 8 hours shift.

The piling was the heaviest work element in both work methods. However, it was relatively much more strenous in the old one. Energy expenditure was significantly explained by weight of worker and by degree of strain. Whereas degree of strain was explained by max. $O_2$-uptake.

No variable explained significantly the productivity. This may be due to big variation of workers' skill and small variation of an average work capasity of a team. It was concluded that training should be a good mean to increase productivity and deminish ergonomical problems.

The new method seemed to decrease the strain of circulatory system, but it was concluded to be benefical for skeletal system, too. It solves main problems of cutting work in connection of manual loading of forest transport. When using mechanized loading more studies and development of work methods are required.

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# ENERGY POTENTIAL OF THINNING RESIDUE FROM LOBLOLLY PINE (*Pinus taeda*) PLANTATIONS IN THE STATE OF PARANA, BRAZIL

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## Abstract

The objective of the joint study was to evaluate the amount and energy potential of residual crown mass left on site as residue after thinning operations in loblolly pine (*Pinus taeda*) plantations in the state of Paraná in southern Brazil. A sample of 115 trees was collected from 7-, 10-, and 14-year-old stand of loblolly pine that would be submitted to the 1st, 2nd, and 3rd thinnings. The residual crown mass was classified into the following categories: needles, branches less than 0.7 cm diameter, branches 0.7-2.5 cm diameter, and large branch sections and unmerchantable top 2.5-7.0 cm diameter.

For most crown component and stand type combinations, dry mass was estimated best by a simple logarithmic function based on the use of the breast height diameter as the explaining variable. The total residual dry crown mass in the 1st, 2nd, and 3rd thinnings, was 8.3, 15.0, and 14.0 tons/ha. The energy potential of this residue, including needles, was 3.9, 7.1, and 6.6 toe/ha. When needles were excluded, the energy potential was reduced by one fourth.

CONTENTS

## 1. INTRODUCTION

Wood plays an important role in energy production for mankind. In the developed world, its relative importance as an energy source has decreased rapidly after the discovery of fossil fuels, especially after World War II. In the developing world, however, wood still remains the primary source of energy.

In the United States, for instance, at least three fourths of the energy needs in 1870 were covered by wood. That percentage decreased to 25 in 1900 and further to about 2 in 1972. This trend reversed slightly after the world-wide energy crisis in 1973, and in 1980 wood-derived fuels were responsible for 3 % of the total energy produced in the United States (Smith 1981). In some European countries with large forest coverage, wood maintains an important role as a fuel source. In Finland, for example, wood-derived fuels in 1981 provided 16 % (Hakkila 1984) of the raw material for total primary energy consumption.

In Latin America, the use of wood as a source of energy varies from country to country, according to conditions. There are countries, such as Haiti, where almost 70 % of the primary energy is produced from wood. At the other extreme is Venezuela, a country rich in oil, where wood accounts for only 0.1 % of the total energy produced.

In Brazil, which imports about 40 % of the oil consumed, and which has serious problems with the foreign debt, forest biomass appears to be a growing source of energy. In reply to a government call, several industries are substituting residual wood for imported oil as an energy source. This attitude helps to save foreign currency, decreases the dependence on imported oil, generates new job opportunities, and promotes application of new technologies in the field of silviculture and resource utilization.

Nevertheless, the use of forest residue, although it represents a great potential for the future, is still very limited. Presently, millions of tons of residue and non-commercial trees felled during harvesting operations are left to decompose naturally or burned on site. This residue, if wisely used in accordance with available technology, could significantly contribute to the energy needs of the country.

The objectives of this joint study are: 1) to estimate the amount of forest residue left behind after thinning operations in loblolly pine plantations; 2) to determine the heating value of the biomass components of such residue; and 3) to estimate the energy potential of the residue per unit of area in various types of loblolly pine thinnings in Brazil.

## 2. LITERATURE REVIEW

Even though it is frequently referred to as a fuel from the past, wood is again emerging as an important source of renewable energy for the future. The interest in wood-derived fuel is not restricted to developing countries only, since the potential of renewable forest energy is also significant in a number of industrialized countries rich in forests.

Forest residue left on site after logging operations makes up a potential source of energy that should not be disregarded. According to Phillips (1979), the slightly over 200 millions hectares of forests in the United States contain approximately 25 to 30 billion tons of green biomass. From this total, harvesting operations produce about 170 million tons of dry residue every year (Smith 1981). About 27.5 million $m^3$ logging residue, composed of tree crowns, tops, under-sized trees, and stump-root systems, is left behind after annual logging operations in Finland (Hakkila 1984).

Brazil, has approximately 300 million hectares of indigenous productive forests and 5 million hectares of planted forests (Mendonca Filho 1986). There are no estimates of the total amount of residue generated annually by the exploitation of these forests.

Despite the risk of excessive nutrient exportation, whole-tree harvesting and residue recovery are interesting solutions for increased utilization of unmerchantable biomass reserves as fuel. In order to evaluate the energy potential of forest residue in a certain region, it is necessary to quantify and characterize the resource, to determine the heating value of its biomass components and, finally, to estimate its energy potential per unit of area to be exploited.

### 21. Estimation of crown mass

The above-ground residue left on site after thinning operations in loblolly pine plantations consists of branches, needles, tops, and small non-commercial trees. Although some researchers (Storey et al. 1955, Zavitkovski 1971) found a high correlation between crown mass components and stem diameter at the base of the live crown, the diameter at breast height (DBH) is a more convenient variable for estimating the dry mass of various components of the tree crown (Soares and Hosokawa 1984).

Wade (1969) estimated the mass of dominant and co-dominant tree crowns of loblolly pine in Georgia, U.S.A., through the following equation:

$$\ln \text{crown mass} = a + b \times \ln \text{DBH} \qquad (1)$$

The author concluded that this equation could be used for the whole range of the natural occurrence of this species. Woodard (1974), working with Douglas fir (Pseudotsuga menziesii) of different ages and on several sites, also used the same type of equation for estimating the dry mass of branches and foliage.

Pinheiro and Soares (1983) tested 15 independent variables, 3 single (DBH, total height, and commercial height) and 12 combinations of the singles, to estimate the mass of several crown components of Pinus caribaea and Pinus oocarpa in the State of Minas Gerais, Brazil. The authors concluded that DBH was the most efficient single variable for mass estimations of both species.

## 22. Energy production

The trees use sunlight in photosynthesis to convert carbon dioxide and water into carbohydrates and oxygen. Hence, biomass is, essentially, stored solar energy.

In the combustion processes, the energy stored in biomass is released and used to generate heat, steam, or electricity. The amount of energy released in complete combustion is the heating value of the biomass. This energy is expressed in the higher (calorimetric) or lower (effective) heating value, depending on whether the heat released by the condensation of the steamed water present in the fuel is taken in account or not (Brito 1986).

Heating value is determined with an oxygen bomb calorimeter. Values obtained are somewhat higher than those recovered in practice because the calorimeter is a closed system and the products of combustion are contained. Thus, on cooling, water vapor condenses and releases its heat of vaporization.

In an industrial furnace, this heat is normally lost into the atmosphere (Karchesy and Koch 1979). Therefore, the effective rather than the calorimetric heating value is used in practice. Generally, it is possible to obtain the effective heating value by subtracting 1.34 MJ/kg from the calorimetric value (Brito 1986).

The thermal energy of a fuel depends on both its heating value and its moisture content. The heating value depends on the chemical composition of the fuel. High carbon and hydrogen contents mean higher heating values, whereas oxygen, nitrogen, and ash have an opposite effect. An example of the chemical composition of dry wood and bark according to an ultimate analysis is presented below (Arola 1976):

| Element | Wood | Bark |
| --- | --- | --- |
| | Proportion, % | |
| Carbon | 50.8 | 51.2 |
| Oxygen | 41.8 | 37.9 |
| Hydrogen | 6.4 | 6.0 |
| Nitrogen | 0.4 | 0.4 |
| Ash | 0.9 | 5.2 |

The heating value varies little among the species. According to Howard (1979), most conifer species have heating values ranging from 19.2 to 21.0 MJ/kg.

Resin has a much higher heating value (about 39.3 MJ/kg) than wood (Howard 1979). Conifers, because of their higher resin content, have higher heating values than hardwoods. Lignin also has a higher heating value than cellulose. Therefore, bark, branches, and needles, for their higher contents of resin and lignin, have higher heating values than wood. Tomaselli et al. (1983) found heating values of 20.0 MJ/kg for wood and 24.9 MJ/kg for bark of slash pine planted in the State of Paraná.

There are several approximate equations that estimate the heating value of wood as a function of its moisture content (Brito 1986, Countryman 1977, Farinhaque 1981). The presence of water represents a negative heating value since part of the energy must be used for the vaporization of water. Variations in moisture content interfere with process control, calling for periodic adjustments in the furnace system (Brito 1986). The optimum moisture content in terms of combustion efficiency in common furnaces generally ranges between 40 to 55 % on the dry mass basis. If the biomass is too dry, combustion may be very explosive, resulting in energy loss into atmosphere and higher particulate emissions. If the moisture content rises to between 100 and 150 %, combustion efficiency decreases drastically. If it exceeds 150 to 230 %, the heating value of the biomass is not sufficient to maintain the combustion process.

The moisture content varies considerably from species to species. According to Phillips (1979) it may range from 40 to 150 % on the dry mass basis. Tomaselli et al. (1983) found moisture contents of 189 % in fresh slash pine wood in the State of Paraná.

Although biomass presents a much lower heating value than fossil fuels, it offers, on the other hand, important advantages as a fuel. The ash content of forest biomass is very low, usually less than 2 % of the dry mass, while the ash content of coal is 3 to 5-fold. Besides, wood ash can be recycled and used as a fertilizer both in agriculture and in7 forestry, especially for its trace elements and for raising of acid soils (Hakkila 1986). The amount of sulfur in wood fuels is negligible, and the formation of pollutant sulfur products during wood combustion is no problem, while it constitutes a serious problem when coal and oil are burned (Howard 1979). The main pollution problem when burning wood is the emission of solid particulates and smoke (Soares 1985).

# 3. MATERIAL AND METHODS

This study was carried out at the "Monte Alegre" farm of Klabin do Paraná Agro-Florestal. The farm is located in Telemaco Borba county, the central region of the State of Paraná, approximately between the meridians 50°21' and 50°43' W and the parallels 24°03' and 24°28' S. The altitude is about 850 m above sea level.

The mean annual temperature of the region is 19°C, the annual precipitation 1400 mm, and the average relative humidity approximately 76.5 %. According to Köppen's classification, the region belongs to the Cfb climate type; temperate, wet without a definite dry season, and fresh summer. Mean temperature of the hottest month, February, is 21.8°C, and that of the coldest month, July, 15.5°C. Precipitation during the driest month, August, is 60.8 mm and during the wettest month, January, 170.7 mm.

The research data were collected from loblolly pine (Pinus taeda) stands planted on a medium-quality site, at an initial spacing of 1.70 m by 2.50 m. The stands were 7, 10, and 14 years old and would be submitted to the 1st, 2nd, and 3rd thinnings, respectively. The dendrometric characteristics of the sampled stands are presented in Table 1.

Table 1. Characteristics of the sample stands.

| Stand area, ha | Stand age, a | Medium DBH, cm | Medium tree height, m | Height of dominant trees, m | Number of trees per ha |
|---|---|---|---|---|---|
| 7.0 | 7 | 13.0 | 10.4 | 12.3 | 2 088 |
| 21.7 | 10 | 20.0 | 16.4 | 18.6 | 1 240 |
| 19.0 | 14 | 25.4 | 20.6 | 22.0 | 731 |

## 31. Sampling techniques

In order to calculate the medium height and diameter, 6 plots in the 7-year-old stand and 20 plots in the 10- and 14-year-old stands were measured. Among those plots, 3 from each stand were randomly selected for estimation of the number of trees to be harvested in order to determine the crown mass of the trees removed. The plots from the 7- and 10-year-old stands included 12 by 10 rows (20.4 m x 25.0 m), totalling 510 $m^2$ each. In the 14-year-old stand where the definition of rows was very difficult, the plots had an area of 500 $m^2$ (20 x 25 m) each.

## 311. Determination of the number of sample trees

The number of trees to be felled for determining the crown mass by components, for each age class, was estimated by Stein's seguential sampling equation (Steel and Torrie 1960), at an 0.05 risk level:

$$n = \frac{t^2 \ s^2}{(0.1 \ DBH)^2} \qquad (2)$$

where:

$n$ = number of sample trees

$s^2$ = diameter variance

DBH = medium DBH of a plot

0.1 = maximum error limit

In order to increase sampling precision, Stein's formula was applied to the whole set of data of each stand type and within each diameter class. The number of sampled trees was always the higher between the two determinations.

## 312. Sample processing

The DBH, total and commercial height, and live crown length were measured from each felled tree. The trees were delimbed and topped. The branches were classified according to diameter as follows: <0.7 cm (small); 0.7 to 2.5 cm (medium); and 2.6 to 7.0 cm (large). Since branch material over 7.0 cm in diameter is used by the industry, it was not included in the residue.

The crown components were weight scaled in the field. Samples were collected and taken in plastic bags to the laboratory for determination of moisture content and dry mass from each branch diameter class and from needles.

The samples were dried in an oven at a temperature of 100$^{o}$C at the Silviculture Laboratory of the Forestry School, Paraná Federal University, until constant oven-dry weight was established after approximately 48 hours. Moisture content is expressed on a dry mass basis.

## 32. Equations for estimating the residue mass

The dry mass of each crown component constituted the dependent variable of the tested models. These components consisted of the needles, small branches, medium branches, large branches, and total crown with and without needles. The independent variables were DBH, total height, commercial height, and live crown length.

Linear and logarithmic models were tested through the BMDP2R stepwise regression program, developed by the University of California. Specific and generic equations were generated in order to estimate the dependent variables within each stand type, and for the whole set of data, respectively. All data were processed with a VAX 11/785 computer at the Finnish Forest Research Institute at Helsinki.

## 33. Estimation of residual biomass

All trees that were to be felled in the 1st, 2nd, and 3rd thinnings were marked and measured. The best equations for each crown component were used to estimate the residue remaining on site after thinning. For each thinning operation two estimations were made, one using the specific equations for the respective stand type and another using the generic equations that combine the data of all stand types.

## 34. Determination of the heating value of residue

Samples were collected from all crown components of the three stand types for the determination of the calorific heating value. The samples were dried in an oven and ground. The ground material from the three stands was mixed up by crown components in order to produce average samples of each component.

About 200 g of dry ground material of each component was taken to the Domestic Fuel Laboratory of the Technical Research Centre of Finland for determination of the calorific heating values. The determinations were made with the AC-300 SYSTEM 789-500 Automatic Calorimeter.

The null hypothesis of no difference among the calorific values of the residue components was tested through an analysis of variance of the data obtained from the calorimeter, followed by a comparison through the Student-Newman-Keuls (SNK) test, at an 0.05 probability level.

The energy potential of logging residue left on site after thinning was estimated from the mass and heating value of the residue components. Estimations were made for four different moisture contents; 0, 40, 80, and 120 % on an oven dry basis. For evaluating the calorific heating value at different moisture levels the following equation (Countryman 1977) was used:

$$H_w = H_d \frac{100 - \frac{U}{7}}{100 + U} \qquad (3)$$

where:

$H_w$ = calorific heating value of moist material

$H_d$ = calorific heating value of dry material

U = moisture content on an oven dry basis

The final estimations, per unit of area, were made in Giga-Joules (Joules x $10^9$) and tons of oil equivalent (toe). The following conversion figure was used: 1 kg of oil = 40.7 MJ.

## 4. RESULTS AND DISCUSSION

### 41. Number of sampled trees

The number of sample trees required for the desired precision level by stand type is shown in Table 2.

Initially, when Stein's formula is applied to all trees in the plots, the number of sample trees is proportional to the observed frequency in the respective diameter class. However, when the formula is applied within each diameter class the proportionality is annulled, providing the variability exists within these classes. Therefore, the higher the variability, the more trees must be sampled in the respective diameter class.

In the sampling plots of the 10-year-old stand only one tree was found in the 30.0 to 34.9 cm diameter class. However, other trees from this diameter class were found in the outskirts of the plot and 5 trees could be sampled.

The sampling plots of the 14-year-old stand did not contain trees larger than 35 cm DBH. However, several trees with diameters over 35 cm were found outside the sample plots. From those, 4 in the 35.0 - 39.9 cm class and one in the 40.0 - 44.9 cm class were sampled.

Table 2. Number of trees required and effectively sampled, by diameter class and site type.

| Stand age a | DBH class cm | Observed frequency in the plots Number of trees | % | Number of trees to be sampled: Applying Stein's formula to the whole set of data | Applying Stein' formula within each DBH class |
|---|---|---|---|---|---|
| 7 | 5.0 - 9.9 | 57 | 18.6 | 7 | 14 |
| | 10.0 - 14.9 | 142 | 46.4 | 16 | 7 |
| | 15.0 - 19.9 | 96 | 31.4 | 12 | 4 |
| | 20.0 - 24.9 | 11 | 3.6 | 2 | 3 |
| | Total | 306 | 100.0 | 37 | 28 |
| 10 | 10.0 - 14.9 | 21 | 10.5 | 3 | 8 |
| | 15.0 - 19.9 | 69 | 34.3 | 7 | 4 |
| | 20.0 - 24.9 | 83 | 41.3 | 8 | 3 |
| | 25.0 - 29.9 | 27 | 13.4 | 3 | 8 |
| | 30.0 - 34.9 | 1 | 0.5 | 1 | 3 |
| | Total | 201 | 100.0 | 22 | 26 |
| 14 | 15.0 - 19.9 | 10 | 9.0 | 3 | 4 |
| | 20.0 - 24.9 | 40 | 36.0 | 5 | 5 |
| | 25.0 - 29.9 | 43 | 38.8 | 5 | 3 |
| | 30.0 - 34.9 | 18 | 16.2 | 3 | 4 |
| | 35.0 - 39.9 | - | - | - | 4 |
| | 40.0 - 44.9 | - | - | - | 1 |
| | Total | 111 | 100.0 | 16 | 21 |

## 42. Equations for estimation of crown mass

### 421. Equations for the 7-year-old stand

The equations selected for estimating the crown mass in the stand to be submitted to the first thinning are presented in Table 3. Logarithmic equations were the best except for large branches, that were better estimated through a second degree equation.

The low precision of the equation for large branches is due to the inclusion of the below 7 cm stem portion. Therefore, the whole stem of the smallest trees was considered residue, and some small trees possessed higher large-branch mass than did trees of larger DBH. Setting an extra class for residual tops in the 7-year-old stand was not practical. In the other age classes the fit was satisfactory.

Table 3. Dry mass equations for the crown components in the 7-year-old stand.

| Equation | $R^2$ | $S_{xy}$, kg | F |
|---|---|---|---|
| Small branches: | | | |
| ln y = - 7.67534 + 1.57507 ln DBH | 0.70 | 0.399 | 116.9 |
| Medium branches: | | | |
| ln y = - 10.83078 + 2.55697 ln DBH | 0.93 | 0.282 | 619.6 |
| Large branches and top: | | | |
| y = 6.29665 - 0.08545 DBH + 0.000445 DBH2 | 0.48 | 1.885 | 21.7 |
| Needles: | | | |
| ln y = - 12.27110 + 2.79207 ln DBH | 0.93 | 0.303 | 638.7 |
| Total crown with needles: | | | |
| ln y = 6.52743 + 1.88385 ln DBH | 0.94 | 0.186 | 770.7 |
| Total crown without needles: | | | |
| ln y = - 5.69652 + 1.64388 ln DBH | 0.91 | 0.209 | 466.8 |

### 422. Equations for the 10-year-old stand

The equations selected for estimating the dry mass of the crown components in the stand to be submitted to the second thinning are presented in Table 4. Again, except for the large branches, the logarithmic equations are the best. The large branches were estimated better by using a second degree equation, and its precision was much higher than for the corresponding equation of the 7-year-old stand.

The low value of the coefficient of determination ($R^2$) in the small-branch equation is due to the great variation in this component among some trees. Nevertheless, the standard error of estimate was small. The fit can be considered satisfactory.

Table 4. Dry mass equations for the crown components in the 10-year-old stand.

| Equation | $R^2$ | $s_{xy}$, kg | F |
|---|---|---|---|
| Small branches: | | | |
| $\ln y = - 5.84179 + 1.22069 \ln DBH$ | 0.58 | 0.350 | 50.2 |
| Medium branches: | | | |
| $\ln y = - 8.09077 + 2.00904 \ln DBH$ | 0.86 | 0.276 | 218.3 |
| Large branches and top: | | | |
| $y = 42.72202 - 0.52640\ DBH + 0.001688\ DBH^2$ | 0.73 | 9.407 | 47.9 |
| Needles: | | | |
| $\ln y = - 13.86491 + 2.95618 \ln DBH$ | 0.86 | 0.400 | 225.3 |
| Total crown with needles: | | | |
| $\ln y = 8.96509 + 2.33620 \ln DBH$ | 0.90 | 0.266 | 319.8 |
| Total crown without needles: | | | |
| $\ln y = - 8.61931 + 2.22506 \ln DBH$ | 0.87 | 0.294 | 237.6 |

423. Equations for the 14-year-old stand

The equations selected to estimate the dry mass of the crown components in the stand to be submitted to the third thinning are presented in Table 5.

In this stand type, all crown components were best estimated by logarithmic equations. The equation for small branches showed low coefficients of determination. In contrast with the other stands, large branches were estimated best using a logarithmic equation.

Table 5. Dry mass equations for the crown components in the 14-year-old stand.

| Equation | $R^2$ | $s_{xy}$, kg | F |
|---|---|---|---|
| Small branches: | | | |
| $\ln y = - 8.19528 + 1.60044 \ln DBH$ | 0.50 | 0.471 | 23.3 |
| Medium branches: | | | |
| $\ln y = - 6.05816 + 1.63877 \ln DBH$ | 0.74 | 0.291 | 63.9 |
| Large branches and top: | | | |
| $\ln y = - 15.38501 + 3.32164 \ln DBH$ | 0.92 | 0.299 | 248.6 |
| Needles: | | | |
| $\ln y = - 14.24835 + 2.98338 \ln DBH$ | 0.69 | 0.593 | 51.0 |
| Total crown with needles: | | | |
| $\ln y = - 9.46556 + 2.43469 \ln DBH$ | 0.93 | 0.202 | 294.2 |
| Total crown without needles: | | | |
| $\ln y = - 9.46584 + 2.39685 \ln DBH$ | 0.93 | 0.193 | 309.7 |

## 424. Generic equations

The generic equations, based on the total sample including all age classes, are presented in Table 6. The generic equations provide higher precision than the specific equation. Medium branches in the first thinning, needles in the first and second thinnings, and large branches in the third thinning are exceptions.

Table 6. Generic dry mass equations for the crown components.

| Equation | $R^2$ | $s_{xy}$, kg | F |
|---|---|---|---|
| Small branches: | | | |
| $\ln y = - 6.62962 + 1.35166 \ln DBH$ | 0.71 | 0.413 | 274.7 |
| Medium branches: | | | |
| $\ln y = - 9.21555 + 2.21703 \ln DBH$ | 0.92 | 0.304 | 1359.8 |
| Large branches and top: | | | |
| $y = 16.07355 - 0.25224\ DBH + 0.001068\ DBH^2$ | 0.85 | 7.662 | 307.1 |
| Needles: | | | |
| $\ln y = 9.94864 + 2.25288 \ln DBH$ | 0.81 | 0.514 | 491.6 |
| Total crown with needles: | | | |
| $\ln y = - 7.30165 + 2.03766 \ln DBH$ | 0.94 | 0.239 | 1868.6 |
| Total crown without needles: | | | |
| $\ln y = - 7.42745 + 2.00970 \ln DBH$ | 0.93 | 0.267 | 1449.1 |

The deviation of observations from the generic equations is presented in Figures 1 to 6. Except for large branches where the fit is less precise for small trees, the accuracy of the equations tends to decrease from the 30 cm DBH trees on. However, this fact does not significantly affect the results because trees over 30 cm DBH were removed only in the 3rd thinning, and even then in a proportion lower than 6 %.

## 43. Estimation of the residual biomass

The residual biomass per unit area was estimated by stand type. Table 7 shows hypothetical examples of trees to be removed in the 1st, 2nd, and 3rd thinnings.

The dry mass of the residual biomass per ha for each crown component is estimated by stand type using the specific and generic equations in Table 8. The numbers are not additive, i.e. the total crown mass is not exactly the sum of the components, because each component was estimated by using a separate equation.

Table 7. Number of trees to be removed in the three hypothetical thinning operations.

| DBH cm | Number of trees to be removed per ha | | |
|---|---|---|---|
| | 1st thinning | 2nd thinning | 3rd thinning |
| 2 | 3 | - | - |
| 3 | 3 | - | - |
| 4 | 10 | - | - |
| 5 | 23 | - | - |
| 6 | 67 | - | - |
| 7 | 67 | - | - |
| 8 | 59 | - | - |
| 9 | 85 | - | - |
| 10 | 101 | 4 | - |
| 11 | 82 | 8 | - |
| 12 | 75 | 18 | - |
| 13 | 75 | 23 | - |
| 14 | 42 | 29 | - |
| 15 | 39 | 39 | - |
| 16 | 29 | 42 | 3 |
| 17 | 16 | 60 | 12 |
| 18 | 16 | 54 | 8 |
| 19 | 7 | 25 | 13 |
| 20 | 3 | 47 | 25 |
| 21 | 7 | 40 | 33 |
| 22 | - | 27 | 34 |
| 23 | - | 24 | 22 |
| 24 | - | 22 | 19 |
| 25 | - | 12 | 21 |
| 26 | - | 15 | 17 |
| 27 | - | 6 | 18 |
| 28 | - | 3 | 20 |
| 29 | - | 3 | 13 |
| 30 | - | 4 | 12 |
| 31 | - | - | 5 |
| 32 | - | - | 1 |
| 33 | - | - | 4 |
| 34 | - | - | 6 |
| 35 | - | - | 1 |
| Total | 809 | 505 | 287 |

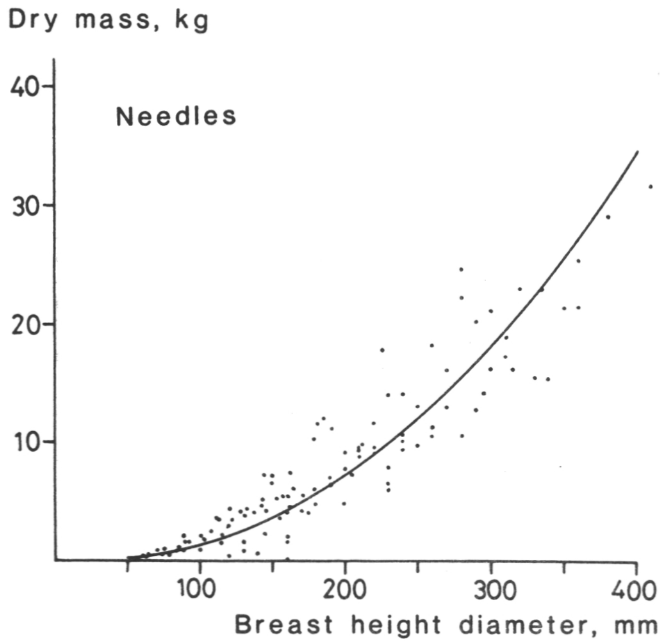


Fig. 1. Dry mass of needles as a function of dbh.

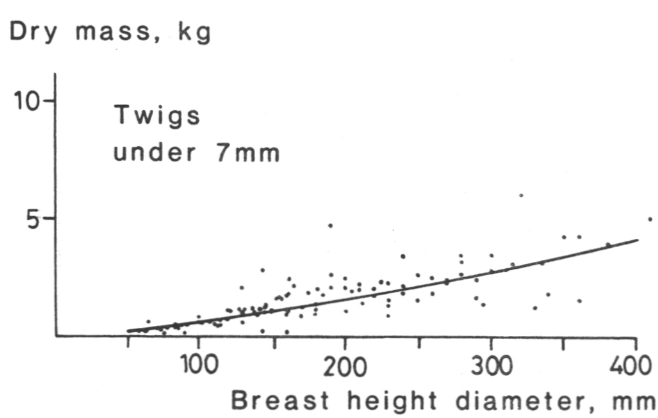


Fig. 2. Dry mass of needles of under 7 mm twig sections as a function of dbh.

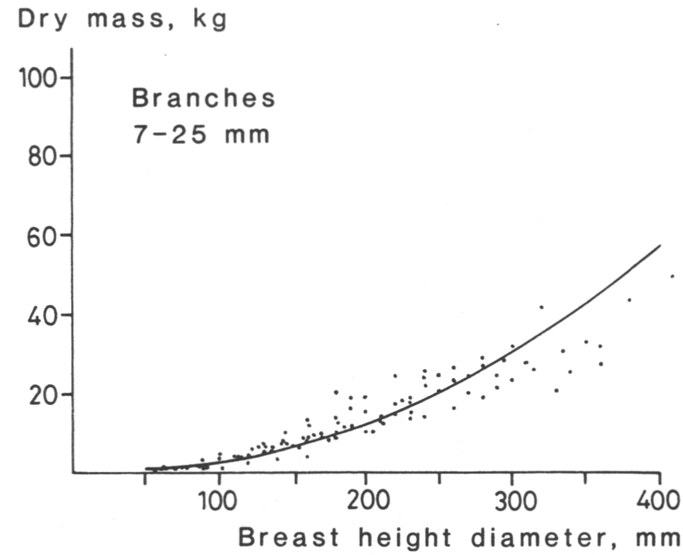


Fig. 3. Dry mass of needles of 7-25 mm branch sections as a function of dbh.

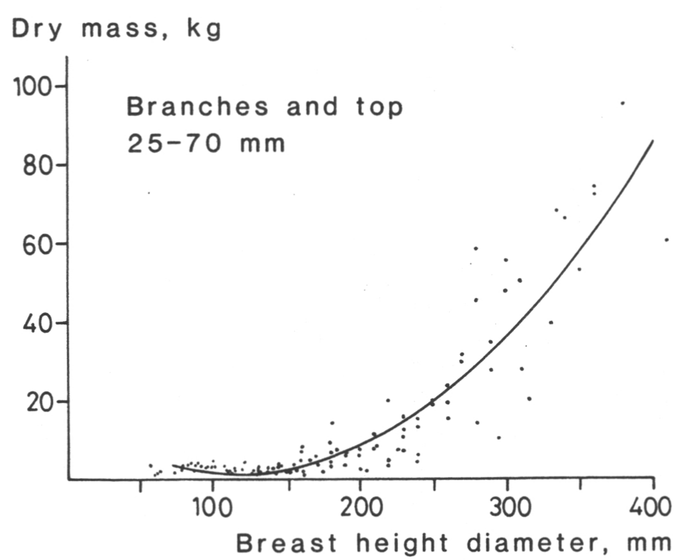


Fig. 4. Dry mass of needles of 25-70 mm branch sections and unmerchantable tops as a function of dbh.

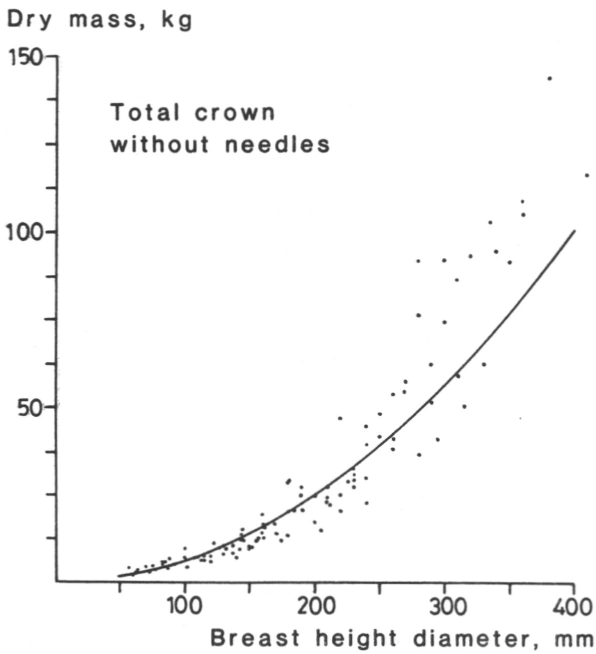


Fig. 5. Total crown mass without needles as a function of dbh.

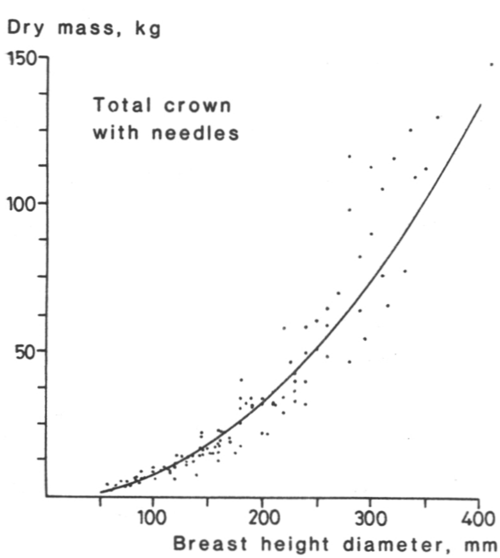


Fig 6. Total crown mass with needles as a function of dbh.

Table 8. Residual dry mass in tons per hectare in three thinnings, as estimated using the specific and generic equations.

| Crown component | 1st thinning | | 2nd thinning | | 3rd thinning | |
|---|---|---|---|---|---|---|
| | Specific | Generic | Specific | Generic | Specific | Generic |
| | Tons per hectare | | | | | |
| Small branches | 0.62 | 0.61 | 0.87 | 0.79 | 0.51 | 0.63 |
| Medium branches | 3.00 | 2.90 | 5.85 | 5.71 | 5.38 | 5.56 |
| Large branches and top | 2.25 | 2.10 | 2.99 | 3.92 | 6.11 | 5.32 |
| Needles | 2.24 | 1.66 | 2.79 | 3.32 | 2.53 | 3.26 |
| Crown with needles | 8.55 | 8.27 | 13.81 | 14.97 | 14.43 | 14.00 |
| Crown without needles | 6.21 | 6.37 | 10.82 | 11.39 | 11.70 | 10.58 |

Differences between estimations using specific and generic equations were less than 10 %, except for large branches in the 2nd and 3rd thinnings, and for needles in all stand types. In order to evaluate the energy potential of the residue, the crown mass with or without needles can be estimated using the generic equations (Figs. 5 and 6).

## 44. Heating value of logging residue

The heating value of each component of the residual biomass was determined from two samples. The results are presented in Table 9. The larger the proportion of wood in biomass, the lower the heating value. That is mainly due to the fact that extractives are present in higher proportions in needles, bark and small branches.

Table 9. Calorific heating value of the residue left on site after thinning operations in loblolly pine stands.

| Residue component | Calorific value of oven dried material (MJ/kg) | |
|---|---|---|
| | Calorific heating value, MJ/kg | Effective heating value, MJ/kg |
| Small branches | 20.76 | 19.52 |
| Medium branches | 20.40 | 19.15 |
| Large branches and top | 20.22 | 18.97 |
| Needles | 20.92 | 19.68 |

An analysis of variance detected significant differences among the heating values of different residue components at an 0.05 significance level. However, the SNK test showed significant differences only between the needles and large branches.

## 45. Energy potential of logging residue

The energy potential of logging residue was estimated from the crown mass with and without needles for the three stand types using the generic equations.

Small branches represent 6 % of the total crown mass with needles, medium branches 40 %, large branches 31 %, and needles 23 %. The weighted average for the effective heating value was 19.24 MJ/kg.

Small branches represent 8 % of the crown mass without needles, medium branches 52 %, and large branches 40 %. The calorific average effective heating value was 19.11 MJ/kg.

The energy potential of logging residue left on site after thinning operations is presented in Table 10. Considering that the moisture content of the residue from thinnings varies between 40 and 80 % of the dry mass (McMinn and Nutter 1981, Phillips 1979), its energy potential ranges from 2.6 to 5.0 tons of oil equivalent per hectare when only the wood and bark components are taken into account. When the needles are included, the energy potential of logging residue from typical thinning operations is 3.5 to 6.7 toe respectively.

One of the main concerns with respect to the utilization of forest residue for energy generation is loss of nutrients from forest soil (Phillips 1979). Removal of foliage increases the risk and may result in an impoverishment of the soil. Since leaves contain larger amounts of nutrients than branches (Carlisle and Methven 1979), the effect of nutrient removal on soil fertility may thus be reduced if foliage is left on the site.

Logging residue is naturally available to the plants through natural decomposition. Additional research is required to verify whether it is ecologically and economically feasible to recover the total crown with needles or only the woody parts of branches and the top for energy production. It should not be forgotten that the ashes from the forest residue combustion could be returned to the forest as a fertilizer (Hakkila 1986).

Table 10. Energy potential of residual biomass left on site after thinning operations, at alternative levels of moisture content.

| Moisture content/component | Moisture content, % | 1st thinning GJ | 1st thinning TOE | 2nd thinning GJ | 2nd thinning TOE | 3rd thinning GJ | 3rd thinning TOE |
|---|---|---|---|---|---|---|---|
| | | Energy potential per hectare | | | | | |
| Crown with needles | 0 | 159.0 | 3.9 | 288.1 | 7.1 | 269.4 | 6.6 |
| Crown without needles | 0 | 121.7 | 3.0 | 217.6 | 5.3 | 202.2 | 5.0 |
| Crown with needles | 40 | 149.9 | 3.7 | 271.4 | 6.7 | 253.8 | 6.2 |
| Crown without needles | 40 | 114.8 | 2.8 | 205.2 | 5.0 | 190.6 | 4.7 |
| Crown with needles | 80 | 140.9 | 3.5 | 255.2 | 6.3 | 238.6 | 5.9 |
| Crown without needles | 80 | 107.8 | 2.6 | 192.7 | 4.7 | 179.0 | 4.4 |
| Crown with needles | 120 | 131.8 | 3.2 | 238.8 | 5.9 | 223.3 | 5.5 |
| Crown without needles | 120 | 100.9 | 2.5 | 180.4 | 4.4 | 167.6 | 4.1 |

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SUMMARY

The objectives of the study were: i) to evaluate the amount of residual biomass left on the site after thinning operations in loblolly pine (Pinus taeda) plantations in southern Brazil; ii) to determine the heating value of the crown components; and iii) to estimate the energy potential of the residual biomass per unit of area.

The data were collected from 7-, 10-, and 14-year-old stand of loblolly pine that would be submitted to the 1st, 2nd, and 3rd thinnings, respectively. The plantations, owned by "Industrias Klabin de Papel e Celulose", were located in Telemaco Borba county, State of Paraná, Southern Brazil.

In order to construct equations for estimating the residue mass, 51 trees from a 7-year-old stand, 39 trees from a 10-year-old stand, and 25 trees from a 14-year-old stand, were sampled. The stems were delimbed and topped, and the residual material was classified into the following categories: needles, small branches (less than 0.7 cm diameter), medium branches (0.7 to 2.5 cm diameter), and large branches plus unmerchantable tops (2.5 to 7.0 cm diameter). Branches over 7.0 cm in diameter were not included as they are normally recovered for commercial use.

The results allow the following conclusions:

i) Breast height diameter is an efficient and practical variable for estimating the dry mass of crown components of loblolly pine trees removed in thinning operations in southern Brazil.

ii) For most crown component and stand type combinations the dry mass (y) was estimated best by using the following simple function:

$$\ln y = a + b \ln DBH$$

However, the mass of large branches, including under 7 cm stem top, was predicted best by using the following function:

$$y = a + b\,DBH + c\,DBH^2$$

iii) The generic equations, based on combined data from all stand types, were found practical for estimating the residual crown biomass in the three subsequent thinnings.

iv) The total dry crown mass, estimated through the generic equations, were 8.3, 15.0, and 14.0 tons/ha respectively in the 1st, 2nd, and 3rd thinnings.

v) The effective heating value was 19.52 MJ/kg for small branches; 19.15 MJ/kg for medium branches; 18.97 MJ/kg for large branches; and 19.68 MJ/kg for needles. The weighted average was 19.24 MJ/kg for the crown mass with needles and 19.11 MJ/kg for crown mass without needles.

vi) The energy potential of the residual crown mass, including needles, was 3.9, 7.1, and 6.6 toe/ha in the 1st, 2nd, and 3rd thinnings. The dry mass of woody crown material, needles excluded, was 3.0, 5.3, and 5.0 toe/ha respectively.

vii) When the moisture content of the residue increases from 0 to 40, 80, or 120 % of the dry mass, the energy potential is reduced, respectively, to 94, 89, and 83 % of the initial value for oven-dried material.

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