Thesis

Growth performance of Pinus elliottii

University of Applied Sciences VAN HALL LARENSTEIN PART OF WAGENINGEN UR

UNICENTRO PARANÁ

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Preface

This Bachelor thesis "Growth performance of Pins elliottii" represents the completion of my International Timber Trade studies. For this work, both, physical (preparing the tree discs) as well as mental work (analysis and desk work) was necessary. I started my Bachelor of Science Forestry studies in 2008 at the University of Applied Sciences in Rottenburg/ Neckar (HFR) in Germany.

After two successful years in Germany (where I completed my undergraduate studies) I continued my studies with the encouragement of the ERASMUS grant from the European Union with the specialization International Timber Trade (ITT) at the partner universities of HFR in Skinnskatteberg/ Sweden (Swedish University of Agricultural Sciences [SLU]) and Velp/ The Netherlands (University of Applied Sciences van Hall Larenstein Part of Wageningen UR [VHL]). During this time I also have had the opportunity to perform interesting and instructive internships together with APP Timber Limited in Kuala Lumpur/ Malaysia, an international timber trading company and Klausner Holz Thüringen GmbH in Germany.
For the final year of my studies, I received a scholarship from the DAAD (Deutscher Akademischer Austausch Dienst/ German Academic Exchange Service) and get the chance to study my final two semesters in Irati/ Brazil.
The State University Unicentro Irati/ Paraná offered me during my stay in Brazil the opportunity to perform this final work.
The entire university was very helpful with advice and assistance and supported me in all kinds of situations. Very special thanks to Prof. Dr. Afonso Figueiredo Filho who has maneuvered me as an external supervisor through so many difficult situations. Likewise also all other members of the Unicentro Paraná and the representatives of the plantation industry my deepest thanks. It was a wonderful time with all of you and this time will stay forever in my memories. I do not want to forget to thank my family. Over two continents, they have been very supportive and made this work possible.

Thanks Alex!

Sebastian Breier

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ANATRO	Analise de Tronco/ stem analysis
$d_{1.3}$	diameter at breast height (dbh)
Embrapa	state-owned company
FLONA	Floresta nacional de Irati/ National Forest Irati
g	basal area
h	height growth
ha	hectare
IBAMA	Instituto Brasileiro do meio ambiente/ Brazilian Institute for the Environment
ICA	incremento corrente annual/ current annual increment
IMA	incremento media annual/ average annual increment
PR	Paraná, Brazilian State
R$	Brazilian real, currency in Brazil, 1 R$ = 0.3680 € (exchange rate12.12.2012)
SC	Santa Catarina, Brazilian State
t	time
v	Volume

Abstract

The continually increasing demand for raw materials for the wood and paper industry in South America, especially in Brazil, makes a fundamental scientific investigation of suitable tree species for the region Paraná necessary, because the available land related to forestry is limited. As part of a cooperative government/ private sector study for this purpose different tree species which are already growing in Paraná be scientifically accurate analyzed.

This study, which represents one part of this Brazilian overall investigation, analyzes the growth performance of the conifer tree species Pinus elliottii. The focus of this study is the development of the diameter at breast height (d1.3), the height growth of the species (h), the development of the basal area of the individual tree (g) and the volume increment of these conifer species (v) over the time (t).

With the analyzed data an economic analysis of a large-scale use (more than 10,000 hectares of cultivated area) of the tree species Pinus elliottii for similar agricultural plantations is carried out.

To collect the necessary data, at the FLONA Irati (Floresta Nacional de Iratí) 79 Pinus Elliotti trees in the age range of 23 to 45 years were sampled and analyzed with the ANATRO (Análise de Tronco/ stem analysis) method.

The collected data were analyzed and transformed with mathematical/ statistical methods (Marquardt “Least-Squares Estimation of Nonlinear Parameters”) to different model for the value of the growth of the diameter at breast height ($d_{1.3}$), the value of the height growth (h) of the whole tree, the basal area per tree (g) and volume increment (v) per tree.
With these models it is now possible to determine accurate predictions about the stock development of Pinus elliottii plantation in the area of Paraná/ Brazil.
The main question,”Is it in terms of growth and economic efficiency, economically feasible to cultivate Pinus elliottii in the area of Paraná/ Brazil in large scale plantations?” could be answered and a yield of 6,7% for a Pinus elliottii plantation was calculated during this study. With the growth models for $d_{1.3}$, h, g and v is it now possible to calculate the development of Pinus elliottii very close to the reality.

Keywords: Pinus elliottii, plantation, growth model

1 Introduction

Since the colonization of South America, there is a growing demand for the raw material wood. This demand could be met initially with the naturally grown trees in this area. In the beginning the newly arrived immigrants uses the trees in a sustainable way as the natives of South America did it all the time before. At this time the major use of the trees was the utilization as construction material and energy source (firewood).

With the rise in population and the increasing level of industrialization, the sustainable use of this resource was no longer feasible. It emerged additional new uses for wood, which consumes large amounts of raw material. Besides the rising energy and construction wood demand was also the export of tropical wood and the production of paper.

This led to a very strong reduction of the original forest-covered areas in Brazil and is also felt around the world by influencing the world's climate. Over the last decades there are therefore efforts to use the areas of Brazil sustainably and to ensure an independent supply with the raw material wood for the country. There are protected areas established and built up a plantation industry. Industry and government together try to maintain the wood production in Brazil sustainable and profitable. This includes the basic study of the growth performance of different tree species in the different growing areas of Brazil.

1.1 Study Area

The State of Paraná is one of 27 states in Brazil. In the South the State of Paraná borders on Santa Catarina (SC), and in the west to Argentina (AR) and Paraguay (PA), in the north on Mato Grosso do Sul (MS) and Sao Paulo (SP) (Fig.01). The state is divided into six main regions and 399 municipalities. The city Irati is also an independent municipality and is located in the south of the State of Paraná.

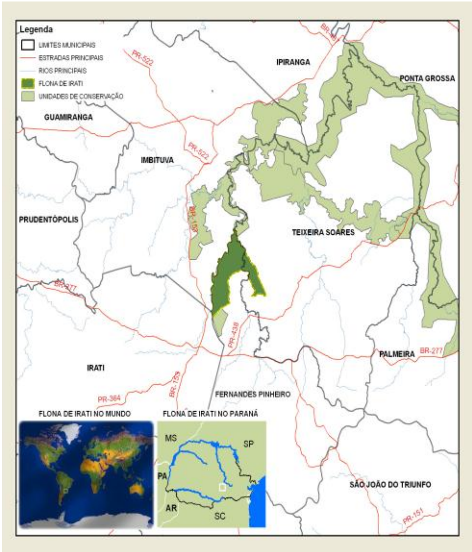

Fig. 1 Location FLONA Irati

FLONA Irati

The FLONA Irati (Floresta Nacional de Iratí) is located on the Second Plateau of the Paraná state, in the mid-southern region of the state. It covers an area of 3495 hectares, with both native vegetation and a portion of approximately 1310 ha reforested with Araucaria, Pinus and Eucalyptus (Instituto Brasileiro do meio ambiente - IBAMA, 2009). It is located in the physiographic zone of Irati, in the parallel 25º27’56" latitude south, intersecting the meridian 50º37’51" west longitude, at 812 m above sea level. The climate in the region is type Cfb – Humid Subtropical and Mesothermal, with mild summers, frequent and severe frosts and no dry season. The mean annual temperatures in the warmest months remain below 24 ºC and in the coldest months below 18 ºC, and with mean annual temperature of 17 ºC. The region’s mean monthly rainfall is 193.97 mm, and the relative humidity is 79.58%.

1.2 Pinus elliottii

In this section takes a comprehensive presentation of the conifer Pinus elliottii place. It presents the commonly used names, the distribution areas, natural durability, processing characteristics, physical/ mechanical properties of the wood and the uses of Pinus elliottii.

Commonly used names

Botanical name: Pinus elliottii Engelmann, Pinaceae
Other names: Pinheiro, Pinheiro americano (American pine), Pinus, Pinus eliote
International names: Slash Pine, Southern Pine (international), Southern yellow Pine

Distribution

For the territory of Brazil Pinus elliottii is an introduced exotic conifer species. Today, this species can be found in plantations in the following Brazilian states:

- Paraná,
- Santa Catarina,
- Rio Grande do Sul (South),
- São Paulo,
- Minas Gerais,
- Rio de Janeiro,
- Espírito Santo (Southeast)

Natural durability

In laboratory tests Pinus elliottii showed low resistance to all types of fungi (molds, stains and decay), as well as to termites and borers.

Processing Characteristics

Working properties

Pinus elliottii wood is easy to work with both hand and machine tools. Good properties and results in operations as sawing, planing, peeling, sanding, turning, boring and gluing. Finishes with good results.

Drying

easy to dry; dries fast with good results, very few defects

PHYSICAL PROPERTIES

Density

Apparent density at 15% moisture content: 480 kg/m³

Shrinkage (green to 15% m.c.)

Radial: 3.4 %
Tangential: 6.3 %
Volumetric: 10.5 %

MECHANICAL PROPERTIES

Static bending

Strength
Green wood: 489 kg/cm² (48 MPa)
Wood at 15% m. c.: 710 kg/cm² (69.6 MPa)
Modulus of elasticity - Green wood: 65904 kg/cm² (6463 MPa)

Compression parallel to grain

Strength
Green wood: 189 g/cm² (18.5 MPa)
Wood at 15% m. c.: 321 kg/cm² (31.5 MPa)
Modulus of elasticity - Green wood: 90204 kg/cm² (8846 MPa)

Other properties

Impact bending strength (shock) - Wood at 15% m.c.
Work absorbed to rupture: 14.5 J
Shear strength- Green wood: 59 kg/ cm² (5.8 MPa)
Janka hardness - Green wood: 197 kg (1932 N)
Tension perpendicular to grain - Green wood: 31 kg/cm² (3 MPa)
Cleavage - Green wood: 4 kg/ cm2 (0.4 MPa)

MAIN USES

Civil construction

Structural, light interior:	light load-bearing components, laths
Utility grade, light interior:	wall panelling, ceilings, skirting panels, trimmings, finishing
Temporary use:	scaffoldings, posts and braces, concrete forms

Furniture

Utility grade:	utility furniture, concealed parts of furniture, including decorative

Other uses

Veneers and plywood, turning, broomsticks, toys and sports goods, packaging, paper production

1.3 Problem description

In the past, timber was very strong demanded in Brazil, which reduced the natural forest area and led to a very early use of the newly planted plantation stocks in small, young dimensions of the trees. Legally harvested, natural grown big trees were gradually reduced and the Brazilian government recognized the need for establishment of protected forest areas. For the region of the Atlantic forest (Mata Atlântica), this strong deforestation is clearly visible by the area of the early 20th Century and the still preserved area. At the beginning of the 20th century, the Atlantic forest area consisted of 131,550,000 ha compared with 10,200,000 ha today, which are fragmented dispersed throughout the original Atlantic forest area. This means that only about 7.75% of the original forest of this area is still preserved.
In Brazil, the original timber production from native forests has been converted into a large-scale plantation economy.
The total area covered with forest plantations in Brazil (2011) is 6,515,844 ha with 1,641,892 ha (25.2%) planted with the conifer species Pine. The main areas for pine plantation located in the southern part of Brazil and mainly offer the Brazilian wood industry with raw material for paper, lumber and veneer production. In order to ensure the future self-sufficiency with Brazilian raw material wood, it is part of this work to identify bases on the growth of Pinus elliottii in the area of Paraná (special feature: collection of data in old growth stands: 25-45 years old Pinus elliottii stocks), and thus provide a basis for review of the economic efficiency of this tree species in plantations.

1.4 Purpose of the study

In Brazil, there are various studies on the growth of different species of Pinus which were mainly carried out by the private plantation sector. But they have the disadvantage that they could only be imposed for relatively young stocks, since due to the extremely strong demand for wood no old tree stands for the investigation were available. In addition, the respective studies were only used internally and not published because only the respective companies operated the research effort for themselves.

Through the cooperation of government and private sector and with the aim of reaching self-sufficiency for Brazil for the raw material wood, it is with this study now possible to perform a publicly available study on the growth performance of Pinus elliottii by using government owned and protected old tree stands for the growth performance analysis for the local territory of Paraná/ Brazil.

The research focuses on:

- the growth performance of Pinus elliottii for the area of Paraná/ Brazil
- the profitability of a Pinus elliottii plantation

This research will provide answers to so far still open questions for plantations of Pinus elliottii in the region of Paraná/ Brazil as part of the cooperation of government and private sector for the investigation of different tree species on their further usability for plantation use in South Brazil which are performed in further studies.

1.5 Research questions

The following research questions will be addressed:

Main question:

Is it in terms of growth and economic efficiency, economically feasible to cultivate Pinus elliottii in the area of Paraná/ Brazil in large scale plantations?

Subquestions:

- Which diameter at breast height (cm) Pinus elliottii reached during the growth of the tree?
- What is the height (m) which Pinus elliottii reached over the growth years?
- Which basal area (m^2) reached Pinus elliottii over the years?
- What is the volume (m^3) which will be achieved from Pinus elliottii?
- Is there a mathematical model for the calculation of the growth of Pinus elliottii?
- What is necessary to cultivate Pinus elliottii as plantation?
- At what point are the rotations of the plantation?
- What are the possible end products of a Pinus elliottii plantation?

1.6 Report Outline

The first chapter is the introduction with objectives and research questions. In chapter two, the research methodology will be explained. Basically, in this chapter, the steps of the study and the methods used will be explained. Then, in chapter three; the findings of the study are mentioned. This is related to the real measured tree samples, on the developed mathematical models of growth and the basic observation of a large-scale plantation in southern Brazil. Finally, a discussion will analyze the results of the study and answer the main question of this report.

2 Research Methodology

This chapter will explain the scope of the study with a detailed description of the used methodologies. This includes the 5 steps of the study, including ANATRO, the statistical analysis and the economic analysis.

2.1 Scope of the study

The scope of the study includes the analysis of the growth performance of the conifer Pinus elliottii and the economic evaluation of a Pinus elliottii plantation in southern Brazil. The study is divided into five separate steps (Fig.2 Study steps), which represent different phases during the study.
As a first step, the Exploratory Phase was necessary in order to get an overview and deeper knowledge of the subject. The second step followed with the Execution Phase with mostly practical work during the sample collection. The third step followed with the Analysing Phase, in which the collected data were analyzed. With the obtained data the fourth phase, the Simulation Phase, was conducted. Finally, with the fifth step Conclusions and Recommendations, the study was completed.

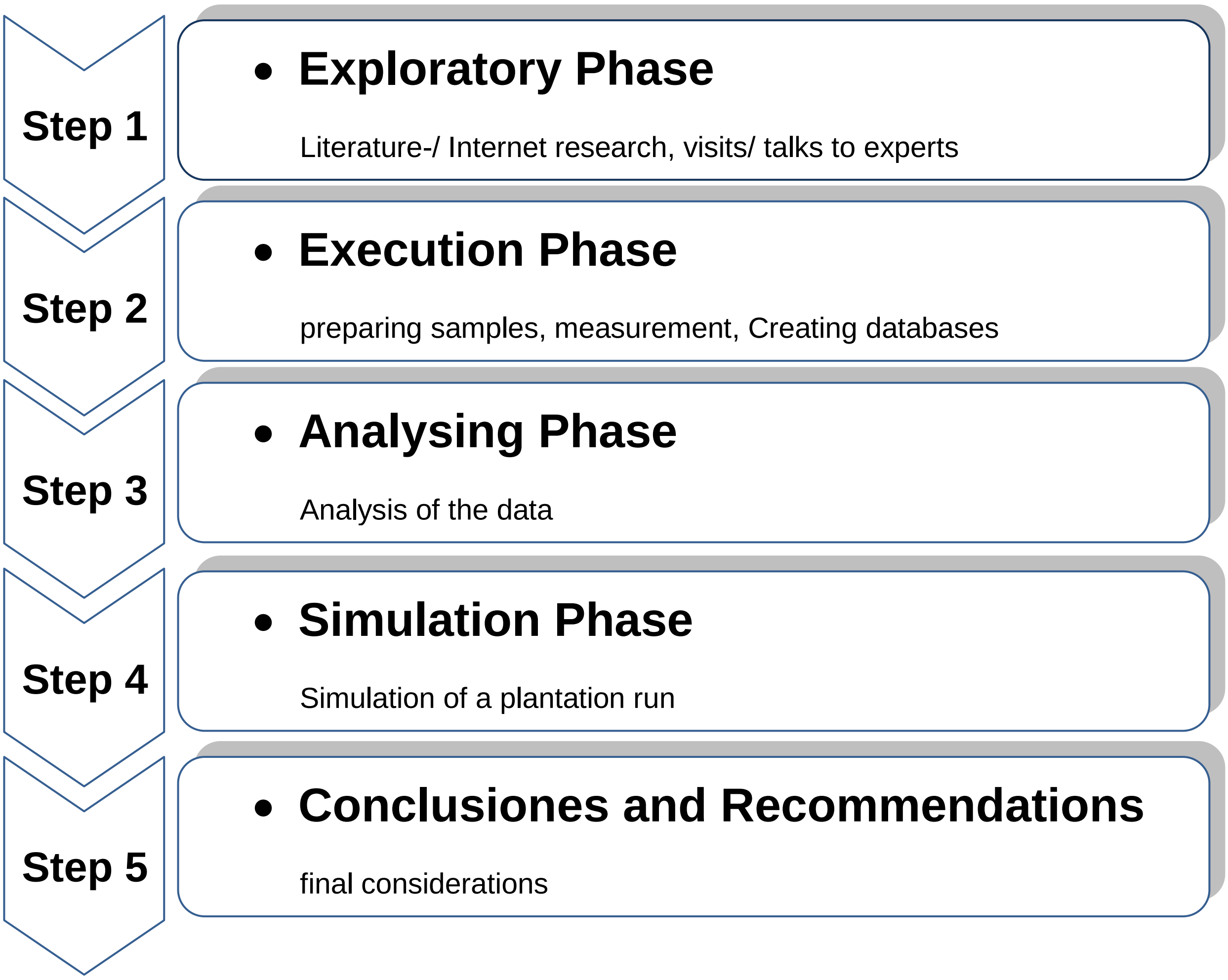

Fig. 2 Study steps

2.2 Step 1 Exploratory Phase

At the beginning of the study it was necessary to get an overview of the topic. It was necessary to get information about the natural conditions in southern Brazil, the general characteristics of Pinus elliottii, the general structure of forestry in South America, the past and current situation of the plantation and wood processing Industry in Brazil, the methods of cultivation of this conifer species, the used technology for the Brazilian plantation industry and the monetary relations in Brazil. As well the basics of determining growth performance of trees have been acquired.

Therefore, a literature- and Internet research was necessary and also meetings and discussions with representatives of the Brazilian plantation/ Timber industry were arranged.

- Klabin   Telêmaco Borba, PR
- MWV Rigesa   Três Barras, SC
- LP Brasil   Ponta Grossa, PR

More information which contributed to the understanding of the matter resulted from direct interviews with the academic staff of the Unicentro Irati.
The planning of the sample collection was to perform in consultation with Prof. Dr. Afonso Figueiredo Filho/ Unicentro. First it was necessary to get a special government permission to harvest trees in the governmental reserve FLONA Irati. FLONA Irati was chosen because it has a representative location which represents the typical site characteristics for the territory of Paraná and because there are trees in the protected area with an age of more than 30 years (something of a rarity because of the strong demand for wood in Paraná). The authorized permit included a maximum removal of 85 trees, which limited the maximum sample size. The main criterion for the selection of the sample trees was the age. The age of the trees before sampling was determined based on records of the Forestry Administration of FLONA Irati and directly on site determined by estimation of tree height and diameter at breast height. Suitable trees were selected for sampling.

2.3 Step 2 Execution Phase

For the study, all to be examined trees of the species Pinus elliottii from the FLONA Irati/ Paraná were measured for their growth performance.
From each tree, 11 tree sample discs were taken at precisely defined points of the trunk. Using the ANATRO-system (Análise de Tronco/ stem analysis), the worked up samples were investigated by using the LINTAB tree ring measurement station in combination with the data acquisition software TSAP-Win. Thus resulted in a database for the following values for each sample disk:

- Number of annual rings
- four values of the width of each annual ring for each annual ring (mm)

The resulting databases are transferred for further usage via the computer software FlorExel (productivity calculation tool with the possibility to add data table for further use of the data with Microsoft Excel).

ANATRO (Análise de Tronco/ stem analysis)

The ANATRO is a method to study accurate the growth of a tree during the course of his life based on annual tree ring structure. For such a growth analysis, it is necessary to cut down the full tree which should be examined, to work up the stem, to measure well-defined measurement points of the tree trunk and to analyze the resulting data.
At the fallen log at 11 well-defined positions stem discs are removed for examination (Fig.03). These points refer to a percentage of the total length of the trunk. They are at 0.1m, 1.30m (diameter at breast height) and at 15%, 25%, 35%, 45%, 55%, 65%, 75%, 85% and 95% of the total length of the standing tree.

Fig. 3 Sample kit for one tree

The collected samples are to be marked clearly and directly at the sampling point by using metal marks (Fig.04), which can be engraved easily with a simple nail, to identify the samples correct at a later date of the analysis. The use of metal marks has the advantage that it can be performed easily and regardless of weather conditions on-site and also by rain or storm no loss of marks is to be expected.

Fig. 4 unprocessed sample

The collected 11 samples per trunk are packed together in a bag and transported for further processing to the laboratory.
For workup the obtained samples, the stem discs be sanded to get a planar surface and an undisturbed view of the annual tree ring structure.

Fig. 5 sample prepared

After sanding the stem discs, a measurement cross which mark the largest expansion of the sample is applied (Fig.05). The axes of the measuring cross are at a 90 degree angle. On the axes of the measuring cross each annual ring is marked.
All scaled stem discs are measured with the LINTAB 6 equipment (Fig.06).

LINTAB 6 is a robust and precise tree ring measurement station for stem disks from the German manufacture RINNTECH. Together with a high quality stereo microscope (in this case a Leica stereo microscope) the LINTAB 6 can reach an optional precision of 1/1’000 mm. The markings on the stem disks are measured semi-manually and directly stored digitally (with the data acquisition software TSAP-Win) and organized in digital databases. The databases are used for computer-assisted analysis of the data. The average annual growth results from the annual ring difference of stem disk to stem disk. The measured data are stated in the unit of millimeters. The number of counted annual rings for the age determination is expressed in whole numbers. In addition to the increment from the stem analysis values for stem taper function can be obtained.

Fig. 6 LINTAB 6

2.4 Step 3 Analysing Phase

For the analysis of the data, the computer programs FlorExel, Microsoft Excel 2007 and StatPoint Technologies STATGRAPHICS Centurion XV are used (Figure 07). By using the software, it was possible to evaluate and process the real data obtained in Step 2 (Execution Phase) and to create growth models for Pinus elliottii.

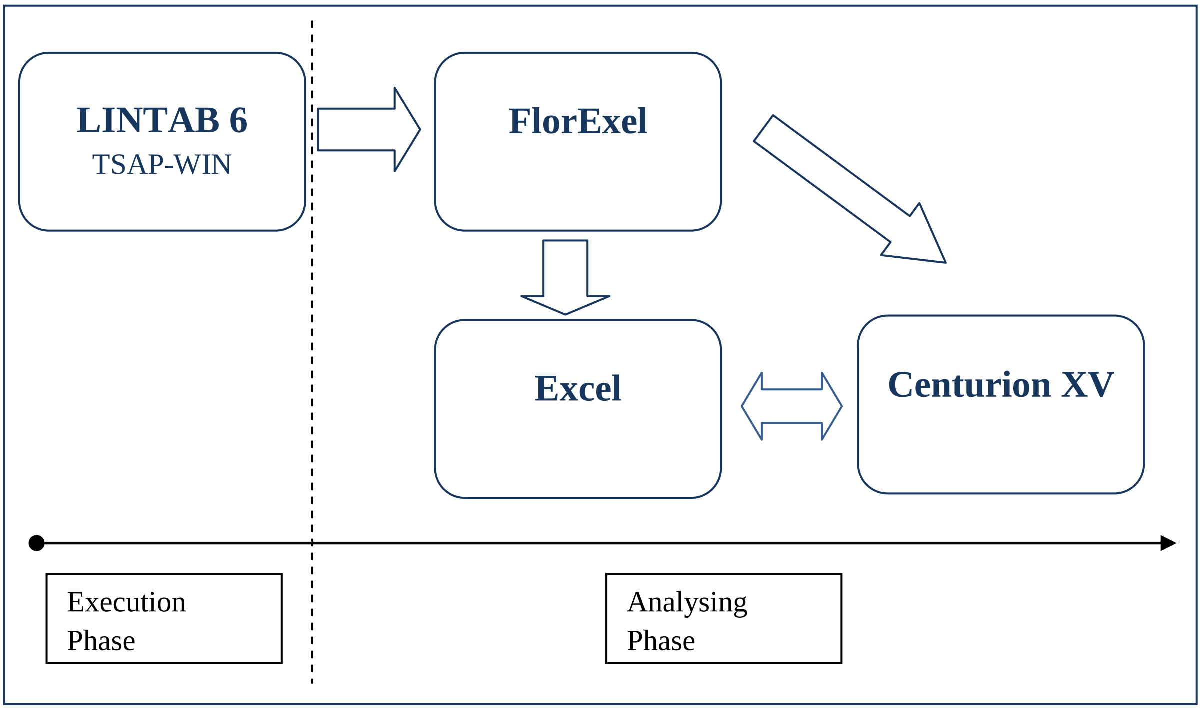

Fig. 7 digital data flow

Used software during the analysis phase

FlorExel is a productivity calculation tool with the possibility to add database from TSAP-Win to database for Microsoft Office Excel, which is designed specifically for the forest environment thematic as area of application. It also serves as a transmission tool for the digital measurement data of LINTAB equipment for further use in Microsoft Excel and StatPoint Technologies STATGRAPHICS Centurion XV.

Microsoft Office Excel 2007 is computer software which enables the user to create and format spreadsheets and analyze and share information to make more informed decisions.
Excel 2007 was used with the Microsoft add-in Solver to determine the estimated regression coefficients of the non-linear regression models of growth.

StatPoint Technologies STATGRAPHICS Centurion XV is Statistical software for implementation of the nonlinear regression calculations.

Application areas of the software

- FlorExel

With the databases from the tree ring measurement of the stem disks from step 2 (Execution Phase), it was possible to calculate with FlorExel a table of values for each tree, which contains the following data for each year of growth:

- Breast height diameter d1.3 (cm)
- Current annual increment ICA d (cm)
- Average annual increment IMA d (cm)

- Height of the tree h (m)
- Current annual increment ICA h (m)
- Average annual increment IMA h (m)

- Basal area of the tree g (m^2)
- Current annual increment ICA g (m^2)
- Average annual increment IMA g (m^2)

- Volume of the tree v (m^3)
- Current annual increment ICA v (m^3)
- Average annual increment IMA v (m^3)

- Microsoft Office Excel 2007/ STATGRAPHICS Centurion XV

Afterwards, the databases from Florexel are analyzed by using the software Microsoft Excel and STATGRAPHICS Centurion XV with the aim to obtain a mathematical description of the growth of the conifer species Pinus elliottii by non-linear regression functions.

Analysis calculations

Evaluation of the real growth values

To evaluate the measured data with Microsoft Excel first a computational and graphical processing of the height growth measurements was performed.
Height growth was chosen as a clear representative basis for the classification of the growth performances of the sample trees. By the expected large variation of the height growth performance of all examined trees three different growth groups were formed in order to reduce the variance of the range. Based on the average (media) of the height growth performance of all examined trees an accrual of +/- 7.5% was the limit value to separate all trees with greater deviation from the average growth performance (see Annex 1).

There was a division into the three following groups:

- **Group I** Above-average growth in height (more than 107.5% of the average height growth of all trees)
- **Group II** Average height growth (92.5% to 107.5% of the average height growth of all trees)
- **Group III** Below average height growth (lower 92.5% of the average height growth of all trees)

The used data by each growth group for the evaluation of the real growth values are:

- IMA $d_{1.3}$ average annual increment diameter at breast height
- ICA $d_{1.3}$ current annual increment diameter at breast height

- IMA g average annual increment basal area
- ICA g current annual increment basal area

- IMA v average annual increment volume
- ICA v current annual increment volume

Calculation of the growth performance models

To create a model for the growth performance of Pinus elliottii, the existing, original measured data for each group were further used in Microsoft Excel and Centurion XV.

From a mathematical perspective the Marquardt algorithm forms the basis for further calculations.

Estimation method
Marquardt algorithm "Least-Squares Estimation of Nonlinear Parameters"

The method of least squares is a standard mathematical method for Adjustment. Thereby to a point cloud of data, a curve is searched which passes as close as possible to the data points.

$$y = b_0*(1-\exp(-b_1*i))^{\wedge} b_2$$

y = dependent variable (Searched value)
b0 = independent variable 1, estimated regression coefficients
b1 = independent variable 2, estimated regression coefficients
b2 = independent variable 3, estimated regression coefficients
i = time

All measurement data are available as a point cloud, so the calculation could be performed.

First, using Microsoft Excel and the Microsoft add-in Solver, the three estimated regression coefficients (b0, b, b2) are approximately determined. Then the approximately determined estimated regression coefficients were calculated exactly with the StatPoint Technologies STATGRAPHICS Centurion XV software. The now obtained exact values for the coefficients were then calculated with the original model of the Marquardt algorithm in Excel and the values of the model calculation were displayed in diagrams.

Finally, for all three growth groups in each case the following values were calculated as a growth model:

- $d_{1.3}$
- h
- g
- v

2.5 Step 4 Simulation Phase

Economic Analysis

The economic analysis of all costs and revenues in a plantation rotation are analyzed quantitatively and financially.

Furthermore, an economic assessment of Pinus elliottii plantations in southern Brazil takes place. To accomplish this it was necessary to simulate one complete run of such a plantation.
It will be regarded the special plantation techniques in Brazil, the costs and revenues, as well as the end products obtained in quantity and economically aspects.

2.6 Step 5 Conclusions and Recommendations

The developed mathematical growth models are compared with the actually measured values and evaluated.

3 Findings

In this part of the study the individual findings are presented. Firstly, the results of the measurements of tree samples from FLONA Irati and the determined mathematical models of the growth performance of Pinus elliottii are presented. Followed by a fundamental illustration of a suitable rotation for a Pinus elliottii plantation situated in southern Brazil. The consideration includes the individual steps as well as the required technology and a presentation of possible end products of a Brazilian Pinus elliottii plantation. Finally, there is an economic analysis of a large scale Elliotti Pinus plantation.

3.1 Evaluation of the real recorded measurement values

First, the samples are divided into groups of trees in order to obtain accurate results of the work. Then there is an evaluation of the data on diameter at breast height, height growth, basal area and volume.

Breakdown of all examined trees due to the readings on the height growth

Because the entire number of sampled trees (finally, measurement results from 79 sample trees were available) having a large range of various development, due to the characteristic of the height growth performance of each individual tree a subdivision of the total samples was performed and three different growth groups emerged. This should contribute to more accurate determination of the growth model values.
Group I includes all the trees which have a greater height growth than 107.5% average value of all sample trees.
Group II includes all the trees which have a height growth in the range from 92.5% to 107.5% from the average of all sample trees.
Group III includes all the trees which have a smaller height growth than 92.5% average value of all sample trees (see Annex 01).

Each sample tree get a uniquely identify mark which is composed out of the letters A (due to the Portuguese word tree: árvore) and a continuous number. The markings start with A01 and run until A85. Because of incomplete data sets of 6 sample trees, this resulted in a total number of 79 sample trees for this study.

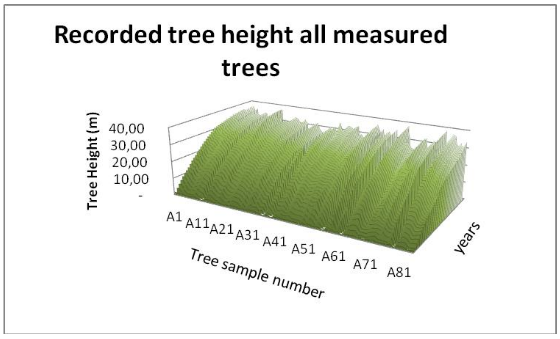

Fig. 8 recorded tree height all measured trees

	Sample tree identification	∑
Group I	**1, 5, 17, 18, 19, 20, 21, 23, 44, 55, 58, 66, 78**	**13**
Group II	**2, 3, 4, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 22, 24, 25, 26, 28, 29, 31, 32, 33, 37, 38, 40, 41, 42, 43, 45, 46, 47, 48, 49, 50, 51, 53, 54, 56, 60, 61, 62, 64, 65, 67, 68, 71, 72, 73, 75, 76, 80, 81, 83, 85**	**54**
Group III	**27, 30, 34, 35, 52, 59, 69, 70, 74, 77, 82, 84**	**12**

Tab. 1 group division sample trees

3.1.1 Diameter at breast height $d_{1.3}$

For the evaluation of the diameter at breast height ($d_{1.3}$) growth data, the ICA $d_{1.3}$ (current annual increment) and IMA $d_{1.3}$ (average annual increment) values for each growth group was calculated and displayed in diagrams.

The ICA $d_{1.3}$ (cm) value for each year is calculated as follows:

Difference between the actual $\text{diameter}_{1.3}$ from the $\text{diameter}_{1.3}$ of the previous year.

The IMA $d_{1.3}$ (cm) value for each year is calculated as follows:

The current $\text{diameter}_{1.3}$ divided by the number of years.

For each growth group, the calculated data are shown in a diagram. The X-axis is shown the time in years and on the Y-axis, the respective values of $d_{1.3}$ in the unit centimeter (cm).

In all three diagrams (Fig.18-20), there is a point of intersection between the two curves IMA $d_{1.3}$ and ICA $d_{1.3}$. At this intersection, the current annual increment and the average annual increment have the same value. That means after this point, the current annual increment is less than the average annual increment.
Therefore represents the intersection of the two curves an ideal time for thinning of the Pinus elliottii plantation.

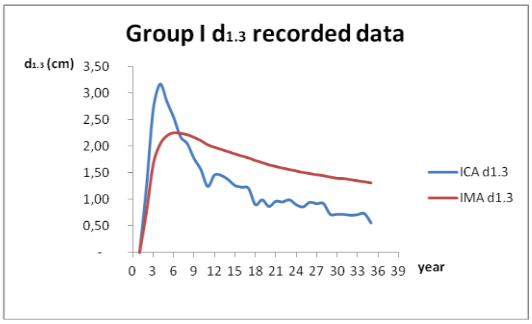

Fig. 9 Group I d1.3 real

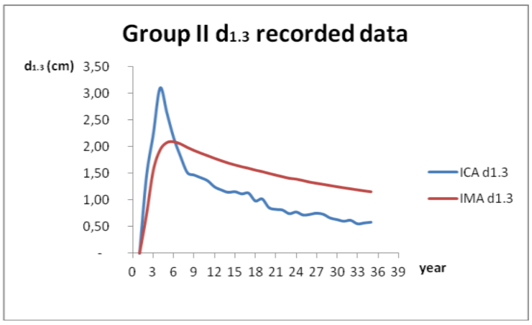

Fig. 10 Group II d1.3 real

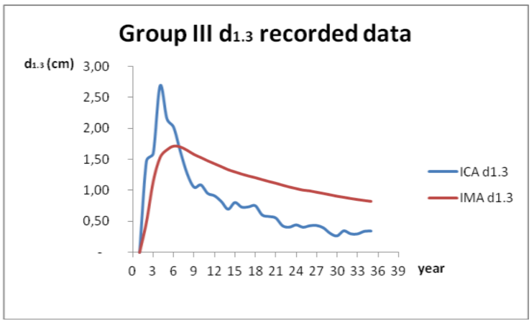

Fig. 11 Group III d1.3 real

The values of the intersections of each growth group are as follows:

- Group I year 6 2.25 cm
- Group II year 6 2.09 cm
- Group III year 6 1.72 cm

Regarded temporally the intersections are the same for all three growth groups. The values have a range from 1.72 to 2.25 cm.
Group I, with the greatest height growth performance over 107.5% of the average of all trees represent with 2.25 cm at the year 6 also the greatest value for $d_{1.3}$.
Compared with Group III with the lowest height growth performance under 92.5% also represent with 1.72 cm the lowest value for $d_{1.3}$.
Group II is terms of value for both observations in the midfield.

3.1.2 Height growth h

For the evaluation of the height growth (h) growth data, the ICA h (current annual increment) and IMA h (average annual increment) values for each growth group was calculated and displayed in diagrams.

The ICA h (m) value for each year is calculated as follows:

Difference between the actual height of the tree from the height of the previous year.

The IMA h (m) value for each year is calculated as follows:

The current height of the tree divided by the number of years.

For each growth group, the calculated data are shown in a diagram (Fig. 11-13). The X-axis is shown the time in years and on the Y-axis, the respective values of h in the unit meter (m).

For all three groups, there is an intersection of the two curves ICA h and IMA h.
This means that at this time the current annual growth value and the average annual value are equal.
Thus obtained as a basis for the determination of an appropriate time for thinning.

The values in which there are the intersections of the curves for the respective groups are as follows:

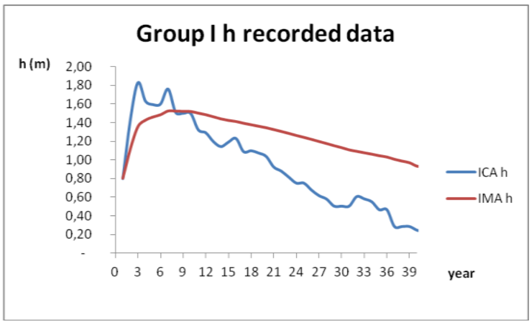

Fig. 12 Group I h real

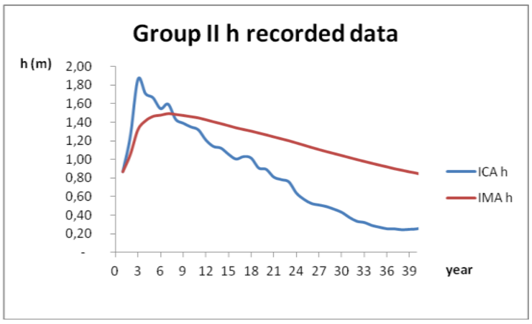

Fig. 13 Group II h real

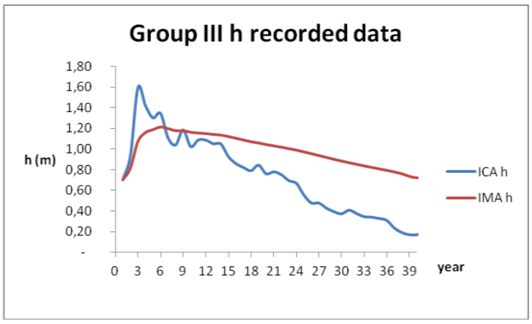

Fig. 14 Group III h real

- Group I year 7
- Group II year 7
- Group III year 7

Futher it can be recognize that between the three groups different heights growth values exist. The highest values are represented in Group I, the mean values in Group II and the lowest values in Group III.

3.1.3 Basal area g

For the evaluation of the basal area (g) growth data the ICA g (current annual increment) and IMA g (average annual increment) values for each growth group was calculated and displayed in diagrams (Fig. 21-23).

The ICA g (m²) value for each year is calculated as follows:

Difference between the actual basal area from the basal area of the previous year.

The IMA g (m²) value for each year is calculated as follows:

The current basal area divided by the number of years.

For each growth group, the calculated data are shown in a diagram.

The X-axis is shown the time in years and on the Y-axis, the respective values of g in the unit square meter (m²).

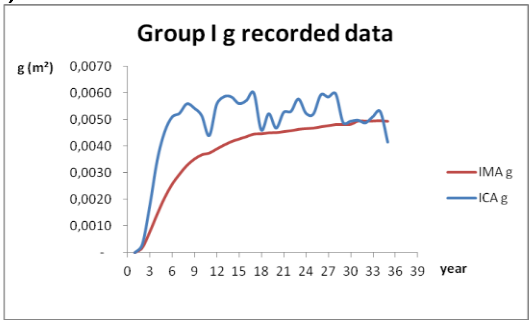

Fig. 15 Group I g real

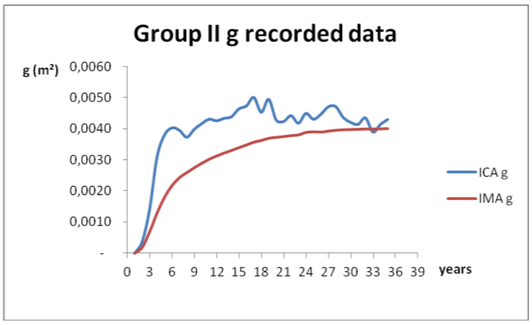

Fig. 16 Group II g real

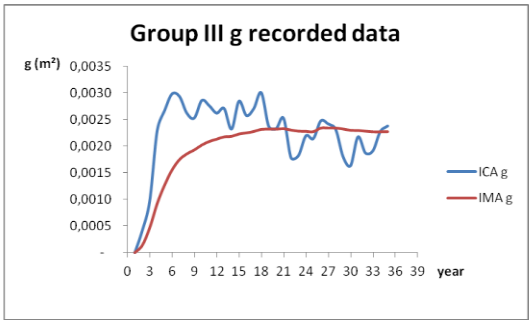

Fig. 17 Group III g real

The current annual increment basal area curves (ICA g) in all three diagrams fluctuated greatly. The real measured data show a very fluctuating ICA g curve. The IMA g curve behaves more quietly without major fluctuations during its course.
An interpretation of the two curves is very difficult to perform caused by the strong fluctuations of ICA g. There are several points of almost intersection of the two curves, but the real intersection points are in each case at later time points (Group I approximately year 35, Group II approximately year 34, Group III approximately year 20).

Example values for the year 12 from the diagrams:

- Group I year 12 ICA g 0.0056 m² IMA g 0.0039 m²
- Group II year 12 ICA g 0.0043 m² IMA g 0.0031 m²
- Group III year 12 ICA g 0,0026 m² IMA g 0.0021 m²

What is clearly to see, are the different heights of the g values per growth group considered at the same time. Here are the values of Group I the highest and the lowest values are from Group III. Group II with their values, is located in the midfield.

3.1.4 Volume v

For the evaluation of the volume (v) growth data the ICA v (current annual increment) and IMA v (average annual increment) values for each growth group was calculated and displayed in diagrams (Fig. 24-26).

The ICA v (m³) value for each year is calculated as follows:

Difference between the actual volume from the volume of the previous year.

The IMA v (m³) value for each year is calculated as follows:

The current volume divided by the number of years.

For each growth group, the calculated data are shown in a diagram.

The X-axis is shown the time in years and on the Y-axis, the respective values of v in the unit cubic meters (m³).

All three diagrams show tendentially a similar profile. For a long time, the value of the current annual increment (ICA v) is above the value for the average annual increment (IMA v) located. Over time from approximately year 42 there is an intersection of the two curves in all three groups. The values of v (m³) are graded according to the respective growth groups.

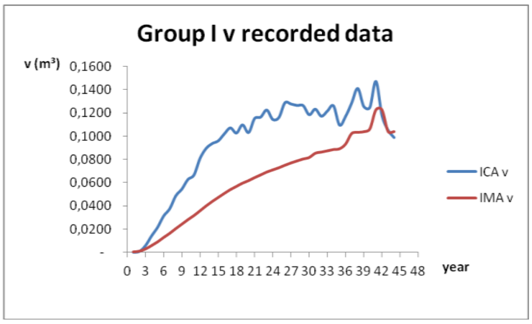

Fig. 18 Group I v real

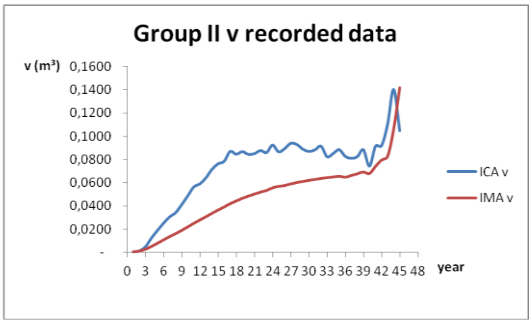

Fig. 19 Group II v real

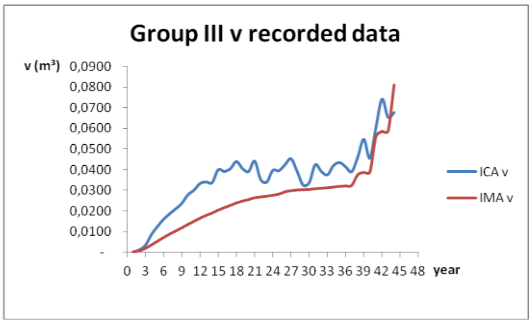

Fig. 20 Group III v real

Example values for the year 12 from the diagrams:

- Group I year 18 ICA v 0.1029 m³ IMA v 0.0566 m³
- Group II year 18 ICA v 0.0843 m³ IMA v 0.0440 m³
- Group III year 18 ICA v 0,0440 m³ IMA v 0.0238 m³

Group I has the highest values and group III has the lowest values. Group II with their values, is located in the midfield.

3.2 Mathematical calculation of the growth performance

For group I, II and III separately the values for a mathematical functions for $d_{1.3}$, g, h, v will be calculated in the next chapter.

3.2.1 Diameter at breast height $d_{1.3}$

b_0 = 58,4119
b_1 = 0,0490
b_2 = 1,16

y = 58,4119*(1-exp(-0,0490*i))^1,16

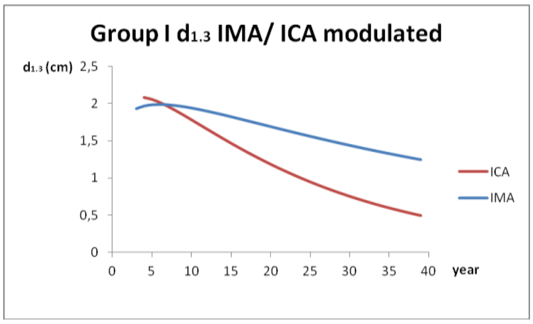

Fig. 21 Group I $d_{1.3}$ IMA/ ICA modulated

b_0 = 50,7392
b_1 = 0,0488
b_2 = 1,095

y = 50,7392*(1-exp(-0,0488*i))^1,095

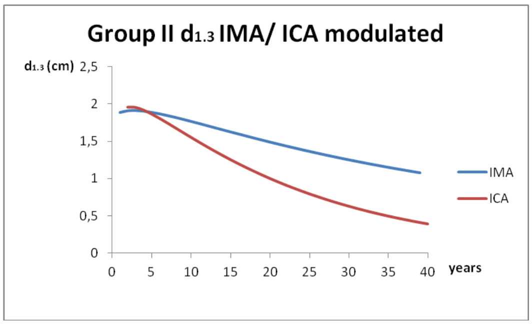

Fig. 22 Group II $d_{1.3}$ ICA/ IMA modulated

b_0 = 34,8697
b_1 = 0,0630
b_2 = 1,2

y = 34,8697*(1-exp(-0,0630*i))^1,2

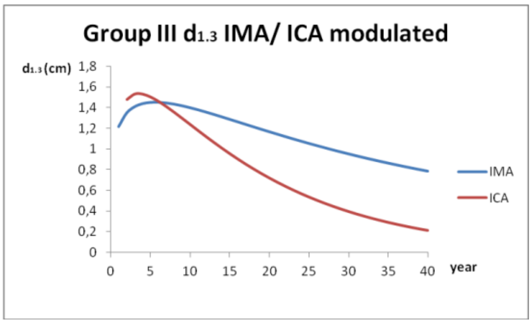

Fig. 23 Group III $d_{1.3}$ ICA/ IMA modulated

For all three groups, an algorithm for the mathematical description of the diameter at breast height growth was calculated (regression coefficients b_0, b_1, b_2). Thus it is now possible to calculate the diameter at breast height mathematically and to predict the developments of $d_{1.3}$.
Thereby a graphic representation of the evolution of growth (Fig. 21-23) is possible. Used for this purpose the X-axis represents time (year) and the Y-axis d1.3 (cm).
For using the algorithm the user must insert the searched time in years as replacement for the variable i and receives as y the value of the diameter at breast height (cm) in the requested time.

By the subdivision into three different groups, it is possible to perform the calculation for very good (Group I), average (Group II) and below average (Group III) growth regions for the conifer Pinus elliottii.

3.2.2 Height growth h

$b_0 = 43{,}3962$
$b_1 = 0{,}0590$
$b_2 = 1{,}3105$

y = 43,3962*(1-exp(-0,0590*i))^1,3105

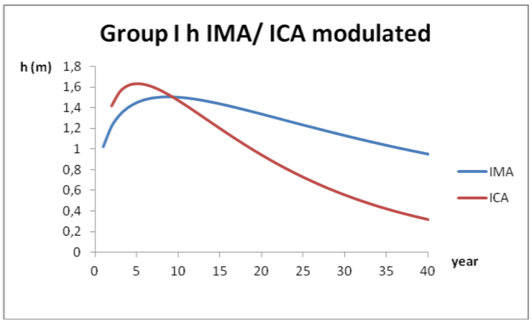

Fig. 24 Group I h IMA/ ICA modulated

$b_0 = 37{,}0854$
$b_1 = 0{,}0702$
$b_2 = 1{,}3572$

y = 37,0854*(1-exp(-0,0702*i))^1,3572

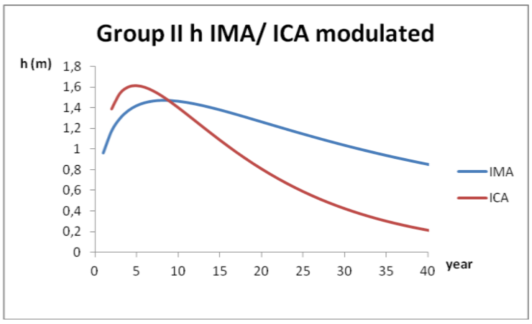

Fig. 25 Group II h IMA/ ICA modulated

$b_0 = 33{,}4003$
$b_1 = 0{,}0612$
$b_2 = 1{,}3279$

y = 33,4003*(1-exp(-0,0612*i))^1,3279

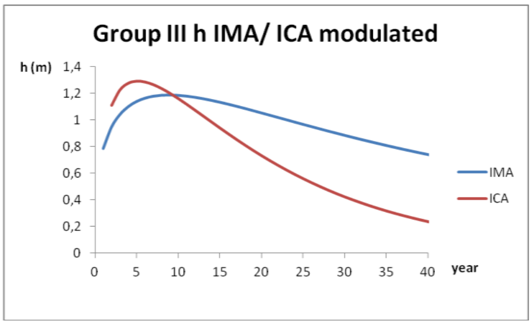

Fig. 26 Group III h IMA/ ICA modulated

For all three groups, an algorithm for the mathematical description of the height growth (h) was calculated (regression coefficients b_0, b_1, b_2). Thus it is now possible to calculate height mathematically and to predict the developments of h.
Thereby a graphic representation of the evolution of growth (Fig. 24-26) is possible. Used for this purpose the X-axis represents time (year) and the Y-axis h (m).
For using the algorithm the user must insert the searched time in years as replacement for the variable i and receives as y the value of the height (m) in the requested time.

By the subdivision into three different groups, it is possible to perform the calculation for very good (Group I), average (Group II) and below average (Group III) growth regions for the conifer Pinus elliottii.

3.2.3 Basal area g

$b_0 = 0,2196$
$b_1 = 0,0728$
$b_2 = 3,1084$

y = 0,2196*(1-exp(-0,0728*i))^3,1084

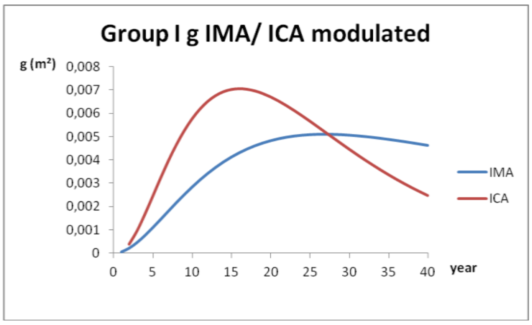

Fig. 27 Group I g IMA/ ICA modulated

$b_0 = 0,2510$
$b_1 = 0,0421$
$b_2 = 2,1515$

y = 0,2510*(1-exp(-0,0421*i))^2,1515

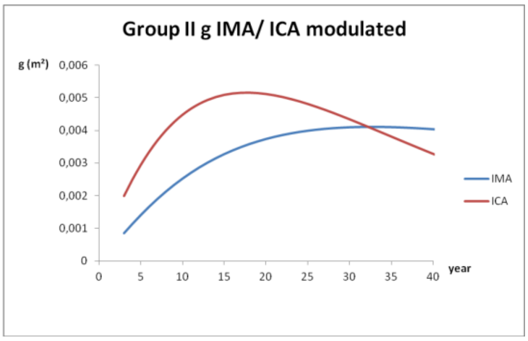

Fig. 28 Group II g IMA/ ICA modulated

$b_0 = 0,3070$
$b_1 = 0,0193$
$b_2 = 1,7013$

y = 0,3070*(1-exp(-0,0193*i))^1,7013

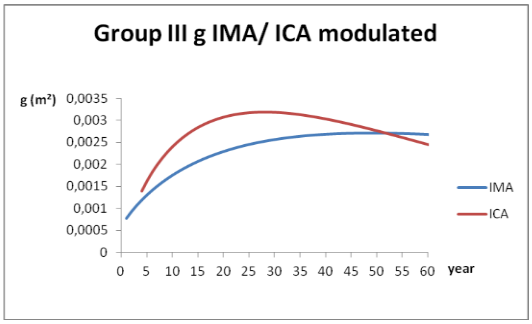

Fig. 29 Group III g IMA/ ICA modulated

For all three groups, an algorithm for the mathematical description of the basal area (g) was calculated (regression coefficients b_0, b_1, b_2). Thus it is now possible to calculate basal area mathematically and to predict the developments of g.
Thereby a graphic representation of the evolution of growth (Fig. 27-29) is possible. Used for this purpose the X-axis represents time (year) and the Y-axis g (m^2).
For using the algorithm the user must insert the searched time in years as replacement for the variable i and receives as y the value of the basal area (m^2) in the requested time.

By the subdivision into three different groups, it is possible to perform the calculation for very good (Group I), average (Group II) and below average (Group III) growth regions for the conifer Pinus elliottii.

3.2.4 Volume v

b_0 = 4,2979
b_1 = 0,0897
b_2 = 6,8445

y = 4,2979*(1-exp(-0,0897*i))^6,8445

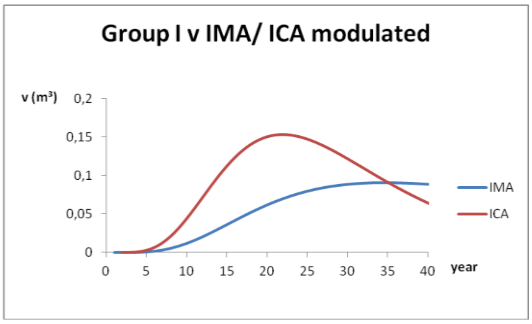

Fig. 30 Group I v IMA/ ICA modulated

b_0 = 6,7145
b_1 = 0,0328
b_2 = 2,7240

y = 6,7145*(1-exp(-0,0328*i))^2,7240

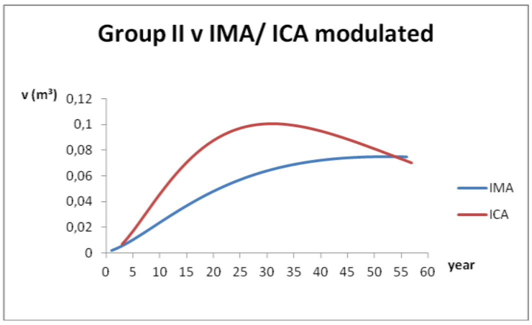

Fig. 31 Group II v IMA/ ICA modulated

b_0 = 5,7095
b_1 = 0,0250
b_2 = 2,7506

y = 5,7095*(1-exp(-0,0250*i))^2,7506

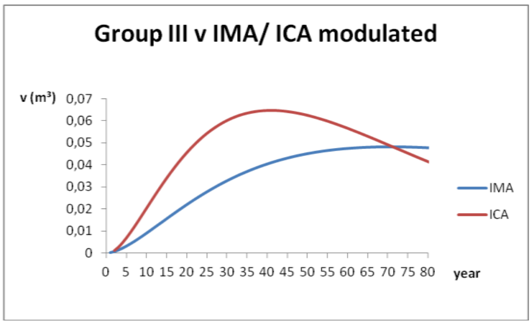

Fig. 32 Group III v IMA/ ICA modulated

For all three groups, an algorithm for the mathematical description of the volume (v) was calculated (regression coefficients b_0, b_1, b_2). Thus it is now possible to calculate volume mathematically and to predict the developments of v.
Thereby a graphic representation of the evolution of growth (Fig. 30-31) is possible. Used for this purpose the X-axis represents time (year) and the Y-axis v (m^3).
For using the algorithm the user must insert the searched time in years as replacement for the variable i and receives as y the value of the volume (m^3) in the requested time.

By the subdivision into three different groups, it is possible to perform the calculation for very good (Group I), average (Group II) and below average (Group III) growth regions for the conifer Pinus elliottii.

3.3 Rotation of a Pinus elliottii plantation in the area of Paraná / Brazil

In this section, the rotation of a Pinus elliottii plantation in the area of Paraná / Brazil is presented for Pinus elliottii plantations with an area of more than 10,000 ha company size. All necessary steps for one rotation will be explained and the therewith related resulting costs listed.

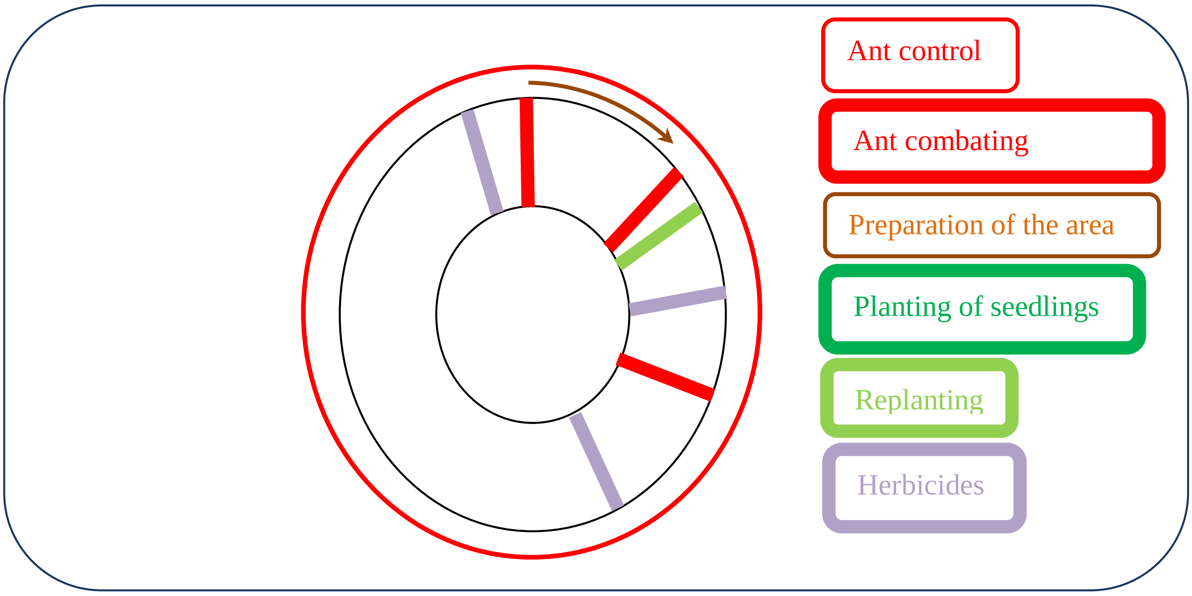

Fig. 33 rotation cycle

3.3.1 Rotation cycle of a Pinus elliottii plantation

Already one year before planting the plantation starts the work for the new plantation of combating the very frequently occurring ants in South America.
At the first year it is necessary to prepare the ground, to plant the new plants, to fertilize and to reduce unwanted vegetation/ weed and ants.

Ant control

Fig. 34 Ant control

Before starting the work for future plantation area one year in advance, the ant control and ant combating (focus on the Leafcutter ants which include 47 species of leaf-chewing ants belonging to the two genera Atta and Acromyrmex) is starting. Workers manually destroy the nests of ants. They also bring out gel, which is designed to prevent resettlement of the ants in the area. By the voracity of these insects and the very large size of the ant colonies, these insects represent a very large, permanent danger for the plantations in this area of South America. An annual check on resettlement of the ants and if necessary combat of the ants is essential to ensure a vital, undisturbed growth of the plantation. Scheduled combating ants place one year before planting, during planting and in the sixth year. The arising cost during the rotation of a Pinus elliotii plantation for planned ant combating amount to 324.80 R$/ ha.

Preparation of the area


Fig. 35 Hypper

For the preparation of the area which is intended for the use as a plantation, it is state of the art, that Brazilian companies use a multitasking machine like Hypper. Hypper machines are tracked vehicles (reduced soil compaction), which vacate the ground of all unwanted plants, loosen the soil, forming plant rows and fertilize the soil in the same operation (for several operations only one crossing of the area with a heavy machine is necessary - soil protection). For all these steps merely one worker who operates the machine is necessary. Hypper distributed 200 kg of fertilizer per hectare, the material cost of the fertilizer amount to R$ 1.50/ kg. Altogether, 300 R$ per hectare are to be calculated for the fertilizer.

Planting of seedlings


Fig. 36 Planting stick

In by Hypper created plant rows, the seedlings are semi manual planted by hand with a planting stick at a distance of 2 x 3 (1,667 plants/ ha). The price of such a young plant of Pinus elliottii amounts to 0.20 R$. The plant stick absorbed at each planting in the same operation with the plant a dose of gel ant control in order to protect the young plant. 8 men per hectare are needed for one day. The planting of seedlings results in labor costs of 360 R$/ ha and 333.40 R$ for the planting material/ ha.

Replanting


Fig. 37 Replanting

Since not all plants to 100% take root, a replanting is necessary. For the replanting 40 R$ per hectare be estimated. The replanting includes a pacing off of the entire area with simultaneous, manual replanting by one worker.

Herbicides


Fig. 38 herbicide distribution

During the preparation of the planting surface in year 0 mechanical weed control is done through the use of Hypper. The young plants therefore have an undisturbed environment and can grow. In the years 4, 10 and 18, a weed control is necessary. For weed control herbicides are sprayed semi-manually by the workers on the plantation. In the years 4 and 10, the cost per hectare are calculated with 383 R$ and in the year 18 with 582 R$, because the final weed control treatment has an 8-year interval to the last treatment in year 10 of the plantation (previous intervals are 4 and 6 years) and should be done very carefully before the final cutting.

Final cutting/ Harvest

The final cutting of a pine plantation in Brazil takes place in a combination of different partial operations. It starts with the felling of the trees with a Feller Buncher, transport of the full trees with a Skidder to a working space and the final workup of the full trees with a Processor. The harvesting costs can be calculated with 23.65 R$/ m³ including transport to the production facility within 40 kilometers.

Feller Buncher


Fig. 39 Feller Buncher

The Feller Buncher harvests several trees in a single operation. Combining a large circular saw blade and gripper arms such as machine like the Tigercat 860 model is able to harvest 160 tons per hour (corresponds approximately to 333 m³ pine per hour). After cutting, the felled full trees controlled deposited in the direct working range of the machine in a logistically useful formation for the subsequent operation. The costs are 1.32 R$/ m³

Skidder


Fig. 40 Skidder

Following, the deposited full trees from the Feller Buncher operation pulled by a Skidder from the stand and transported to a workup site. As a representative of today's technology, for example, the Tigercat 635 is used in Brazil. Depending on the distance between the stand and the workup side and the terrain conditions, this machine is designed for a working capacity of 160 tons per hour (same performance as the Feller Buncher). The costs of using a Skidder for the rearrangement of the full trees amount to 1.36 R$/ m³.

Processor


Fig. 41 Processor

On the workup site the full trees are pruned and cut to the appropriate length (2.4 m and 3.1 m lengths as standard) of the assortments which are to be produced. The respective lengths are then deposited in orderly piles so that they can be picked up by trucks and taken to the places of production. For the processor arise costs of 3.04 R$/ m³ for the workup.

Transportation


Fig. 42 stack in the plantation

The worked up assortments in the forest must be loaded and finally by truck transported to the production site. The loading costs 1.34 R$/ m³ and the transport within 40 kilometers radius costs 16.59 R$/ m³.

3.3.2 Possible end-products

The end-product classes were defined assortments of personal information from the interviews with MWV Rigesa, Klabin and LP Brasil and are consistent with the requirements of the industry which are working with plantations in the region of Paraná/ Brazil.

utilization	diameter with bark (cm)	Length of logs (m)
Residues/ bioenergy	< 08	≤ 2.4
cellulose	≥ 08 < 16	2.4
sawmill	≥ 16 < 35	3.1
peeled veneer	≥ 35	3.1

Tab. 2 possible end-products

Residues/ bioenergy

For sections with a diameter of less than 8 cm and a length of up to 2.4 m, in the past, the only use of this material was as waste. But in recent years rethinking has taken place in the plantation industry in Brazil. More and more companies are using this assortment for bioenergy production and chop the resulting biomass into wood chips on site. The current price (11/2012) is 28.9 R$/m³.

Cellulose

Assortments from 8 to less than 16 cm in diameter with a length of 2,4 m are used for the pulp and paper industry. This industry is very strong in growth, accordingly, there is a huge demand for this assortment in Brazil.
The current price (11/2012) is 28.90 R$/m³.

Sawmill

Assortments from 16 to less than 35 cm in diameter with a length of 3.1 m are used for the sawmill. The current price (11/2012) is until a diameter of 25 cm 50,70 R$/m³ and with a diameter of 25 to 35 cm 74,00 R$/m³.

Peeled Veneer

Assortments with more than 35 cm in diameter with a length of 3.1 m are used as Pelled Venneer. This is a very common application for the larger sized logs because the Brazilian furniture and construction industry use rather composite wood products instead of solid wood products. The current price (11/2012) is 105.90 R$/m³.

3.3.3 Financial Overview

The costs of establishing a plantation of Pinus elliottii be 2.025,55 R$/ha in the first year (Tab.3). In the subsequent years, again accruing costs for the insecticide treatment, Weed and ant control (Tab.4).

			First year	
	unit	***costs (R$/ha)***	***Units/ ha***	***Costs/ ha (R$/ha)***
Plants				
Pinus elliottii	1	0,20	1667	333,40
Fertilizer				
Fertilizer	kg	1,50	200	300,00
Insecticides/ Herbicide				
Ant control agent	kg	13,00	2	26,00
Weed control agents	liter	21,00	2	42,00
Oil	liter	5,00	0,83	4,15
Material costs (MC)				***705,55***
Working hours formation of stand				
Preparation of the ground	1 man/day	40,00	8	320,00
Ant control agent	1 man/day	40,00	2	80,00
Herbicide	1 man/day	40,00	2	80,00
Planting	1 man/day	40,00	8	360,00
Replanting	1 man/day	40,00	1	40,00
Labour costs (LC fs)				***880,00***
Working hours / maintenance costs				
Ant control	1 man/day	40,00	4	160,00
Weed control (Manually)	1 man/day	40,00	2	80,00
Weed control (Herbicide)	1 man/day	40,00	4	160,00
Spreading fertilizer	1 man/day	40,00	1	40,00
Labour costs (LC mc)				***440,00***
Total costs (TC)				***2.025,55***

Tab. 3 Culture grounds cost/ ha

time	cost item	Costs/ ha (R$/ha)
1st year	formation of stand	2.025,55
2nd year	insecticide	146,00
4	Weed control	383,90
6	Ant control	58,80
10	Weed control	383,90
18	Weed control	582,90
	Total costs	***3.581,05***

Tab. 4 total costs

In total 3.581,05 R$/ha are necessary to run a Pinus elliottii plantation.

3.3.4 Calculation of a plantation circulation

Presuppositions:

For the simulation, a rotation period of 20 years is assumed for the area of 1 hectare. Thinnings are carried out in the years 7 and 12.
The planting distance is 2x3 m for the species Pinus elliottii (1667 plants per hectare).

Applied formula for determining the diameter at breast height (cm) per tree:

$$d_{1.3} = 50{,}7392*(1-\exp(-0{,}0488*i))^{1{,}095}$$

with i = age of the tree

Applied formula for determining the height (m) per tree:

$$h = 37{,}0854*(1-\exp(-0{,}0702*i))^{1{,}3572}$$

with i = age of the tree

Applied formula for determining the volume (m^3) per tree:

$$v = 6{,}7145*(1-\exp(-0{,}0328*i))^{2{,}7240}$$

with i = age of the tree

year	d1.3 (cm)	h (m)	v (m^3)
1	x	0,96	x
2	3,77	2,35	0,0037
3	5,72	3,89	0,0106
4	7,63	5,49	0,0223
5	9,50	7,11	0,0391
6	11,31	8,71	0,0616
7	**13,05**	**10,27**	**0,0898**
8	14,73	11,79	0,1237
9	16,35	13,25	0,1634
10	17,90	14,65	0,2087
11	19,39	15,99	0,2594
12	**20,82**	**17,27**	**0,3153**
13	22,18	18,48	0,3762
14	23,49	19,63	0,4416
15	24,75	20,72	0,5115
16	25,94	21,74	0,5853
17	27,09	22,71	0,6629
18	28,18	23,63	0,7439
19	29,23	24,49	0,8280
20	**30,23**	**25,30**	**0,9149**

Tab. 5 growth values group II

3.3.4.1 Calculation of the quantity of wood

At the beginning of the plantation 1667 plants of Pinus elliottii are planted. After replanting it gets to a loss of 5% (83 plants). At the seventh year 50% of the trees (791 plants) harvested by the thinning number one. The still on site growing 792 plants get at the 12th year the second thinning. Also in this case 50% of the stock (396 plants) is removed. The remaining 396 plants are in the 20th year harvested by the final cutting.
For the value of the volume total extraction (m³), the volume of one extracted tree (m³) is multiplied with the number of trees extracted. The volume of one extracted tree (m³) is calculated with the formula for the Group II v modulated:

$$v = 6,7145*(1-\exp(-0,0328*i))^\wedge 2,7240$$

year (i)	Number of trees befor extraction	Number of trees extracted	Volume of one extracted trees (m³)	Volume of total extraction (m³)
0	1667	0	0	0
7	1583	791	0,0898	71,0010
12	792	396	0,3153	124,8588
20	396	396	0,9149	362,3004
Total		**1583**		**558,1602**

Tab. 6 Volume (m³) extracted

Determination of timber volume harvested in the years 7, 12 and 20

Pinus elliottii volumes at year 07

At the time of the first thinning at year 07 the trees reach a $d_{1.3}$ of 13,05 cm and a height of 10,26 m. Calculated with the Group II v modulated formula one single tree reach 0,0898 m³.

$d_{1.3}$ year 7 (cm)	h year 7 (m)	v year 7 (m³)
13,05	10,26	0,0898

The whole extracted assortment is below 16cm diameter (utilisation bioenergy/ cellulose) in the price range of 28,90 R$/m³. This results in a value of **2.052,82 R$** for 71m³ (791 trees x 0,0898 m³per tree x 28,90 R$/m³) during the first thinning.

Pinus elliottii volumes at year 12

During the time of the second thinning at the year 12 the trees reach a $d_{1.3}$ of 20,82 cm and a height of 17,27 m. The calculated volume per tree is 0,3153 m³.

$d_{1.3}$ year 12 (cm)	h year 12 (m)	v year 12 (m³)
20,82	17,27	0,3153

During the time of the second thinning the trees reach also the price range of 50,70 R$/m³ (16-25 cm diameter, 3,1 m length). Therefore it is necessary to see how much timber reach the next higher price range.

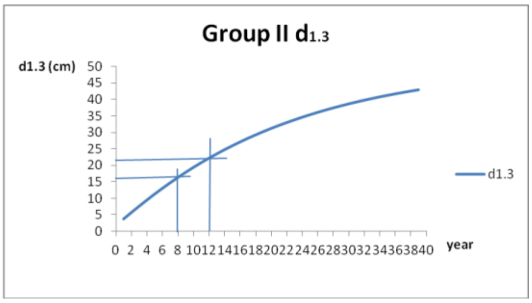

Fig. 43 Group II d1.3

year	d1.3 (cm)	h (m)	v (m³)
1	x	0,96	x
2	3,77	2,35	0,0037
3	5,72	3,89	0,0106
4	7,63	5,49	0,0223
5	9,50	7,11	0,0391
6	11,31	8,71	0,0616
7	13,05	10,27	0,0898
8	14,73	11,79	0,1237
9	**16,35**	**13,25**	**0,1634**
10	17,90	14,65	0,2087
11	19,39	15,99	0,2594
12	**20,82**	**17,27**	**0,3153**

Tab. 7 values until year 12

During year 9 the $d_{1.3}$ gets bigger than 16 cm (jump in price from 28,90 to 50,70 R$/m³). Until the year 12 the tree grow from 13,25 m to 17,27 m. This is a difference in length of 4,02 m. Thus, by the second thinning in the 12th year, the assortment of the sawmill can also be delivered. Due to the cylindrical shape of Pinus elliottii one length of 3.1 m and a guaranteed diameter of 16cm can be sold for 50,70 R$/m³, the other volume per tree can be sold for 28,90 R$/m³ as bioenergy/ cellulose assortment.

General formula for cylinder volume:

$$\text{Pi} * r^2 * h = v_{cylinder}$$

$\text{Pi} * (0{,}08\ m)^2 * 3{,}1\ m = 0{,}0623\ m^3$ Volume one length 3,1 m with min. 0,16 cm diameter
$0{,}0623\ m^3 * 396 = 24{,}6823\ m^3$ Volume total for 50,70 R$/m³ assortment

Total volume in the year 12 in the price level of 50,70 R$/m³ is 24,6823 m³. This produce income in the amount of **1251,39 R$** for the sawmill assortment.
For the bioenergy assortment, the total volume of the second thinning 124,8588 m³ is reduced by the sawmill assortment of 24,6823 m³. This results in total in 100,1765 m³ for the bioenergy/ cellulose assortment with a price of 28,90 R$/ m³. Thus obtained for the bioenergy/ cellulose assortment a amount of **2895,10 R$**.

Pinus elliottii volumes at year 20, final cutting

During the final cutting at the year 20 the trees reach a $d_{1.3}$ of 30,23 cm and a height of 25,30 m. The calculated volume per tree is 0,9149 m³.

$d_{1.3}$ year 20 (cm)	h year 20 (m)	v year 20 (m³)
30,23	25,30	0,9149

At final cutting in the year 20 the tree volume cover three different prices. The bioenergy/ cellulose price range (yellow colour) of 28,90 R$/ m³ and the two sawmill prices of 50,70 R$/ m³ (blue colour) and 74,00 R$/ m³ Green (colour).

year	d1.3 (cm)	h (m)	v (m³)
1	x	0,96	x
2	3,77	2,35	0,0037
3	5,72	3,89	0,0106
4	7,63	5,49	0,0223
5	9,50	7,11	0,0391
6	11,31	8,71	0,0616
7	13,05	10,27	0,0898
8	14,73	11,79	0,1237
9	**16,35**	**13,25**	**0,1634**
10	17,90	14,65	0,2087
11	19,39	15,99	0,2594
12	20,82	17,27	0,3153
13	22,18	18,48	0,3762
14	23,49	19,63	0,4416
15	24,75	20,72	0,5115
16	**25,94**	**21,74**	**0,5853**
17	27,09	22,71	0,6629
18	28,18	23,63	0,7439
19	29,23	24,49	0,8280
20	**30,23**	**25,30**	**0,9149**

Tab. 8 values until year 20

Price range of 74,00 R$/ m³

From the big end of the stem with 30,23 cm diameter a length of 3,1 m (ends with 26 cm diameter) will be calculated with 74,00 R$/m³.

Pi * (0,13 m)^2 * 3,1 m = 0,1645 m³

0,1645 m³ * 74,00 R$/ m³ = 12,173 R$

12,173 R$ * 396 trees = **4.820,50 R$**

Price range of 50,70 R$/ m³

For the next two lengths of 3,1 m the limit for the next lower price level (50,70 R$/ m³) is reached.

Length one from 22,2 m until19,1 m (minimum diameter 23 cm) and length two from 19,1 m until 16,00 m (minimum diameter 19 cm).

Pi * (0,115 m)^2 * 3,1 m = 0,1287 m³
Pi * (0,095 m)^2 * 3,1 m = 0,0878 m³

0,1287 m³ * 50,70 R$/ m³ = 6,525 R$ 6,525 R$ * 396 trees = **2.583,90 R$**
0,0878 m³ * 50,70 R$/ m³ = 4,451 R$ 4,451 R$ * 396 trees = **1.762,60 R$**

Price range of 28,90 R$/ m³

The total volume of one tree minus the volume of the two higher assortment results as the volume for the bioenergy/ cellulose assortment with 28,90 R$/ m³.

0,9149 m³ (v one tree year 20) – 0,1645 m³ - 0,1287 m³ - 0,0878 m³ = 0,5339 m³
0,5339 m³ * 28,90 R$/ m³ = 15,429 R$ 15,429 R$ * 396 trees = **6.109,88 R$**

3.3.4.2 Summary costs and revenues

All costs and revenues are listed.

Costs for Founding in the first year, Thinning (year 7,12), Final cutting (year 20) and 10% as administration costs for the whole plantation.
Revenues are the values of the sold timber volume (year 7, 12and 20)

In order to have a true comparison, all values are converted to the present value (PV). Given by an interest rate of 2%.

$PV = C * (1/ (1 + i)^{-t})$

PV = present value, C = Capital, i = interest rate (2%), t = time

Costs	R$/ ha	PV	Revenue	R$/ ha	PV
title	amount	2%	title	amount	2%
Founding 1	3581,05	**3510,83**	Sale year 7	2052,82	**1787,1**
Thinning 7	1.679,15	**1.461,80**			
Thinning12	2952,7	**2328,18**	Sale year 12	1251,39	**986,71**
Final cutting 20	8568,4	**5766,28**		2895,1	**2282,76**
Admin. 10%		**1306,70**	Sale year 20	4820,5	**3244,06**
				2583,9	**1738,89**
				1762,6	**1186,18**
				6109,88	**4111,77**
Total	16777,75	**14373,79**		21476,19	**15337,47**

Tab. 9 financial values

Financial performance of the plantation

15337,47 R$ - 14373,79 R$ = 963,68 R$
963,68 R$: 143,73 R$ = **6,70 %**

Calculated on the present value, the plantation has a yield of 6,70%.

4. Conclusions and recommendations

First there will be an answer to the main question. Afterwards the sub questions will be answered.

Main question:

Is it in terms of growth and economic efficiency, economically feasible to cultivate Pinus elliottii in the area of Paraná/ Brazil in large scale plantations?

In terms of growth and economic efficiency it is economically feasible to cultivate Pinus elliottii in the area of Paraná/ Brazil in large scale plantations. From the financial side of view is the possibility of a yield of 6,7% to operate such a plantation. Thus, the investment in such a plantation is financially interesting than alternatives in the banking sector, which now produces interest income of 2 - 2.5%. Important to note that this investment was tested for plantations with a total area of more than 10,000 hectares. Only with such a sized plantation the listed cost may achieved. A very good equipment with state machines corresponding to the prior art, which have a very large output per working hour together with the low cost of labor in Brazil make this profitability of the plantation possible. Increasing prosperity in Brazil and the continuing trend towards higher income must be observed in the long term very closely. Since the investment in such a plantation includes a minimum period of 20 years, it cannot predict exactly which social, economic changes will occur in the future. That investment offer the possibility to be successful, but the risk of a negative result of the investment is still possible. As this plantation is a natural product, it can also lead to various natural factors in failure. There is a constant danger of attack by ants, forest fires and drought. Through good management and prevention these dangers can be minimized but never be excluded completely. Therefore, the recommendation to pursue a continuous good ant control and to maintain firebreaks.

Which diameter at breast height (cm) Pinus elliottii reached during the growth of the tree?

Age 40 years Pinus elliottii can reach up to 42.92 cm for the diameter at breast height. (Fig.44)

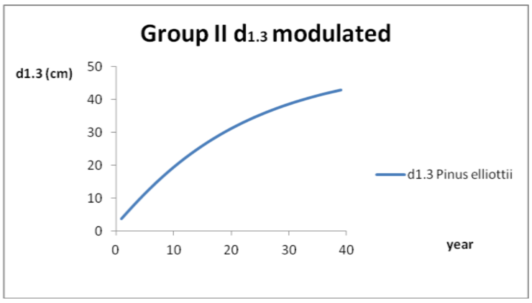

Fig. 44 Group II d1.3 modulated

What is the height (m) which Pinus elliottii reached over the growth years?

Pinus elliottii can reach a height of 36,6 m in the age of 80 years. (Fig.45)

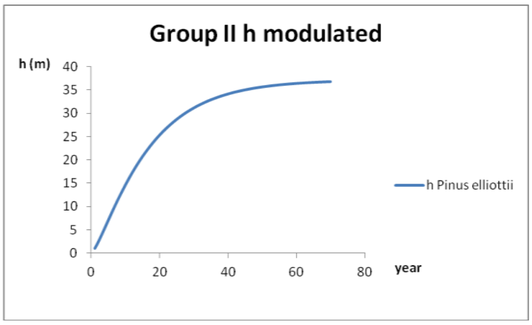

Fig. 45 Group II h modulated

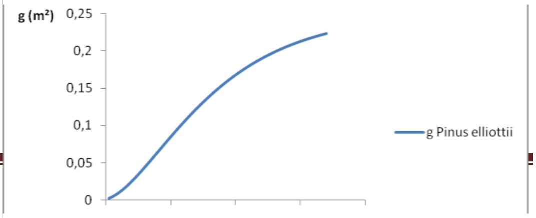

Fig. 46 Group II g modulated

Which basal area (m²) reached Pinus elliottii over the years?

Pinus elliottii can a value of 0,22 m² for the area basal in the age of 75 years. (Fig.46)

What is the volume (m³) which will be achieved from Pinus elliottii?

Pinus elliotti can reach 3,8 m³ in a age of 50 years. (Fig.47)

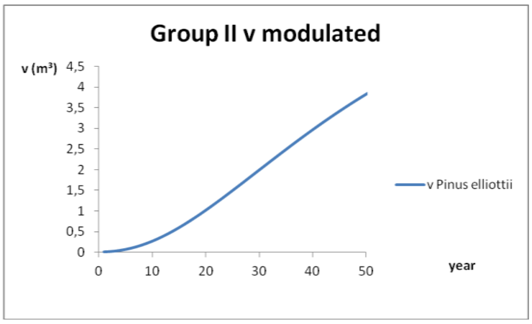

Fig. 47 Group II v modulated

Is there a mathematical model for the calculation of the growth of Pinus elliottii?
Yes there are mathematical models to calculate the growth of Pinus elliottii.

For $d_{1.3}$:
y = 50,7392*(1-exp(-0,0488*i))^1,095

For h :
y = 37,0854*(1-exp(-0,0702*i))^1,3572

For g :
y = 0,2510*(1-exp(-0,0421*i))^2,1515

For v :
y = 6,7145*(1-exp(-0,0328*i))^2,7240

What is necessary to cultivate Pinus elliottii as plantation?

It is necessary to control and combat ants and weed, to prepare the ground, to plant seedlings, to replant and if necessary to use herbicides.

At what point are the rotations of the plantation?

The rotations are in the years 7, 12 and final cutting in the year 20.

What are the possible end products of a Pinus elliottii plantation?
Possible end products are Residues/bioenergy, cellulose, sawmill or pilled veneer.

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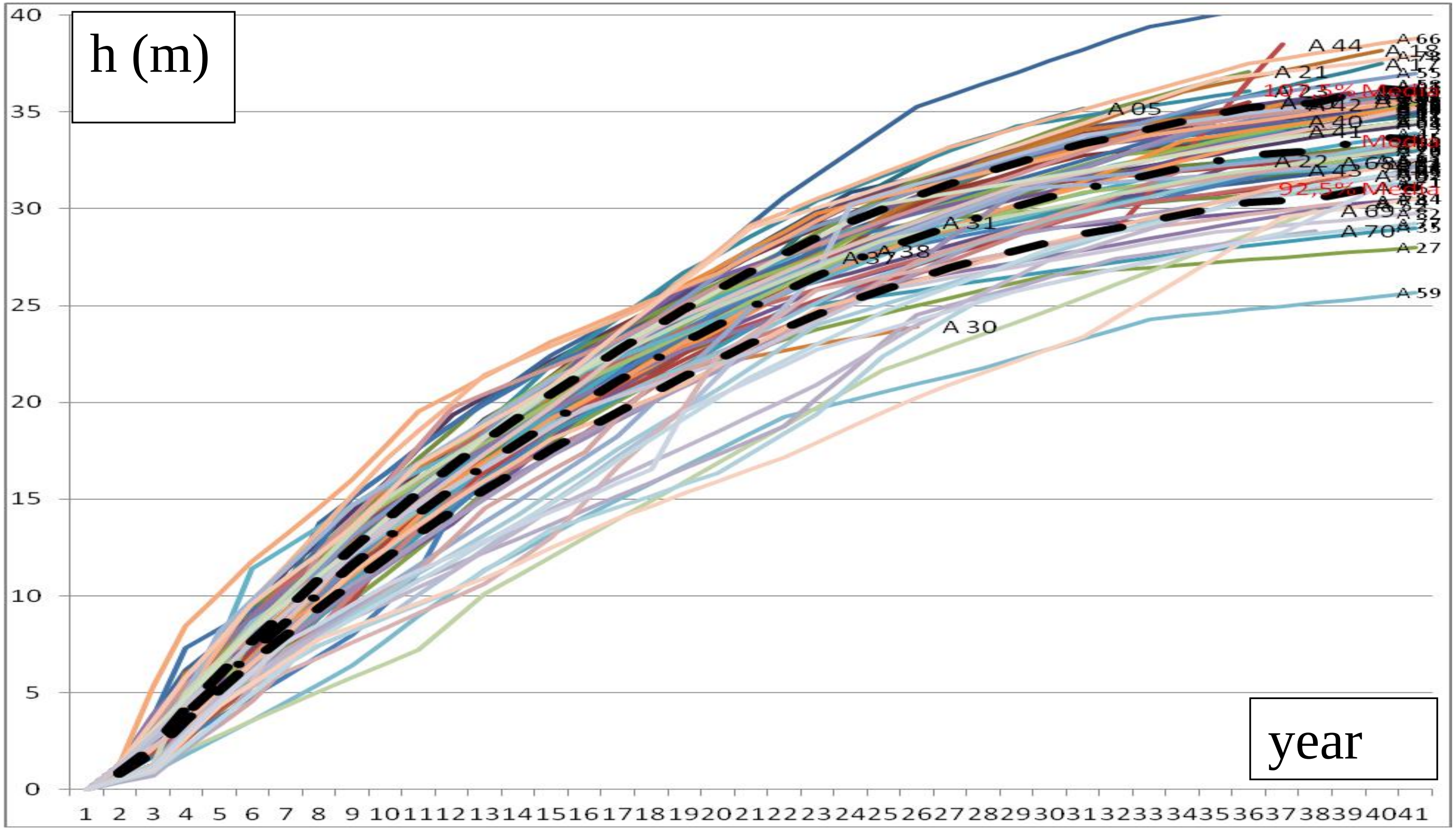

Annex 1 entire sample tree results h real