ACACIA MEARNSII DEBARKING: COMPARING DIFFERENT DEBARKING TECHNOLOGIES IN THE KWAZULU-NATAL AND MPUMALANGA FORESTRY REGIONS OF SOUTH AFRICA

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

J.R. Eggers

Date

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ABSTRACT

Debarking of *Acacia mearnsii* in South Africa has been conducted using mainly manual systems. Labour shortages and reliability of these systems has caused interest in alternative systems that might be able to debark *A. mearnsii*. The aim of the research is to compare three mechanised debarking technologies used to debark *A. mearnsii*. Research trials were conducted on the Demuth, Hyena and Hypro debarkers that would form part of semi-mechanised harvesting systems. The debarking technologies were analysed and compared in terms of productivity per productive machine hour (PMH), debarking quality, system costs and the quality of the bark that was produced. Furthermore, the effect that tree volume, strippability and form have on each of the debarking technologies was determined.

The debarking technologies were affected by each of the factors researched. Decreasing tree form had a negative effect on the productivity of each of the technologies. An increase in strippability class (strengthening wood-bark bond strength) caused a decrease in the productivity of each of the machines. An increasing tree volume had a positive effect on the productivity for the three debarking technologies. After the debarking had taken place, samples of bark were analysed at a laboratory to determine if it was acceptable for the processing facilities. Each of the debarking technologies produced bark of varying dimensions, but they were all found to be acceptable.

The system costs of the three debarking technologies were compared to a manual system cost at tree volumes of 0.1m³, 0.15m³ and 0.2m³. The Demuth debarker had the best system cost for a tree size of 0.1m³, while the manual system was best for tree volumes 0.15m³ and 0.2m³. The Demuth, Hyena and manual system costs were very similar for each of the tree volumes, with the Hypro being a little higher.

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INTRODUCTION AND PROBLEM STATEMENT

1.1 INTRODUCTION

Acacia mearnsii seeds were first introduced into South Africa from Australia in 1864 (Sherry, 1971). About ten years later the first plantings were carried out primarily for firewood, shelterbelts and shade for livestock. The use of the bark extracts for tannin products was only discovered in 1888 (Dunlop and MacLennan, 2002). *Acacia mearnsii* plantations make up approximately 7.6% of the South African plantation forestry estate, amounting to a total of 95 572 hectares (Forestry South Africa, 2008). In 2008, *A. mearnsii* accounted for a total roundwood production of 924 600 m^3, 4.6 % of the total annual roundwood production in South Africa (Forestry South Africa, 2008). *A. mearnsii* extract is mainly used as a vegetable extract in the tanning application of leather for production of products such as shoes, belts, bags and saddles. *A. mearnsii* extract is also used for the production of industrial adhesives used in the manufacturing of weather proof and boil proof particle board, plywood, fibre board and corrugated cardboard (Dunlop and MacLennan, 2002).

Mechanical debarking is fast becoming a reality in the South African forestry industry and there are factors influencing the change from manual to mechanical debarking. Internationally, mechanised debarking has taken preference over manual debarking due to labour being more expensive than in South Africa, and the operation being safer (Dunlop and MacLennan, 2002). In the past in South Africa, manual labour has been available and willing to carry out the task of debarking, but various factors are forcing the South African Forest Industry to start exploring the route of mechanical debarking, to form part of a semi-mechanised operation. Labour shortages, HIV/AIDS and forestry not being a first choice career due to debarking being very difficult work, is causing productivity losses (Steenkamp, 2007; Grobbelaar and Manyuchi, 2000). During the months of December and April, the labour is on leave. These dates fall during the peak debarking season, therefore three productive weeks are lost per year. With debarking being one of the most prominent areas for the occurrence of injuries, safety will also be improved through mechanisation or partial mechanisation of harvesting systems. Due to the abovementioned factors, Forest

Engineering Southern Africa (FESA) has taken decisions to research various systems and machines that could be used to produce a product more cost effectively, with greater productivity and at the same quality as the currently used manual systems. The factor of year-round harvesting could also be improved, therefore preventing the need for large stocks of timber. As people would be constantly working near these timber stocks, timber theft may be reduced. The machines that have been included in this research are machines that have the potential to be used to debark *A. mearnsii.* The machines also have the potential to produce bark of the correct dimensions and quality. The dimensions and shape of the bark will have an effect on the processing facilities and the product produced, as explained in Chapter 2. If the results obtained from the research shows positive figures towards mechanical debarking, the machines could be used internationally to debark similar *Acacia* species.

This research will cover the effect of these bark dimensions/shapes on the extraction efficiency as well as the effect on the quality of the end product. This research will investigate the debarking of *A. mearnsii* using:

1. The Demuth mobile debarker (DDM 420), which is a ring debarker that loosens the bark from debranched logs with rollers, cuts it to size with knives and removes it with scrapers. The bark is removed in chip form (Demuth machines, 2008).

2. The Hypro debarker, which is a tractor-mounted processor that removes the bark from tree lengths by applying pressure with the feed rollers. The bark is removed in strips of varying length depending on the wood-bark bond strength (Hypro, 2008).

3. The Hyena MK 3 debarking head, which removes the bark from tree lengths by applying pressure with the feed rollers. The bark is removed in strips of varying length depending on the wood-bark bond strength. The Hyena was used only to debark the tree lengths, no crosscutting took place.

The effect that tree volume, tree form and strippability (wood-bark bond strength) have on the productivity of each of the technologies will be determined. The effect

that these three factors have on the quality of the bark produced as well as the debarking quality will also be determined.

1.2 PROBLEM STATEMENT

In South Africa, most debarking of *A. mearnsii* is carried out manually. Finding labour to carry out cost effective *A. mearnsii* debarking is becoming increasingly difficult. Further to this, *A. mearnsii* trees are usually small with bark that is difficult to remove. Often no debarking takes place during the drier winter months, due to the wood-bark bond being too strong (Dunlop and MacLennan, 2002). If the bark is to be used by a processing facility, then bark quality in terms of dimensions, amount of damage to the bark and time after debarking also becomes important. One of the most limiting factors to mechanised *A. mearnsii* debarking, is the quality of the bark that is produced. If a large area of the cambium layer is exposed during the debarking process, caused by the knives or rollers damaging the bark, it increases oxidation leading to a darker tannin powder. The mechanical debarkers also produce bark of varying length and size. Consistency of bark size once chipped is of vital importance for the processing plants. It determines the quality of the end product, due to it affecting the defusing process by affecting the amount of possible extractives to leach out (Mimosa central co-op, 2007). The processing plants are able to overcome incorrect chip sizes by using drum chippers to create acceptable sizes from larger chips of bark (Dobson, 2009). *A. mearnsii* bark processing brings with it a unique set of circumstances, because unlike *Pinus* and *Eucalyptus* species, the bark is not a waste product to be disposed of. *A. mearnsii* bark is processed to yield tanning extract (Dunlop and MacLennan, 2002; Sherry, 1971). In order to extract the tannin efficiently the bark needs to be resized, traditionally into uniformly small bark chips of 6mm x 6mm in dimension before it can be used in the leaching process. Increasing chip size reduces the extraction efficiency which in turn affects the profitability of the factory. The three systems being studied each have different methods of debarking and thus produce different bark forms.

1.3 RESEARCH QUESTION

The various problems discussed in Section 1.2, when summarised, leads to the following research question:

Are there mechanical debarking alternatives to manual debarking that are able to debark <u>Acacia mearnsii</u>, achieving the correct quality and production levels at an acceptable cost?

1.4 AIM AND OBJECTIVES OF RESEARCH

The aim and objectives of the research can be defined as follows:

1.4.1 Aim

The research will determine whether the mechanical debarking technologies are commercially viable alternatives to current manual debarking in the areas of productivity and quality, from the perspective of the grower and the bark processing facilities. The three technologies used in the research will also be compared against one another in terms of the above mentioned factors. The factors that constrain any of the technologies from being productive or from producing a product of the desired quality will also be determined.

1.4.2 Objective

The objective of the research is to:

- Conduct a literature review and identify different machines that have been used to debark *A. mearnsii* in the past, both nationally and internationally.
- Determine the effect that tree volume, strippability and tree form have on the productivity and bark quality of the different debarking technologies.
- Research the assigned machines in terms of quality of debarking and the acceptability of the bark at the processing facilities.

- Estimate the costs associated with the different technologies and determine the various system costs.

This will assist the South African forestry industry in the selection and evaluation process when deciding on which machines to purchase for use in the debarking process of *A. mearnsii*.

1.5 DATA COLLECTION

Infield trials were used to collect the data that was used in the research. Once the machines to be researched had been identified, owners of these machines were located. *A. mearnsii* compartments in the near vicinity of the machines were inspected to identify those with a wide variation of tree volume, form and strippability, to get a good sample distribution for the research. Sites within each of the compartments were then demarcated. Tree height, diameter and form were then documented for each tree and each was assigned a number. The number was then used to track the tree and to determine the productivity and debarking quality of each of the machines. Samples of bark were randomly collected after debarking, as discussed in Chapter 3, to be analysed at the processing facilities. This was done to determine the effect of the different bark dimensions produced by the machines on the tannin extraction efficiency at the mill.

1.6 VALIDITY AND RELIABILITY

Validity refers to the trustworthiness and accuracy of scientific findings. It is defined by the accuracy with which an instrument measures what it claims to measure (Burns and Grove, 2005; Welman and Kruger, 2004). Reliability refers to the degree of consistency by which the research produces the same results with repeated use (Burns and Grove, 2005).

The validity and reliability of the conducted research is described as follows:

1.6.1 Validity

The research conducted involved the marking and measuring of trees. The measurements that were taken were the height and diameter of each tree. A calliper was used to determine the breast height diameter (1.37m) of each of the trees. When diameter measurements were taken, the author would stand on the upslope side of the tree which is the standard when taking measurements (South African Forestry Handbook, 2000). With trees that did not have a round form, two measurements were taken and the average of the two was used as the diameter reading. For the height measurements, a vertex hypsometer was used. The device was calibrated each time that measurements were taken to ensure that there were no inaccuracies regarding the heights. After some trees were felled, actual heights were measured with a tape measure to compare with the results from the vertex hypsometer to ensure accuracy, and it was found to be accurate.

Each of the sample trees was given a ranking for form, volume and strippability. For the determination of form class, there were three different ranks. The ranks were determined according to the physical form of the tree - how straight or bent the stem of the tree was. The trees were always ranked by the researcher to ensure that there was no variation in interpretation of the three different rankings, therefore ensuring uniformity in decisions. The strippability was divided into five different ranks. These were determined by the ease with which the bark could be removed from the stem of the trees. Manual tests were conducted by the researcher to determine the strippability and they were ranked accordingly. The tree volumes were calculated using the same calculation throughout the studies (Schumacher and Hall formulae). The calculation used the breast height diameter (DBH) and the height of each of the trees. Due to vertex hypsometer being calibrated correctly and diameter measurements being taken in a standard and consistent way, the tree volume results did not vary throughout the entire research.

The time and motion studies were conducted in deciminutes (100’s of a minute). The elements were determined by the researcher and machine operators, and remained constant throughout the research as well as between the different machines.

1.6.2 Reliability

The reliability of the research was confirmed by the data collection methods that were used, as described under validity. The rankings of the different measurements were never changed throughout the studies. The calibration of the equipment was done correctly and frequently. The method is discussed in more detail in Chapter 3, describing how the research data was collected.

1.7 SIGNIFICANCE OF THE RESEARCH

Various factors such as shortage of labour and the possibility of longer debarking seasons have forced the South African forestry industry to investigate various machines that could be used to debark *A. mearnsii*. Without any productivity or quality information for any possible machines, it is impossible to make informed business decisions. The research results will have a marked effect on the possible mechanisation of *A. mearnsii* debarking in the South African forestry industry.

1.8 JUSTIFICATION FOR THE RESEARCH

Various industry stakeholders have shown interest in purchasing machines to be used for the debarking of *A. mearnsii*. There is a shortage of information on the productivity and costs of the various debarking machines in the South African forestry situation. The results will determine the productivity and quality of the different debarking machines, as well as the different machine and system costs associated with each of them. It will therefore be possible to make informed decisions on which machines to purchase. This research is also mainly funded by industry, showing that there is a direct need for the research to be conducted.

1.9 FOCUS OF THE RESEARCH

The research was primarily limited to companies and industry stakeholders that were currently using the various machines to be researched in the South African forestry industry.

The geographic area in which the research was conducted included the major forestry areas of Mpumalanga and KwaZulu-Natal where more than 95% of *A. mearnsii* plantations occur.

The research focused on the effect that differing tree volumes, tree form and strippability would have on the quality of debarking, and the quality of the bark produced. The subsequent effect that bark quality had on extraction efficiency at the processing facility was also determined. The research also focused on the costs that were associated with each of the machines as well as the different system costs. These results were used to determine the most productive and cost effective system.

1.10 ORGANISATION OF THE RESEARCH

Chapter 1 serves as a general introduction to the research with specific reference to the current problems facing the *A. mearnsii* plantation industry, the problem motivating the research, the significance of the research and the aim and objectives of the research.

The literature review gives an overview of the *A. mearnsii* plantation industry in South Africa, in terms of areas, markets and product requirements. It also determines and discusses the machines which have been used to debark *A. mearnsii* as well as those that have been used successfully to debark cold tolerant *Eucalyptus* species.

Chapter 3 explains the methodology followed to achieve the defined aim and objectives of the research.

The results obtained from the three technologies are described in Chapters 4, 5 and 6. This includes the effects that tree volume, tree form and strippability have on the productivity of the technologies and the quality of the bark produced.

With the productivity and quality of the different debarking technologies being covered in the previous chapters, the costs of the different machines and systems are discussed in Chapter 7.

The three machines are compared against one another in Chapter 8.

Chapter 9 concludes the research findings and discusses further recommendations for the machines and systems used.

1.11 DEFINITION OF KEY CONCEPTS

The following key concepts need to be explained and defined to ensure the correct understanding in the chapters to follow:

Three wheel logger- A loader developed by Bell Equipment in South Africa. It consists of two drive wheels in the front, also used to steer the loader, and a smaller jockey wheel at the back. The loader is either used infield to load log lengths for extraction, or to sort and load logs on a landing.

Debarking and debranching head- A boom-mounted unit which performs one or more processing functions. It consists of a steel head with debranching knives on either side and rollers situated in the head. It has the ability to debranch, using debranching knives, and debark trees through pressure applied by the rollers. The rollers are used to pull the tree through the head (Granvik et al., 1983). The debarking head therefore has the ability to debranch and debark a tree.

Harvester head- A harvester head is a boom-mounted unit which has the capabilities of a debarking head, but also has the ability to fell or crosscut the trees. In addition to the debranching knives and rollers, the harvester head has a hydrostatic chainsaw used to cut the trees into lengths (Kellogg et al. 1992). The harvester head therefore has the ability to fell, debranch, debark and crosscut a tree.

Debarker- A machine used to remove bark from trees or logs prior to them being processed (Kellogg et al., 1993).

Crosscut- Cutting a felled tree into log segments (Stokes et al., 1989).

Diameter at breast height (DBH)- The diameter of a tree taken at a height of 1.37m, used to calculate tree volumes (Forestry South Africa, 2008).

Productive Machine Hours (PMH)- PMH is the time that the machine is planned to actually carry out its work. A PMH is when the machine is actually available and is working. It includes work time and any delays which are directly related to the everyday work of the machine, such as moving of stumps in the path of the machine.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

In South Africa, most debarking of *A. mearnsii* is carried out manually. Finding labour to carry out cost effective *A. mearnsii* debarking is becoming increasingly difficult (Steenkamp, 2007). Further to this, *A. mearnsii* trees usually have a small tree volume (research trials showed an average of 0.120m³) with bark that is difficult to remove. Often no debarking takes place during the drier winter months, due to the wood-bark bond being too strong (Dunlop and MacLennan, 2002). If the bark is to be used by a processing facility, then the bark quality also becomes important. One of the most limiting factors to mechanised *A. mearnsii* debarking, is the quality of the bark that is produced (Mimosa central co-op, 2007). If the bark is damaged during the debarking process, it increases oxidation leading to a darker tannin powder. Consistency of bark dimensions is of vital importance for the processing plants. It determines the quality of the end product produced, as it affects the defusing process by determining the amount of possible extractives to leach out (Mimosa central co-op, 2007). The processing plants are able to overcome incorrect chip sizes by using drum chippers to create these sizes from larger chips of bark (Dobson, 2009). *A. mearnsii* bark is different to *Pinus* and *Eucalyptus* species, as its bark can be used economically and not merely be discarded. When it becomes possible to debark mechanically, the percentage of total time spent on the debarking element will be reduced considerably (Wattle Research Institute, 1975). *A. mearnsii* bark is processed to yield tanning extract (Dunlop and MacLennan, 2002). In order to extract the tannin efficiently the bark needs to be resized; traditionally into uniformly small bark chips of 6mm x 6mm in dimension before it can be used in the leaching process. Increasing chip size reduces the extraction efficiency which in turn affects the profitability of the processing facility.

2.2 OVERVIEW OF *ACACIA MEARNSII* INDUSTRY IN SOUTH AFRICA

The history and current *A. mearnsii* products and markets are discussed below.

2.2.1 History

A. mearnsii seeds were first introduced into South Africa from Australia in 1864 (Sherry, 1971). About ten years later the first plantings were carried out primarily for firewood, shelterbelts and shade for livestock (Sherry, 1971; Williams, 1932). The use of the bark extracts for tannin products was only discovered in 1888 (Dunlop and MacLennan, 2002).

2.2.2 Plantations

A. mearnsii plantations make up approximately 7.6% of the South African plantation forestry estate, amounting to a total of 95 572 hectares (Forestry South Africa, 2008). In 2008, *A. mearnsii* accounted for a roundwood production of 924 600 m^3, 4.6% of the total annual roundwood production in South Africa (Forestry South Africa, 2008).

2.2.2.1 Areas

The majority of *A. mearnsii* plantations occur in the KwaZulu-Natal and Mpumalanga provinces, each having 79 178 and 13 932 hectares planted to *A .mearnsii* respectively (Forestry South Africa, 2008). The other 2 462 hectares occur in the Western and Eastern Cape as well as the Limpopo provinces (Forestry South Africa, 2008).

2.2.2.2 Products

One of the factors separating *A. mearnsii* from other commercially planted species is the utilisation of the bark as well as the timber. The timber is mainly used in the production of particle board and pulp (Dunlop and MacLennan, 2002). The bark is used mainly to extract tannin for the tanning of leather hides and the production of adhesives.

2.2.2.3 Timber

A. mearnsii timber was traditionally used for firewood and building purposes, along with other products such as rayon, charcoal, furniture, flooring blocks and mining timber, structural timber and fencing poles (Dunlop and MacLennan, 2002). In the past few years it has become a popular source of high quality fibre for pulp production. One of the main timber qualities making it good for pulp is a relative density of 670kg/m³ on a bone-dry basis (Dunlop and MacLennan, 2002). The mining timber markets have reduced due to the fact that wattle is now being replaced largely by *Eucalyptus* species (Dunlop and MacLennan, 2002).

In rural areas, there is still a strong demand for *A. mearnsii* firewood and building poles, and a large amount of woodlots have been established in these areas. A large amount of timber that does not meet the pulpwood specifications gets used by charcoal producers (Dunlop and MacLennan, 2002).

Currently the main products produced from *A. mearnsii* are:

- Pulp
- Firewood and charcoal production
- Mining timber (a declining market with demands being met by *Eucalyptus* species)
- Fencing and building poles

(Dunlop and MacLennan, 2002)

2.2.2.4 Bark

One of the reasons for wattle being a very popular species, mostly with private farmers, but also with larger companies, is not only the price received for the timber, but also because the bark can be utilized. This is the only commercially planted species where the bark has an economic value. The additional return made from the

bark will usually be able to cover the harvesting costs therefore will increase net-profit (Dunlop and MacLennan, 2002).

There are many factors that affect the quality of bark used for the production of tannin powders. These factors are influenced by site, method of debarking, time after felling and weather, to name a few. Some factors cannot be changed such as weather, but others can be managed to produce a quality product for processing plants (Dunlop and MacLennan, 2002).

There are various products that are produced by the processing plants, based on current markets as well as the quality of the bark available. When the bark is fresh and of good quality, a higher priced product can be produced, therefore increasing the profitability of both the grower and the processing facility (Eggers, personal communication, 2010). For plantations that are situated further from the processing facilities and cannot send fresh bark, they are able to send stick-bark. Stick-bark is bark that has been air dried after debarking and once dry is bundled and sent to the processing facility. This bark will only be used for the production of adhesives (Dunlop and MacLennan, 2002). When suppliers are able to send wet bark, it is best to send the bark on the same day as when the debarking occurred, and no later than three days after debarking (Dunlop and MacLennan, 2002). The quality of the bark is influenced by the bark colour, thickness, maturity, condition, bundle presentation and the exclusion of extraneous materials such as sand, rocks and branches (Dunlop and MacLennan, 2002).

A. mearnsii extract is mainly used as a vegetable extract in the tanning application of leather for productions of products such as shoes, belts, bags and saddles. *A. mearnsii* extract is also used for the production of industrial adhesives used in the manufacturing of weather and boil proof particle board, plywood, fibre board and corrugated cardboard (Dunlop and MacLennan, 2002).

2.2.3 Processing plants

There are three bark-processing plants in South Africa, namely NTE Co-op Ltd in Iswepe in Mpumalanga and Hermannsburg in KwaZulu-Natal and UCL Company Ltd

in Dalton KwaZulu-Natal. The processing of the *A. mearnsii* bark at the UCL company Ltd plant is explained by Eggers, 2010 and is shown in Figure 1 below.

The bundled *A. mearnsii* bark arrives at the factory, goes over a weighbridge and then to the bark storage shed. From here it is first fed through a set of chippers, where the bark is chopped up into 6mm x 6mm squares. The 6mm sized squares have been found to enable effective leaching of extract (Dunlop and MacLennan, 2002). From the choppers the bark cubes are then conveyor belted to the autoclaves, where a leaching/diffusion process occurs. The cubes are boiled at a temperature of 100 to 118°C for a time of 11hours. This is done to boil the extract out of the bark (Eggers, personal communication, 2010). The spent bark cubes, which still have 71% moisture content, are sent to a drying facility.

In the drying facility moisture is removed from the spent bark by compressing it. The water is sent to the effluent plant and the dried spent bark is sent to the boilers, where it will be used as fuel to run the mill. The water cannot be re-used, as there is a high percentage of iron contamination and this would affect the final product (Eggers, personal communication, 2010). The thin liquor containing the extract from the autoclaves is 10% solid at 100°C and is pumped to the evaporators to evaporate more of the water and leave the extract behind. Once the liquor has passed through the evaporators, it is still 50 to 54% moisture at 60 to 84°C (Eggers, personal communication, 2010).

This liquor can then be used for three different products, depending on the market requirements. The first being the spray dryer: a flash evaporator, heated by air that is generated by either a coal or oil fire (the heated air is usually at a temperature of 250°C), which is blown into the spray dryer by a fan. The liquor is fed into the cylinder by an atomiser, which is a wheel with small holes spinning at a speed of 15000 to 17000 revolutions per minute (Eggers, personal communication, 2010). The liquor is then a fine spray, and as it comes into contact with the hot air, the water flashes off and the powder then falls to the bottom and is fed to the bagging plant for storage.

The second product is the bondtite adhesive plant; here the thick liquor is pumped to storage tanks and then to the bondtite kettle. In the kettle, various confidential chemicals are added to create the end product; here the process time varies between three and twenty four hours, depending on the end product required. The products are either specialised tannin products or adhesives. The liquor for both the specialised tannin products and the adhesives are then pumped to the spray dryer, to be turned into powder (Eggers, personal communication, 2010).

The third process is the continuous finisher. This is also an evaporator, changing the 50 to 54% solid to an 83% solid. This is then put into hessian bags as a solid extract. This extract is then stored in racks to dry and will solidify after about four weeks. In the tannin process, the skins would be put into a trough and the whole hessian bag is put in and hot water is added (Eggers, personal communication, 2010).

2.2.4 Markets

Good marketing schemes by companies such as NCT Forestry Co-operative Ltd (NCT) and Mimosa Central have ensured a good demand for *A. mearnsii* products. The timber will be utilised as pulp or chip board and can be processed in mills all around the country. A high percentage of the fibre is then exported to countries in the Far East such as Japan.

2.2.4.1 Timber

Most of the marketing of *A. mearnsii* pulpwood is carried out by two timber co-operatives, namely NCT in Pietermaritzburg, and Transvaal Wattel Kwekers (TWK) in Piet Retief (Dunlop and MacLennan, 2002).

2.2.4.2 Extract

About 45% of the final product is used for adhesives and 55% for tanning products (Dunlop and MacLennan, 2002). The tannin products are exported mainly to India and China but also to Europe. The adhesive product is mainly exported to CCH chemicals in Australia (Eggers, personal communication, 2010).

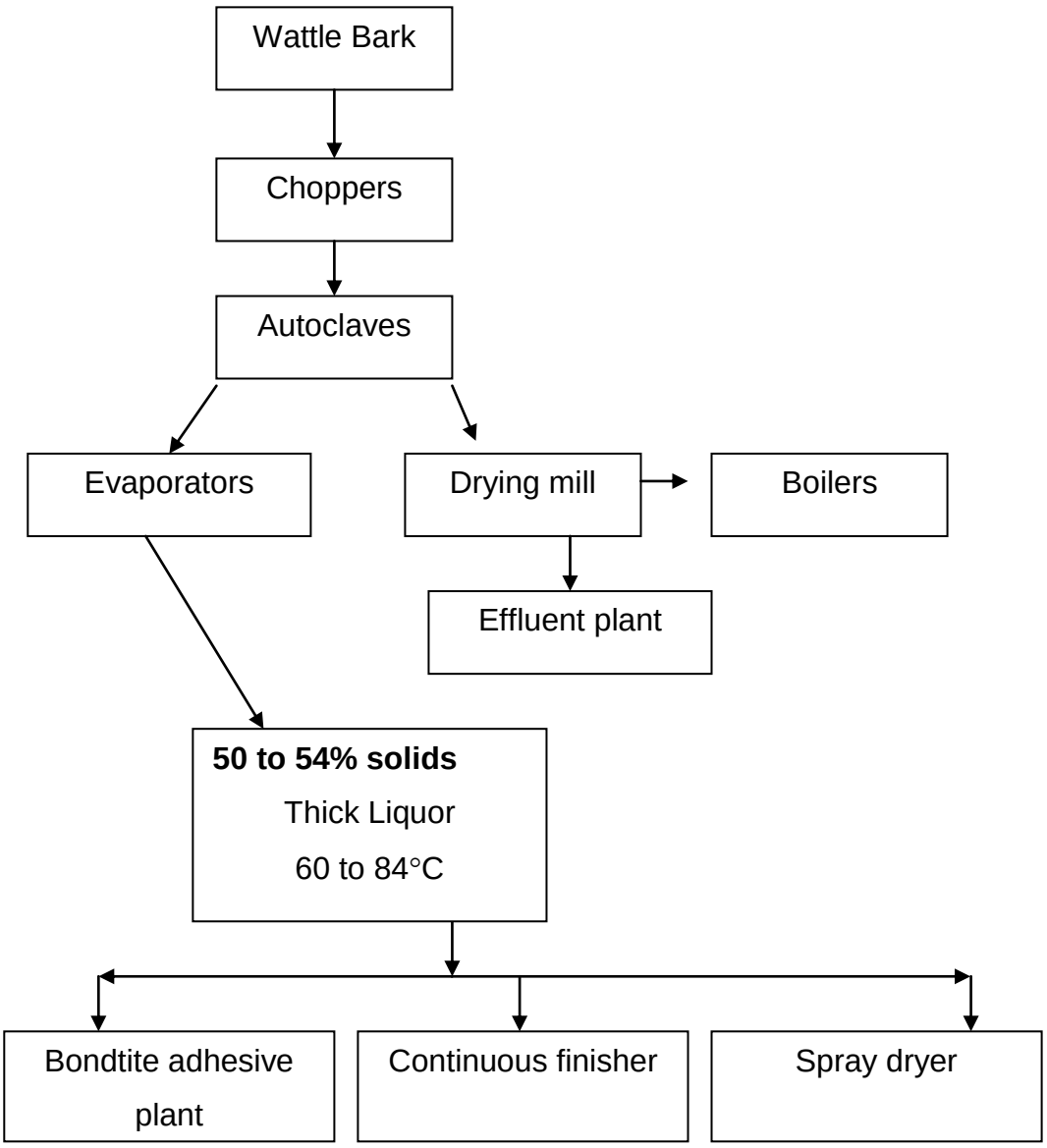

Figure 1: Process of producing tannin powder and adhesives from *A. mearnsii* bark.

2.3 SYSTEMS AND MACHINES USED TO DEBARK *ACACIA MEARNSII*

Traditionally the debarking of *A. mearnsii* in South Africa has been done manually. This was due to the availability of labour, lower costs and better quality of bark compared to mechanised debarking trials that had been conducted. There have been factors such as shortages of labour, HIV/AIDS and the possibility of year round debarking which have caused the interest in mechanised and semi-mechanised debarking systems (Laengin, personal communication, 2009).

2.3.1 Manual debarking

Currently manual debarking is the most widely used method for debarking *A. mearnsii* in South Africa. There is a limitation to the development of new methods or tools to increase productivity of manual debarking. Factors such as ergonomics and lighter tools are the main areas for productivity improvements (Chapman, 2001). Time studies have been carried out on different hand tools for removing bark, to determine the most productive tool. These tools varied from conventional hatchets, modified hatchets to specially designed spade like and cutter-wheel tools. No significant differences were noticed in the productivity of the various tools (Chapman, 2001).

2.3.2 Mobile debarkers

Mobile debarkers are debarking machines that can be moved around during the debarking process. They are usually powered by a drawing vehicle and are used either infield, on roadside or at centralised landings.

2.3.2.1 WRI Debarker

A debarking machine was developed by the Council for Industrial and Scientific Research (CSIR) in 1975. The debarker is mounted on wheels for towing behind an ordinary agricultural tractor and is powered by the power-take-off (PTO) of the tractor (Wattle Research Institute, 1975). The machine was developed to remove bark in longitudinal strips which could then be bundled for delivery to the processing facility. In the initial phases, wattle poles were successfully debarked in the workshop of the Technical Services Department of the CSIR in Durban. A prototype was then developed which was tested under plantation conditions. During the tests, small alterations were made to the machine (Wattle Research Institute, 1975). During the winter months when wattle was not debarked, tests were conducted on *Eucalyptus grandis.*

Two people were needed to operate the machine. Another four to six people were required to remove the loosened bark still adhering to the logs, stack the bark and stack the logs (Wattle Research Institute, 1975). First estimates determined that with

a throughput of five logs per minute of 10 year old trees, 40 tonnes of timber and 10 tonnes of bark could be produced in an eight hour day (Wattle Research Institute, 1975). Originally, four labour units, two working with the machine for part of the day and then helping to bundle the bark and stack the debarked logs, would achieve around four tonnes per day. This would be the same as a team consisting of a chainsaw operator, his assistant and 12 people debarking the logs (Wattle Research Institute, 1975).

Tests early in 1976 were disappointing, showing that training of labour and experience are necessary in order to obtain a satisfactory level of production (Wattle Research Institute, 1975). In these early studies, 10 labour units were used: two loading, two feeding, one removing and stacking logs and five gathering and bundling bark. A total production allocated back to volume per worker per day (eight hours) was 5.425 tonnes of logs per day (Wattle Research Institute, 1975). The trees used for the trials were growing on a very poor site and were therefore very small. In order to determine the productivity of the machine in larger timber, a 19 year old plantation was used in research conducted at Windy Hill Wattle Company in Wartburg on the 27th April 1976 (Wattle Research Institute, 1975). Due to the larger log sizes, the team was increased to 12 people. The largest log used had a diameter of 33.5cm (Wattle Research Institute, 1975). The average production per worker per day (eight hours) was 5.280 tonnes, less than that of the first research, but due to two extra people used, the total daily production had increased (Wattle Research Institute, 1975).

A Durban engineering firm was awarded the contract to manufacture three machines to be used for studies at the start of the 1976-77 debarking season. Two machines were to be used in the KwaZulu-Natal midlands and one in the former South-eastern Transvaal. The machines were to be monitored by the Wattle Research Institute and were anticipated to be sold to growers for no more than R6 000 (Wattle Research Institute, 1975). No mass production or further development of the machines transpired.

2.3.2.2 Valon Kone VK16A ring Debarker

The VK 16A mobile ring debarker is a PTO driven machine, mounted on a two wheel chassis. The debarker is fitted with two cutting and two scraping knives, driven by the PTO of a tractor (Dobson, 2006). Springs force the pressurised knives and scrapers onto the log. This pressure can be set according to log size or ease of strippability (Dobson, 2006).

For the studies conducted by Tanac Forestry Company in Brazil, it was noticed that the debarking needed to take place within hours of felling to ensure the bark was removed efficiently. The bark produced was not of a consistent size, and varied from chips to lengthy strips (Dobson, 2006). At times the bark produced contained chips of wood. After debarking infield, Tanac conducted trials spraying the bark with a liquid metabisulphide to try to reduce oxidation. Following these trials, it was decided to rather try to reduce the time between harvesting and delivery to mill to within 24 hours. The bark was transported to the processing facilities in containers, where it was resized with a drum chipper to obtain the needed chip sizes for processing. During the re-chipping at the processing facility, some pieces of bark were pulled through without being chipped (Dobson, 2006).

After the trials were completed, a decision was taken not to use the VK 16A for further debarking. The decision was based on the time that was taken to get the bark to the processing facility (3-5 days), and it was not possible to treat the bark infield. The debarker also exposed a great deal of surface area to oxidation (Dobson, 2006).

2.3.2.3 Hypro debarker

The Hypro processor was imported from Sweden to be used to debark both Acacia and Eucalyptus species in South Africa. The Hypro processor is mounted on the three point linkage of an agricultural tractor of at least 78kW power output. The weight of the Hypro is 1380kg. It can handle either logs or tree lengths of up to 450mm maximum diameter. Up to four driven rollers feed the log/tree through the Hypro at a feed speed of approximately 3.5 metres per second (Hypro, 2008). The rollers are situated so that contact is made at four different points on the stem; the bark is removed in strips of varying length by applying pressure with the rollers.

The Hypro can be fed from both sides of the tractor and it has a crane which has a maximum telescopic reach of 7m (Hypro, 2008). The crane is very light and not very robust. At full reach it has poor lifting capabilities. The Hypro can also have a bar and chain, and is therefore able to crosscut trees into log lengths. The Hypro can process 10 tonnes of timber per hour and 8-10 tonnes of *A. mearnsii* bark per eight hour shift, depending on tree size, wood-bark bonding strength, slope and operator experience (Chapman, 2006)**.** The machine is suitable for a small landowner with other uses for the tractor besides tree processing, as the Hypro can be removed from the tractor in approximately five minutes which then releases the tractor for other agricultural uses (Hypro, 2008).

2.3.3 Stationary debarkers

Stationary debarkers are mechanised debarking machines which are immobile, and cannot be moved around during the debarking process. They are usually set up either on landings or merchandising yards, but most are situated at the processing facilities. Currently most debarking takes place infield with mobile debarkers or manual methods of debarking. Some tests have been conducted with stationary debarkers. In around 1975, wattle logs were taken to the United States of America (USA) to be debarked by a machine that was reported to be able to remove the bark in strips. A video of the machine working and samples of the removed bark confirmed that without modifications to the machine, the bark produced would not be acceptable to the extract factories (Wattle Research Institute, 1975). The machine was designed for large timber and the smaller wattle logs would therefore decrease the productivity of the machine and therefore cause the machine to become unjustifiable due to the high running costs (Wattle Research Institute, 1975).

Tests have been conducted on a Nicholson ring debarker in South Africa as discussed below.

2.3.3.1 Nicholson A5B debarker

A debarking trial using the Nicholson debarker was conducted at Thesens sawmill in George in 2005. The trials were conducted due to Nicholson stating that their debarkers were suitable to debark stringy *Eucalyptus* and *Acacia* tree species.

One of the main factors to be tested was the chip sizes produced by the debarker. Nicholson stated that their tandem ring debarker with a slitter ring should be used to debark the logs, and the bark could be reduced to the required size using a chipper. Nicholson have a patented slitter ring, which makes it possible to debark *Eucalyptu*s without producing bark wrappings that jam the cutters and result in stoppages. The slitter arm cuts the bark in a helical spiral round the log and the second ring removes the bark. The slitter action results in the bark being cut into short segments, so that it can be removed without jamming the debarker. There is also an option of a counter rotating ring that moves in an opposite direction to the slitter ring, providing better debarking of rough, knotty, or burnt logs. The machine used in the research had a maximum feed speed of 2.3 metres per second. The maximum log dimensions for the machine is 450mm with a minimum of 50mm. The minimum length of logs for the machine is 1.6 metres (Thesens sawmill, 2005).

Sample trees were felled, debranched and cross-cut into 2.4m lengths and then transported to the sawmill. The first trials were conducted three weeks after felling and the logs were successfully debarked, but the mill manager reported his concern that strips of bark would wrap around the debarking head and result in stoppages if done on a production basis. The second trial was conducted on logs 5 weeks after felling. The logs were first tested manually for strippability. It was possible to remove thin strips on either end of the logs. All logs were debarked successfully, but the bark produced was stringy and messy. A sample of logs where the bark was manually cut with a helical spiral (zigzag pattern) were then debarked. It was noticeable how the bark chips fell directly onto the feed conveyor, the logs were also debarked clean with no bark remaining behind knots (Thesens sawmill, 2005).

Bark samples from both trials were transported to Pietermaritzburg, where they were sent through a drum chipper. The bark chips were fed into the chipper first, but were lost somewhere in the system. The stringy bark was then fed into the drum chipper.

The bark was successfully chipped, but the chip shapes and sizes were unsatisfactory (Thesens sawmill, 2005).

2.3.4 Harvester heads

Various types and brands of harvesting heads have been used to debark *A.mearnsii* both in South Africa and internationally. The harvesting and processing heads have been mounted onto purpose-built wheeled and tracked carriers, construction excavator-based machines as well as Bell three wheeled loaders and Bell All Terrain Loaders (ATL). The harvesting and processing heads that have been used are discussed below.

2.3.4.1 Lako harvesting head

In the mid 1980's trials were done with the Lako harvesting head *in E.Oblique, E.sieberi and E.regnans*. The trials were conducted in Victoria and Tasmania (both Australia). The Lako harvesting head was mounted on a Kato excavator based machine. The main components of the head were a hydraulically powered chainsaw used to fell and cross-cut the tree, two hydraulic cylinder-activated arms which clamp the tree in the head, four hydraulically powered rollers to move the tree through the head and two arms carrying delimbing knives (Wingate-Hill and MacArthur, 1991).

In Brazil, the Lako harvesting head is used to fell 50 percent of Tanac Forestry Company's annual *A. mearnsii* order. The Lako heads are used on Caterpillar and Volvo excavator carriers. The trees are felled, debranched, debarked and cross-cut into 2.2 metre lengths (Dobson, 2006).

Once crosscutting is completed, the logs and bark are deposited between brush piles. It was estimated that about 95 percent of the bark gets removed during debarking. Manual labour is used to remove the remaining bark on the logs. Manual labour is also used to stack the debarked timber and bundle the bark. The bark is bundled in one metre lengths and tied together with twine. These bundles are then carried and stacked at roadside for transportation to the processing facility within 24 hours (Dobson, 2006).

Tanac Forestry Company quoted that their labour productivity rates were 100m³ of debarked timber per labourer per month, this translates into four tonnes of timber and 588 kilograms of bark per labourer per day (Dobson, 2006).

2.3.4.2 Ponsse 650 and H7 euca harvesting heads

These Ponsse harvesting heads can be fitted to large Ponsse wheeled carriers, or any excavator-based machines. The Ponsse 650 head weighs 1600kg including the rotor and hangar. The height of the head is 1750mm excluding the rotor and the hanger (Ponsse, 2010). Steel rollers that were developed for use in *Pinus* species were used, and the machine was able to feed logs through the head at six metres per second (Schalkx, personal communication, 2010). The Ponsse 650 has two driven rollers which exert the correct pressure on the log to pop the bark off the stem. While the tree lengths are run through the head they are debranched by three hydraulic movable delimbing knives and two static delimbing knives on either end of the head. The hydraulic delimbing knives can open to 750mm and the knives are separately controlled from the feed rollers (Ponsse, 2010).

In a trial conducted in South Africa, the logs were only fed through the head once before they were cross cut by the harvesting head. The bark was pulled off and bundled manually. The Ponsse 650 is also working in various other *Acacia* and *Eucalyptus* species that have very bad tree form. The successor of the 650 is the Ponsse H7 euca currently working in Brazil, Uruguay and China on various *Eucalyptus* species. According to Schalkx (personal communication, 2010), the main issue is to get the pressures right of the feed roller arms and the delimbing knives correct, in order to get the bark off the tree length. Applying the correct settings depends very much on the machine operator's skill and attitude.

2.3.4.3 SP 591 LX harvesting head

The researcher was also involved in trials that were conducted on the SP 591 LX harvesting head near Kranskop in KwaZulu-Natal in an *A. mearnsii* compartment with an average tree volume of 0.16m³. The head was mounted on a Hitachi 20 tonne excavator (Ramantswana, 2010). The weight of the head excluding the rotator is 1700kg and the height excluding the tilt frame is 1670mm. The three driven rollers

feed the tree length through the head at a feed speed of seven metres per second (SP Maskiner, 2010).

At first the head was fitted with 15 degree steel rollers, designed for debarking *Eucalyptus* species, and later on with 30 degree steel rollers. The rollers have proportional clamping pressure, and for optimum performance individual pressure settings can be made for different tree species (SP Maskiner, 2010). The three driven rollers apply pressure on the stem at three different points causing the bark to come off in strips of varying length depending on the wood-bark bonding strength. The bark was collected and bundled by manual labour and transported to the mill within 24 hours. The bark was accepted at the mill, but the recovery was calculated to be approximately 60 percent, which is low compared to existing manual systems. The head has two fixed delimbing knives on both ends and two hydraulically moveable delimbing knives which can also be set individually for optimum performance. The advantage of the proportional clamping pressure of the rollers and the delimbing knives is that really small diameter trees could be processed without breaking them.

The optimum tree size the head can handle with the feed rollers is from 15cm to 40cm in diameter and the maximum tree size recorded is 45cm in diameter (SP Maskiner, 2010). It was found that the head was least productive in small timber with a tree volume of <0.049m³ and most productive in trees with volume of >0.2m³. The average productivity of the machine is approximately 8.22m³ per productive machine hour. The tree lengths were cross cut with a hydrostatic chainsaw in the harvesting head that had a QuickCut system for length measuring (SP Maskiner, 2010).

2.3.4.4 Waratah HTH616 harvesting head

The Waratah 616 harvesting head has been used to debark *A. mearnsii*. The head was used on a Sappi plantation in Highflats, Umkomaas district, southern KwaZulu-Natal.

The Waratah 616 can be mounted on a 16 to 22 tonne purpose built harvesting machine or on a construction excavator based machine. The head's weight including the rotator and link is 1550kg and the height including the rotator is 2170mm. The tree lengths are fed through the head by three driven steel rollers designed for use in

Eucalyptus species, which are fully synchronized at a feed speed of 6.3 metres per second (Burke, 2008). The rollers exert pressure on the stem causing the bark to come off in strips which differ in length depending on the wood-bark bonding strength. The tree length is debranched by two moveable delimbing knives and one static delimbing knife. The maximum opening of the upper delimbing knives is 520mm while the best delimbing diameters range from 50mm to 400mm (Burke, 2008).

The problems that occurred while working in *A. mearnsii* were that the cost and maintenance demand of the head was much higher due to the vibrations generated whilst the tree passes through the head. Trees that had forks or butt sweep had to be discarded which leads to fibre loss. Lower productivity was achieved than what was expected due to poor stem form and strippability of the trees. 30 to 50 trees were processed per productive machine hour, depending on the stem form, branchiness and strippability of the trees (Johnston, personal communication, 2010).

The John Deere H480 and 762 heads have also been used both nationally and internationally, to debark cold tolerant *Euclayptus* species such as *E. globulus*, and could also be applied to debarking *A. mearnsii* (McEwan, personal communication, 2010).

2.3.5 Debarking and debranching heads

The Hyena and bell debarking heads are described below.

2.3.5.1 Hyena debarking head

The Hyena debarking head can be attached to a wheeled or excavator based carrier. The Hyena weighs 1140kg and has two driven, angled, ribbed rollers which feed the tree lengths through the head at seven meters per second (Küsel, personal communication, 2010). The rollers exert pressure on the stem causing the bark to pop off in long strips depending on the wood-bark bonding strength. The Hyena head has two pairs of moving delimbing knives which can handle a maximum tree diameter of 400mm.

According to Küsel (personal communication, 2010), the Hyena was specifically designed and built to process *E. nitens*, *E. macathurii* and *E. smithii* but, has worked in *A. mearnsii* compartments. No modifications were made to the head while processing in *A. mearnsii*. Productivity is significantly affected by tree size, branchiness, tree form and the wood-bark bonding strength (Küsel, personal communication, 2010).

2.3.5.2 Bell debarking head

The Bell processing head only debranches and debarks the trees. The felling and crosscutting of trees is done manually or by means of a feller buncher. This head can be fitted on a modified Bell, ATL or an excavator based machine.

The Bell debarking head weighs 950kg with two driven rollers and one idler roller at the top (Bell Equipment, 2009). The driven rollers feed the tree through at a feed speed of four metres per second and force the tree against the idler roller exerting pressure causing the bark to pop off in strips depending on the wood-bark bonding strength (The Bulletin, 2005). The Bell head has two sets of moving delimbing knives which operate at low pressures when lifting the stem into the head. Once the tree is in place these knives support the tree in the delimbing and debarking process. On either end of the head there are fixed end knives assisting in denotching (removing branch stubs) and debranching the timber (The Bulletin, 2005).

The maximum tree diameter the Bell debarker can handle is 450mm and the ideal tree size is between 0.16 and 0.2 tonnes per tree (The Bulletin, 2005). The Bell head fitted on the ATL produced 15 to 22 tonnes per hour in *Eucalyptus* and *A. mearnsii*. The Bell Head fitted to a tri wheeler produced 10.97 tonnes per hour in *Eucalyptus macathurii* with a tree size of 0.09 tonnes per tree (The Bulletin, 2004). The production figures will vary depending on the tree size, form and strippability. No information was provided on the conditions encountered during the trials in reaching the productivity figures mentioned.

2.4 MARKET REQUIREMENTS AND QUALITY

With the use of both mechanised and manual methods of debarking *A. mearnsii*, the quality of both the timber and the bark needs to be considered in terms of market requirements (Sherry, 1971).

2.4.1 Timber requirements

Various log lengths are used when crosscutting trees for the processing facilities. When manual debarking is conducted, the most commonly used log length is 2.4m. With the ever increasing semi-mechanised harvesting systems, comprising of mechanical debarking, log lengths of 3m and 5.5m lengths are becoming more common. As long as the chipping system at the processing facility and the transport mode used are able to handle the logs, length is not a hindering factor (FESA, 2009; Dobson, 2008).

The main factor determining the quality of the debarking is the percentage of bark remaining on the stem after the debarking process has been completed (de Wet and Alcock, 2002). This is influenced by the wood-bark bond strength, operating techniques and method of debarking. Manual debarking is not as effective as mechanical debarking when the wood-bark bond strength is very high (FESA, 2009; Eggers, personal communication, 2010).

The most common market requirements and specifications of the timber for pulp are described by de Wet and Alcock (2002), as follows:

- Logs must be debranched flush to the stem
- Logs must be reasonably straight and not forked
- Logs must not be burned or have signs of carbon
- They should be free of foreign matter and debris
- They must show no sign of diseases
- They must show no signs of fungal growth
- Minimum felling age should be eight years
- The logs' diameter should not be less than seven centimetres or greater than 75 centimetres
- Their length should be between 1.8 metres to 6 metres.

2.4.2 Bark Requirements

The biggest factor affecting the quality of the bark is the time between debarking and delivery to the processing facility. This will influence the moisture content as well as the oxidation of the bark (Dobson, 2006). Oxidation of the bark is caused when the cambium layer is in contact with oxygen and it causes the cambium to become a bronze colour. The longer the bark is left, the higher the rate of oxidation (Eggers, personal communication, 2010). This will have a negative effect on the colour of the powder produced at the processing facility.

There are various types of tannin powders produced, determined by the quality of the bark obtained. These powders have different prices and therefore growers obtain a better price for fresh bark, as it produces a higher value product (Eggers, personal communication, 2010). If the growers are unable to achieve delivery of fresh bark, they are encouraged to produce stick-bark, which will be used only in the production of adhesives. Stick bark is produced by drying out the bark before bundling and sending to the processing facilities.

When mechanical methods of debarking have been used, the bark is usually damaged by the rollers, cutters or scrapers of the machine (Kistan, personal communication, 2010; Eggers, personal communication, 2010). This will therefore increase the surface area of cambium, increasing the potential for oxidation. It is therefore important to decrease the delay between debarking and transportation to the processing facility as well as decrease the damage to the bark.

The percentage tannins present in the bark also affect the quality of the bark. This is affected by amongst others, site, tree age, tree breeding and presence of fungi such as gummosis (Hillis, 1997). There is also a direct correlation between the percentage tannin and the height of the bark above ground (Sherry, 1971). Sherry (1971) also explains that bark samples taken from higher up the stem have a thinner bark and a lower tannin content than samples taken from the lower portions of the tree.

CHAPTER 3:
RESEARCH METHODOLOGY

This chapter describes the method used to conduct the research, the research sites as well as the data analysis methods used.

3.1. RESEARCH METHOD

Currently the harvesting and debarking of *A. mearnsii* only occurs during the summer months in South Africa with no debarking taking place in the winter months. This is due to a stronger wood-bark bond strength in the winter months, therefore decreasing productivity as well as the quality of the bark produced (Eggers, personal communication, 2010). Each of the machines was researched during three sets of infield trials. Of the three planned field trials, two trials were conducted during the summer months, which fall in the current manual debarking season, as well as an additional field trial during the winter months when no debarking currently takes place. This was done to obtain a greater sample of trees with stronger wood-bark bond strengths to determine the capabilities of the various machines under these conditions.

As discussed in Chapter 1, suitable compartments were selected that have a good representation of tree volume for South African forestry conditions (correct age and size). Plots were set up in the compartment and the trees were systematically marked with a number using paint. The tree diameter at breast height (DBH) was measured using a diameter calliper at a height of 1.37m, which is the standard height for diameter readings in forestry (Forestry South Africa, 2008). The tree heights were measured using a Vertex hypsometer. A sample of tree heights were also confirmed by measuring them with a 30m tape once the tree had been felled. These measurements were used to determine tree volume, using equations based on the Schumacher and Hall model (Bredenkamp, 2000). Tree age was documented as it could have an effect on productivity and quality. Younger trees should have a better debarking quality due to weaker wood-bark bond strengths, but will be less productive due to smaller tree/log sizes. The age of the tree will also have an effect

on the quality of the bark for processing plants (Dunlop and MacLennan, 2002; Dobson 2006; Hillis 1997).

Each plot consisted of the trees that were debarked by one processing technology in one day. Therefore, three plots were processed each day. For seven days' research, 21 plots were required. Due to different strippability classes being required for the research, some trees were felled and left infield for up to six weeks in order to manipulate the wood-bark bond strength. The longer the time between felling and processing, the stronger the wood-bark bond strength, because of the drying process (loss of moisture in the cambium layer) the bark tightens around the stem of the tree. For the Demuth trials, all plots were felled on the first day. One plot was then processed each day, the other plots were left infield to be processed at a rate of one per day for the remainder of the trials. For the trials conducted with the Hyena and the Hypro, a plot was felled each day. Once all the plots had been felled, they would all be processed on the same day, therefore having a range of trees from those that had been felled that morning through to trees that had been felled seven days ago. The number of trees that were to be processed was within the capabilities of the machines, and could therefore be processed in one day. The stem form and volume classes were determined during the marking of the plots. The strippability class was determined on the day that the debarking was to take place. This was done to ensure consistency between the different machines and plots when each of the classes was determined.

For the Demuth debarker, the trees were debranched and cut into 2.4m logs, as this is the form in which the trees are processed. For the Hyena and Hypro debarkers, only the large branches (>3cm diameter) were removed by chainsaw or hatchet, and the tree lengths were not crosscut, as the machines process the trees as tree lengths and not 2.4m logs. For the trees that were cut into 2.4m logs, the thin and thick-end diameters were documented for each log in order to calculate log volumes needed to calculate productivity. The tree or log volume could have an effect on the quality or the productivity of each technology. This was also used to calculate the productivity per volume class per technology, the optimum average tree volume for each technology as well as the volume class range where the debarking technology

can be commercially applied. Each log was given a number to track which tree it came from as well as which part of the tree it originated from (bottom or top).

Before the trees were processed the strippability of the trees or logs was determined as per the scale below. This was done to relate productivity back to ease of debarking, as well as the effect of the wood-bark bond strength on the ability of the different debarking technologies. As a general reference point, strippability was measured manually with a hatchet before any of the debarking took place. The measurements were always done by the same person to ensure consistency. The following scale was used:

1- **Very good**- Bark can be removed in very long length strips (>10m)
2- **Good**- Bark can be removed in long length strips (4 to 10m)
3- **Medium**- Bark can be removed in medium length strips (1 to 4m)
4- **Poor**- Bark comes off in short length strips (up to 1m)
5- **Very poor**- Bark has to be chipped off the tree

Each of the three technologies would then debark the required trees for that day and time and motion studies were conducted. Unlike most other commercially planted tree species, *A. mearnsii* trees usually have poor stem form and have a large number of branches. Due to this, the stem form was documented in order to relate productivity or debarking quality back to this factor. The form class was evaluated by the same person to ensure consistency.

The form was divided into three groups:

1- **Good** (no stem/log defects, a straight stem)
2- **Average** (slight sweep, but could have a marginal affect on debarking quality or productivity)
3- **Poor** (tree is very crooked and malformed and could have a marked affect on productivity or debarking quality, includes forked trees)

The factors shown in Figure 2 were considered as they are the key factors that would affect the productivity (time to debark) of the debarking technologies, the quality of the debarking as well as the quality of the bark for the processing facilities.

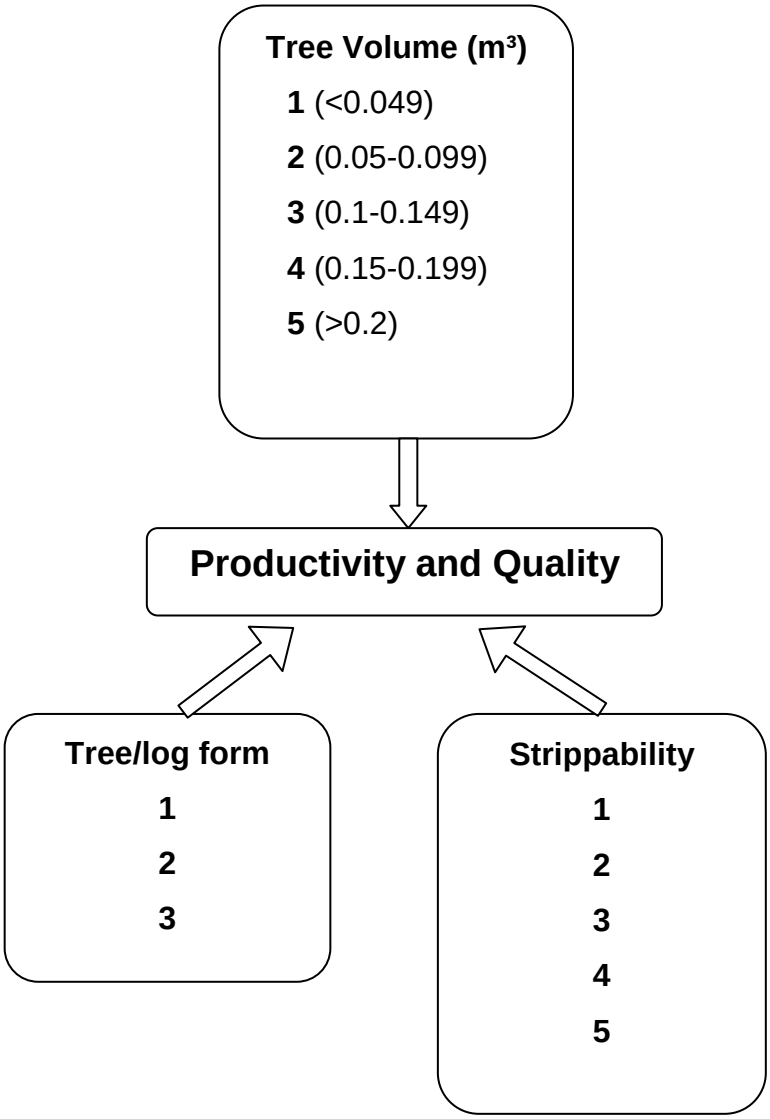

Figure 2: Factors affecting the productivity of each technology (researcher's own construction)

Once debarking had taken place, the visual quality of the debarked logs or trees was noted. Apart from the fact that these technologies have not been collectively studied in *A. mearnsii* before, this research also differs from any previous research in that

the bark needs to be utilised. Each of the debarking technologies removes the bark in a different form. Two of the machines produce bark of varying lengths (Hyena and Hypro), one system in 2.4m lengths (manual) and the other in chip form (Demuth). Once the debarking had been completed, a two kilogram sample was collected and sent to the bark processing facilities where laboratory tests were conducted, as per currently acceptable commercial practice (Dickey, 2009). The samples were sent within 24 hours of debarking, in order to prevent oxidation of the bark. This was carried out in order to enable comparisons between the different debarking technologies.

Time and motion studies were conducted during the research to determine the productivity of each of the technologies. The productivity was determined per productive machine hour (PMH), stoppages due to factors such as breakdowns and delays not related to the work were therefore not included. All the operators that were used to operate the machines were trained and they operated these machines on a daily basis. The machines used in the research were all in a good condition and were operated according to the guidelines stipulated in their operating manual.

3.2 RESEARCH SITE

The research was conducted in the *A. mearnsii* belts in the KwaZulu-Natal and Mpumalanga forestry regions of South Africa. The reason for the research being carried out in KwaZulu-Natal and Mpumalanga is due to more than 97% of South African *A. mearnsii* plantations occurring in these provinces (Forestry South Africa, 2008). The exact sites were chosen according to where suitable compartments were found, as well as where the machinery was working or able to be moved to. It was not possible to have the three debarking methods used simultaneously in the same compartment, but this was not a limiting factor to the research, as the same standard of comparisons was used over the three debarking methods being researched.

The research site date is shown in Table 1. The Demuth ring debarker field trials were conducted in Dalton with the UCL Company Limited (UCL). The Hypro

debarker studies were carried out in the Greytown area on a Masonite estate, and the Hyena debarker studies on a Mondi estate in the Piet Retief area.

Table 1: Research site data

	Demuth	**Hyena**	**Hypro**
Landowner	UCL Company	Mondi	Masonite
Average DBH (cm)	13.62	15.82	13.24
Average tree height (m)	18.88	17.55	16.38
Average tree volume (m^3)	0.122	0.152	0.099
Sample size (no of trees)	740	386	278

3.3 DATA COLLECTION STRATEGIES

The methods used for collecting and analysing the bark qualities are described below.

3.3.1 Bark quality

During the debarking trials, a two kilogram sample was taken per day for each debarking technology and sent to a laboratory at the UCL Company's processing facility for testing. The laboratory staff indicated that a two kilogram sample would be sufficient for testing purposes. A representative sample of bark length and dimensions was placed in a bag each day and taken directly to the processing facility. The tests were carried out to determine the quality of the bark produced by the different technologies. The main factors that were taken into account for these tests were: percentage tannins, percentage non-tannins, percentage insolubles, moisture percentage, percentage extractives, fibre percentage, the amount of red and yellow colours, the index of quality as well as the tannin/non-tannin ratio. The

factors named above are explained in Table 2 (Kistan, personal communication, 2010).

Table 2: Factors assessed when conducting bark quality analyses.

Tannin %	Generally, 30 to 40% tannin content (dry mass basis) is indicative of good quality bark.
Non-tannin %	The general non-tannin content of good quality bark is between 10 to 15% on a dry mass basis.
Insolubles %	This is the amount of ash or insoluble solids present in the bark. It may affect the colour of the extract liquor.
Moisture %	The general moisture content of good quality fresh *Acacia mearnsii* bark is between 40 to 46%.
Extractives %	This is the sum of the % tannins, % non-tannins and the insoluble solids. This is the part of the bark that is extracted into thin liquor, leaving behind the fibre.
Fibre %	The cellulosic part of the bark which after the extraction process is dewatered and used as fuel in the boilers.
Reds & Yellows	The standard adopted for tanners worldwide for extract powder (ME) and extract solid. The reds upper limit is 1.3 and the yellows upper limit is 2.6.
I.Q (Index of Quality)	This is the ratio of the extractives (Tans + Non-tans + Insolubles) to the fibre of the bark. It determines how much of the dry bark is available for liquid extraction. This ratio does not change much with the age of the bark. 1.2 and above is a good index of quality.
N/NTR	The tanin to non-tanin ratio. For hide tanning, a good ratio is 2.6.

The method of conducting the analysis of the bark samples at the processing facility is described in Annexure 3. Kistan (personal communication, 2010) describes the analysis as follows: Firstly the amount of bark to be used in the analysis must be determined. The moisture content of the sample must then be established. The

samples are then boiled for three hours. The solution is then cooled, filtered and dried in an oven for two hours to determine the extractives percentage. The insolubles and non-tannin percentage is determined in a similar way as the extractives percentage, with the adding of various chemicals and filters.

Pictures showing the quality of the debarking and the bark produced by the three different technologies are shown in Annexure 1. The pictures cover the different strippability classes. Due to the fact that trees were felled and left infield to manipulate the strippability class, there were parts of the trees that had “sunburn” on one side. This caused stronger wood-bark bond strengths, therefore the pictures show some remaining bark on some of the logs, caused by this factor. When the trees are transported for debarking directly after felling, this would not be a factor.

3.4 DATA ANALYSIS

The data was first captured in an Excel spreadsheet for sorting and conducting descriptive statistics. This was done to determine the sample sizes, means for each of the research classes (productivity, tree volume, form and strippability classes), variance and standard deviation. Once the descriptive statistics were completed, the data was transferred to STATISTICA to conduct the remaining analyses. Firstly, for each of the technologies a one-way ANOVA was used to determine whether the mean productivity differed significantly for the different levels of the individual factors (tree volume, strippability and form). Then a two factor ANOVA was also used to analyse the effect that a combination of tree volume and strippability, as well as tree volume and form had on the mean productivity of each of the technologies separately. For both the factorial and one-way ANOVAs, the assumptions are that the error terms are normally distributed with equal variance (homoscedasticity). Therefore a test for normality was done to determine if the error terms were normally distributed, homoscedasticity of the error terms was also checked. If the Anova results were significant, then a Duncan’s pairwise comparison was used to determine for which pairs of factor levels the mean productivity differed significantly. In some cases the assumptions were not met. In these cases, the outliers were identified and removed to determine if they had a negative effect.

In order to determine outliers, the data was sorted by tree size and productivity only. The existing data already had specific tree sizes, so besides sorting, no data manipulation was necessary. The first and third quartiles for productivity were determined for each tree size class for each processing technology. The interquartile range was then determined by subtracting the first quartile value from the third value. 1.5 times the interquartile range was added to the third quartile value and subtracted from the first quartile value. Any productivity figures above or below these values were deemed to be outliers, and were highlighted in the data and removed. The data without outliers was then transferred into a clean Excel spreadsheet so that it could be imported into STATISTICA again.

When the outliers had been removed, the assumptions were still not met. The productivity was then sorted from smallest to largest achieved productivity and these were then ranked. The worst productivity was given a value of one and this would increase with the increasing productivity. For tied ranks the average rank was assigned, for example if the equal productivity had a rank of 120 and 121 then 120.5 was used as a rank for both figures. The ANOVA was then conducted on the ranks and not on the raw data and the assumptions were met.

CHAPTER 4:
DEMUTH DDM 420S RING DEBARKER

4.1 INTRODUCTION

The Demuth DDM 420s ring debarker shown in Figure 3, is a mobile debarker manufactured in Brazil. The Demuth is powered through the Power-Take-Off (PTO) of a tractor. The Demuth needs a tractor of minimum 60kW to operate. It has four spring-tensioned debarking arms, two are cutting knives and two are scrapers. The knives are used to cut a spiral groove into the log and the scrapers remove the bark in 75mm x 75mm chip dimensions. The bark is then fed into bags by means of a conveyor belt. The logs are placed onto a feed table and then fed into the machine manually. There are four feed rollers, two on each side of the debarking rotor, which pull the logs into the machine and out the other side once the debarking has taken place (Demuth machines, 2008; Dobson, 2006).

Figure 3: Demuth debarker with tractor and bags used to catch the bark chips.

The Demuth debarker is a mobile debarker that is pulled behind an agricultural tractor and is used infield. The timber is then loaded onto the feed table by means of a three wheel loader and the logs are fed manually into the machine. During the research it was used at a central landing and the timber was delivered to the machine for debarking. This is done in order to make the collection of bark easier. A three wheel loader is used to load the logs onto the feed table and to stack the debarked logs together. One person sorts the logs on the feed table, one feeds the logs into the machine and another aids in the stacking of the debarked logs. Once a

bag is filled with bark, the bell loader is used to remove it and stack it onto a vehicle for transport to the processing plant as shown in Figure 4.

Figure 4: Bell loader removing a bark bag to be loaded onto a transport vehicle.

Due to the bark being removed from the log in chips of 75mm x 75mm in size, a drum chipper needs to be built at the processing plants. The optimal chip size needed to achieve the best extraction efficiency is 6mm x 6mm.

4.2 HARVESTING SYSTEM

The system that was used with the Demuth debarker was as follows:

Felling: The trees were felled motor-manually by a chainsaw operator who had an assistant to help with the felling direction.

Debranching: The debranching and topping was then done manually using a hatchet.

Cross-cutting: The chainsaw operator cross-cut the trees into 2.4m lengths.

Stacking: The stacking was done manually once the crosscutting had been completed.

Extraction: A tractor with a self loading trailer was used to load and transport the log lengths to the Demuth Debarker which was located on a central landing. The logs were offloaded in the near vicinity of the debarker.

Debarking: A three wheel loader (Bell) was used to load the logs onto the feed table of the debarker as well as to stack the debarked logs on a stockpile. Two labourers were needed at the feed table, one to sort and arrange the logs presented by the three wheel loader and another to feed the logs into the machine. Another labourer was needed to ensure that there were no blockages when the debarked logs exited the debarker. While the logs get debarked, the bark falls onto a conveyor belt that drops the bark into bags each of 500 kilograms capacity for transport to the processing facility.

4.3 RESEARCH SITE

The Demuth research sites were setup in two different areas of KwaZulu-Natal. The first week of research trials was conducted on a Mondi plantation in the Hermannsburg area. The Demuth was being operated by a team of Natal Tannin Extract (NTE) company employees debarking Mondi timber. NTE has two Demuth debarkers (including the NTE employees) that are leased out to contractors to operate. The bark was then sent to the NTE processing plant in Hermannsburg.

The second research site was conducted on a UCL Company Limited (UCL) estate. The debarker was purchased by UCL to debark its own timber. UCL's own employees were used to operate the machine. The debarker was set up on Harden Heights farm, situated between the town of Dalton and the Seven Oaks railway siding. Both research sites are shown in Figure 5.

Figure 5: Demuth research sites in Hermannsburg and Dalton (Source: Google maps).

The Demuth trials had an average tree diameter of 13.6cm, an average height of 18.8m and average volume of 0.122m³. A total of 740 trees were debarked during the Demuth research trials.

4.4 FACTORS AFFECTING DEMUTH PRODUCTIVITY

The three factors that were analysed to determine their effect on the productivity of the Demuth debarker were tree volume, strippability and form. The findings showed that an increase in tree volume class has a positive effect on productivity; while an increase in strippability and form class had a negative effect.

Table 3 shows the average volume in cubic metres for each of the strippability and form classes. The table distinguishes if any of the variances in productivity for the form and strippability classes are caused by the average tree volume of the sample. If there are any variances they will be described below.

Table 3: Average tree volume (m^3) for each strippability and form class for the Demuth debarker

	Tree volume class				
	1	2	3	4	5
Strippability	0.143 m^3	0.122 m^3	0.119 m^3	0.121 m^3	0.106 m^3
Form	0.118 m^3	0.126 m^3	0.151 m^3		

4.4.1 Results of strippability on productivity

The five different classes used were discussed in Chapter 3. Figure 6 shows the distribution of sample sizes between the different strippability classes.

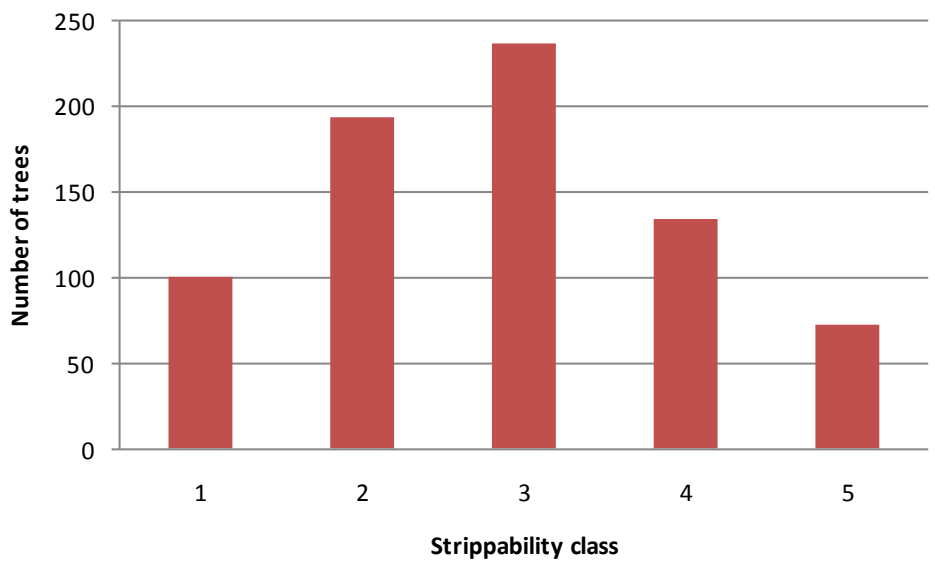

Figure 6: Strippability sample size distribution for the Demuth debarker.

Figure 6 shows a normal distribution of sample sizes. The largest distribution occurred in strippability class three (240 trees). There is a sufficient sample size in each of the strippability classes, with class one having 100 trees, class two 192

trees, class four 137 trees and class five having a sample size of 71 trees. The effect of each of these individual strippability classes on the productivity of the Demuth is shown in Figure 7.

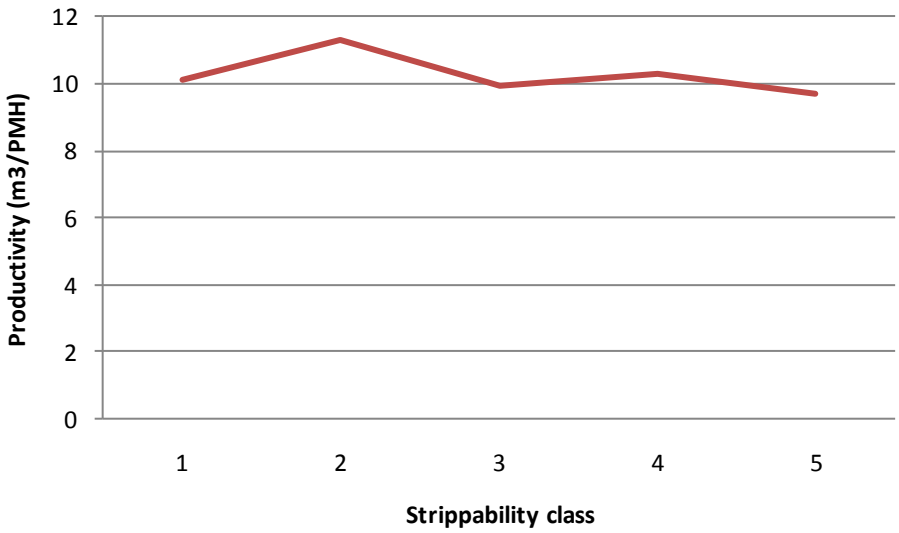

Figure 7: Effect of strippability class on the productivity of the Demuth debarker.

In Figure 7, there is an overall decrease in productivity with an increase in strippability class (class 1 being the best strippability). When there is a low strippability class, meaning the bark can be removed with ease, the bark is removed in strips and at times even along the entire length of the logs. Strippability class one had an average productivity of 10.2m³ per PMH, strippability class two shows the highest average productivity of 11.3m³ per PMH, strippability classes three, four and five achieved productivity levels of 9.9m³ per PMH, 10.3m³ per PMH and 9.7m³ per PMH respectively. This increased productivity is achieved even though strippability class two has a lower average volume (0.122m³) than class one (0.143m³). When a strippability class one is experienced, the bark is shredded and catches on the knives and scrapers, causing the debarking rotor to jam. The time taken to debark the logs is longer, due to less effective debarking when the knives and scrapers are jammed (the logs are sent through the debarker a second time), causing a lower productivity in strippability class one. If all other factors such as tree volume and form remain constant, the lowest wood-bark bond strength does not achieve the best productivity as would be expected with the Demuth debarker.

4.4.2 Results of form on productivity

The form of the tree or log will have an effect on the productivity of the debarker. This is caused due to longer times needed to handle and feed logs into the machine as well as for the machine to debark the log. The distribution of the sample sizes between the three different form classes is shown in Figure 8.

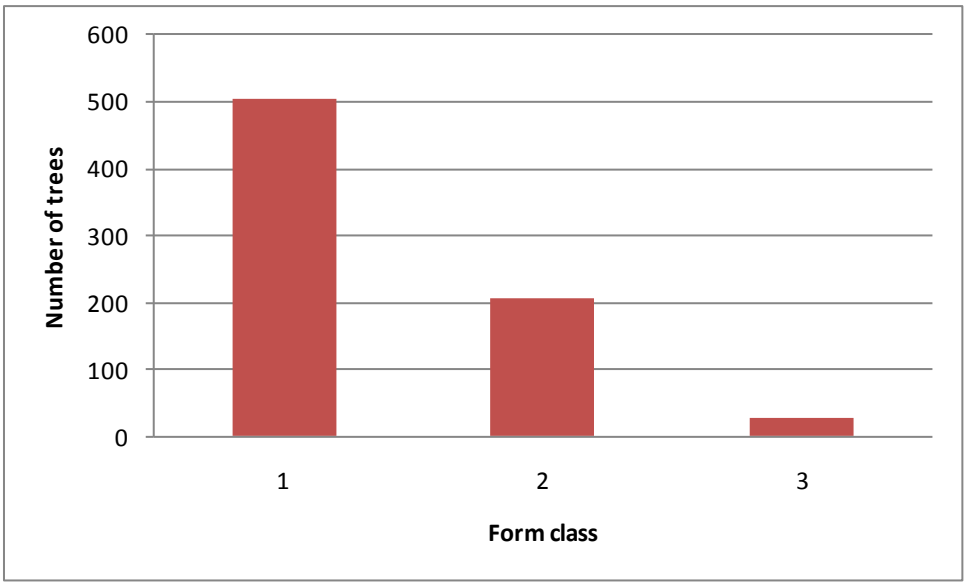

Figure 8: Form sample size distribution for the Demuth debarker.

The largest sample size occurs in the form class one (502 trees) with the best stem form, with the smallest sample in form class three (24 trees). Form class two had a sample size of 207 trees. The majority of the trees therefore had good form and would thus not affect the productivity negatively as an overall sample. The effect that each of the form classes individually have on productivity is shown in Figure 9.

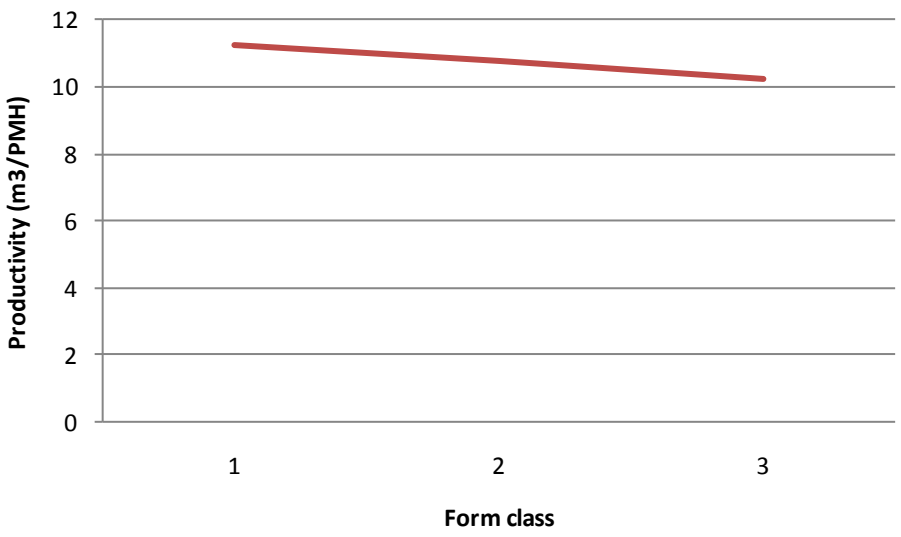

Figure 9: Effect of form class on the productivity of the Demuth debarker.

The effect of the different form classes on the productivity of the Demuth shows a general decrease with increasing form class. Form class one had an average productivity of 11.22m³ per PMH, form class two 10.69m³ per PMH and form class three a productivity of 10.21m³ per PMH. It would be expected that the productivity should decrease as the log form class increases. During the research, logs that had poor form would often jump out of the rollers and cause the machine to jam which would stop the operation in order to remove the log. The feeding time and time taken to arrange the logs also increases when the logs have a poor form, this would therefore affect the daily productivity.

4.4.3 Results of tree volume on productivity

The law of piece volume states that greater productivity is achieved when processing larger piece sizes than when processing smaller piece sizes (De Wet and Alcock, 2002). The time taken per piece might be longer, but volume per given time would be higher. The tree volume would therefore have a definite effect on the productivity of the debarker. With an increasing log volume, the productivity would increase. The sample size distribution between the five different tree volume classes is shown in Figure 10.

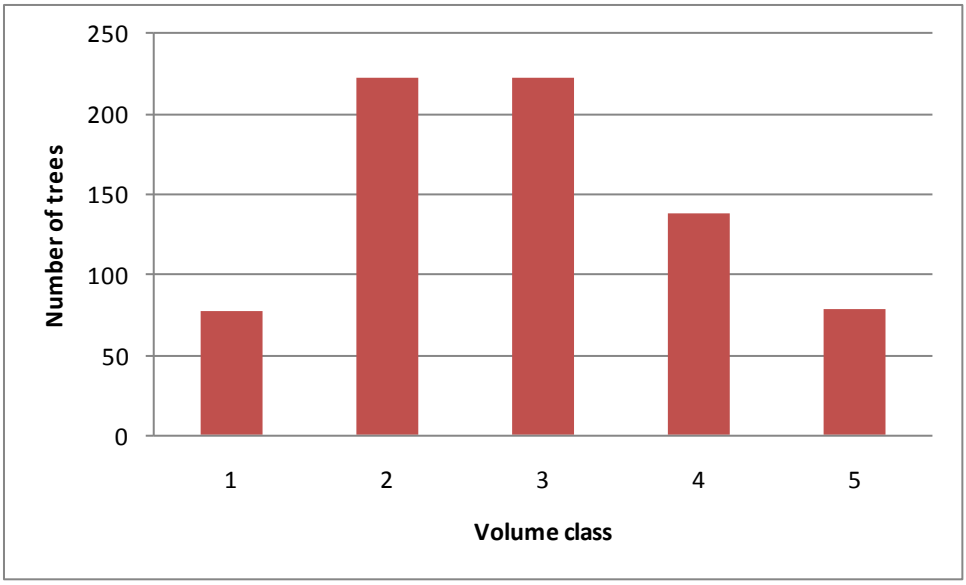

Figure 10: Volume sample size distribution for the Demuth debarker.

Figure 10 shows the distribution for the volume sample sizes. The sample sizes are greatest in the tree volume two (223 trees) and three (224 trees) classes, with class one, four and five having a sample size of 77 trees, 141 trees and 80 trees respectively. The effect that tree volume classes have on the productivity of the Demuth debarker is shown in Figure 11.

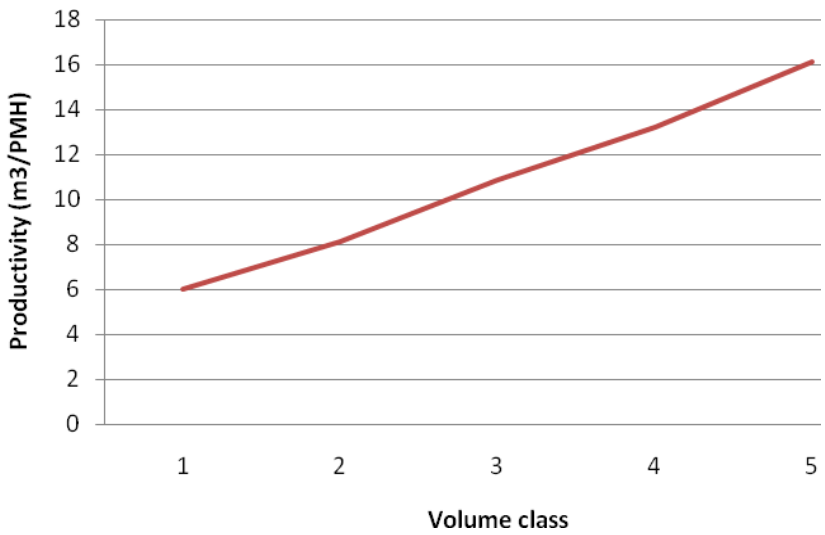

Figure 11: Effect of tree volume on the productivity of the Demuth debarker.

An increase in tree volume class increases the productivity of the Demuth debarker. Tree volume class one shows a productivity of 6m³ per PMH, class two of 8.1m³ per

PMH, class three of 10.2m³ per PMH, class four of 13.2m³ per PMH and class five shows the highest average productivity of 16.3m³ per PMH. Due to the feed speed being constant, larger log volumes had a higher resultant productivity. Bigger logs take longer to feed into the Demuth, due to them being heavier, but the average productivity is still higher.

4.4.4 Results of the combination of tree volume, strippability and form class on productivity

The three factors researched, that affect the productivity of the Demuth debarker have been discussed individually, namely: volume, strippability and form. Figure 12 shows the effect that the three factors combined had on the productivity of the machine. The x-axis is the combination of the three factors, first tree volume, then strippability and then form class.

Figure 12 shows a general increase in productivity over the different strippability, form and tree volume class combinations. The tree volume increases with an increase in tree volume class, and this has shown an increase in productivity. Tree form and strippability showed a decrease in productivity with an increase in tree form and strippability class. Each of the volume classes therefore starts with a good strippability (weak wood-bark bond strengths) and form (straight trees), and at the end of each volume class it has a low strippability (strong wood-bark bond strength) and poor form (malformed trees). At the beginning of each tree volume class, there is therefore a spike in productivity, with a decrease thereafter. This is due to increasing strippability and form classes which have already been demonstrated as reducing productivity. For tree volume class one, there is a total decrease in productivity of 3.6m³ per PMH, in tree volume class two a decrease of 1.4m³ per PMH, in tree volume class three a decrease of 1.1m³ per PMH, in tree volume class four a decrease of 0.3m³ per PMH and in tree volume class five a decrease of 3.2m³ per PMH. The increased productivity at the start of each volume class, and the sudden decrease shown by increasing strippability and form classes per tree volume class shows that strippability and form having a large effect on the productivity of the Demuth debarker.

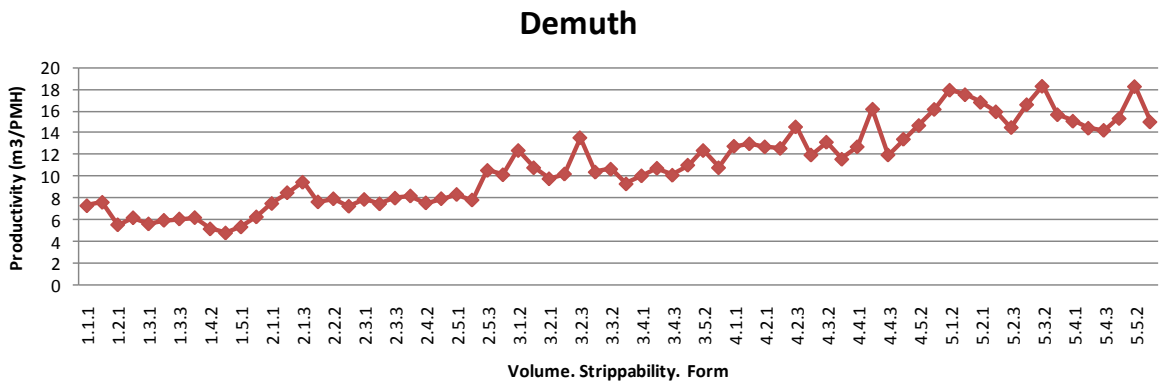

Figure 12: Productivity levels achieved by the Demuth debarker under various tree volume, strippability and form categories.

The productivity of the Demuth debarker ranges from the lowest productivity per productive machine hour (PMH) of 2.282m³ to a highest productivity per PMH of 19.129m³. The average productivity per PMH for the research was 10.227m³ per PMH.

4.5 ANALYSES RESULTS

Firstly descriptive statistics were used to determine sample means, standard deviation, variance and sample sizes. The data was then transferred to STATISTICA to conduct both factorial ANOVAs and one-way ANOVAs. This was used to analyse the difference in productivity of the three technologies, for each of the different factors (volume, strippability and form). For both the factorial and one-way ANOVA's, the assumptions are that the error terms are normally distributed and there is an equal variance. Therefore a test for normality was done to determine if the error terms were normally distributed and the homoscedasticity of the error terms was also checked to see if there was equal variance. If the ANOVA results were significant, then a Duncan's pairwise comparison was used to determine if there were any statistically significant differences in mean productivity of each of the different factor versus technology combinations. The means and sample sizes as obtained from the descriptive statistics are shown in the figures and tables throughout this chapter.

4.5.1 Tree volume

Both tests were first conducted using the raw data for the normality test. The points were not lying along the line in the normal probability plot and therefore the assumptions of normality were not met. A plot of the residuals against the predicted values suggested that the assumption of homoscedasticity was also not met. The outliers were then determined and removed as explained in Chapter 3. The assumptions were still not met. The productivity was then ranked, and both the assumptions were met as shown in Figure 13.

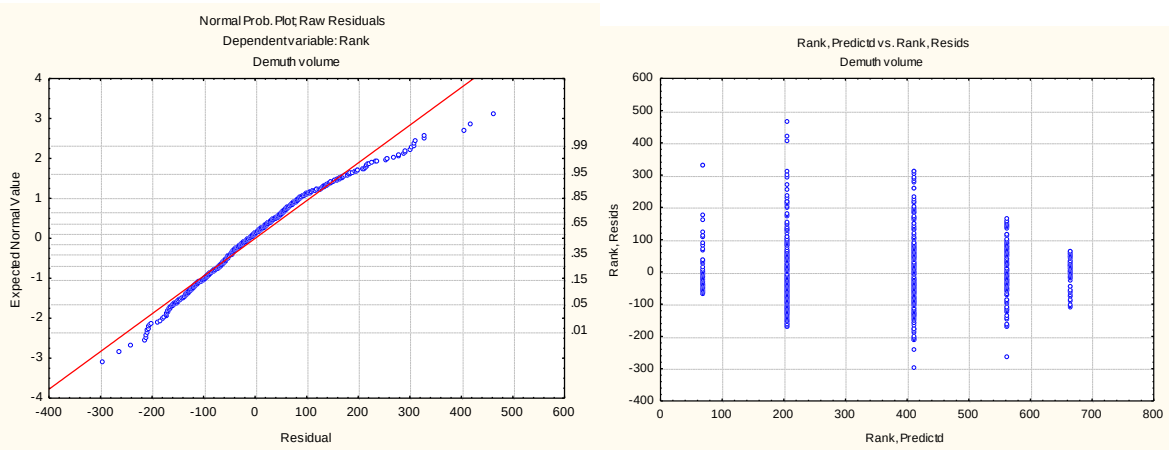

Figure 13: Results of Normality and Homoscedasticity tests of the Demuth debarker for tree volume.

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that there were statistically significant differences between the productivity of all the different volume classes with all of them having a $p < 0.05$ value.

4.5.2 Tree form

Both tests were first conducted using the raw data for the normality test. The points were not lying along the line and therefore the assumptions of normality were not met. The variance for the test of homoscedasticity was not constant and therefore the assumption of homoscedastic variance was not met either. The outliers were

then determined and removed as explained in Chapter 3. The assumptions for both normality and the variance of the error terms were met as shown in Figure 14

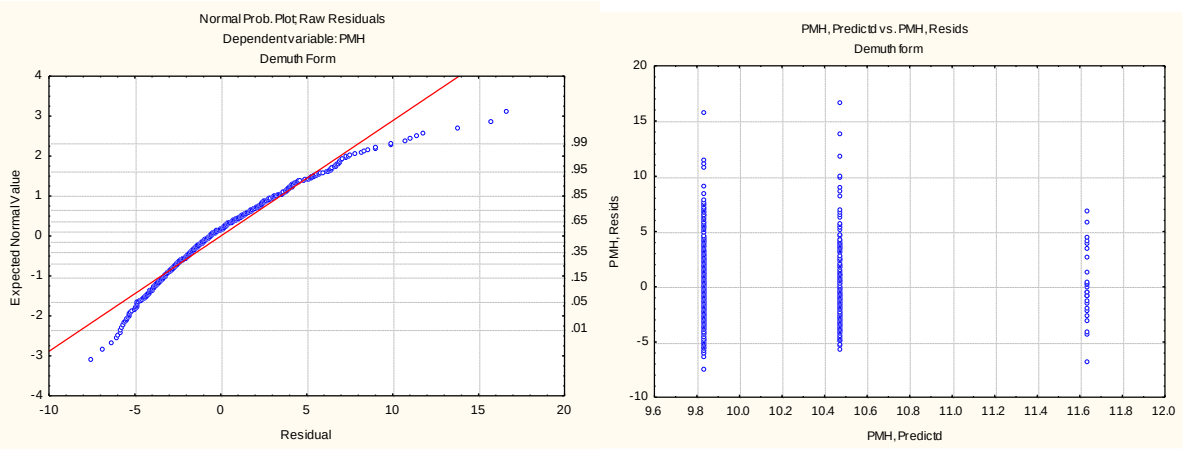

Figure 14: Results of Normality and Homoscedasticity tests of the Demuth debarker for tree form

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that for the form classes, form class 3 had a significant difference in productivity when compared to class one and class two. Productivity of form class one and class two also differed significantly from one another.

4.5.3 Strippability

Both tests were first conducted using the raw data for the normality test. The points were not lying along the line and therefore the assumptions of normality were not met. The variance for the test of homoscedasticity was not constant and therefore the assumption of homoscedastic variance was not met either. The outliers were then determined and removed as explained in Chapter 3. The assumptions for both normality and the variance of the error terms were met as shown in Figure 15.

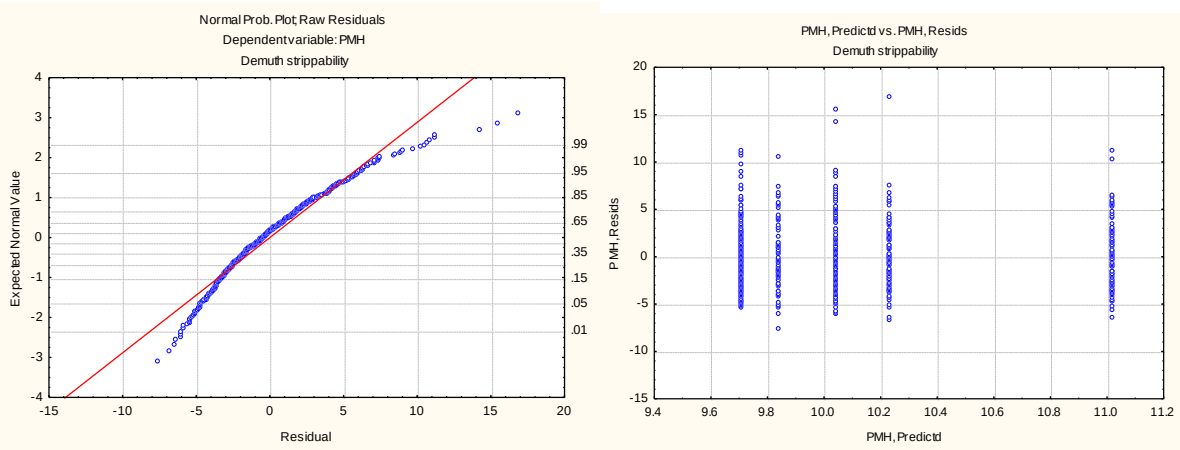

Figure 15: Results of Normality and Homoscedasticity tests of the Demuth debarker for strippability.

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that strippability class two differed significantly from the other classes, while there was no significant difference between any of the other classes.

4.6 BARK QUALITY RESULTS

The effects that tree volume, form and strippability have on the productivity of the Demuth debarker have been discussed in detail. Each of these factors will also have an effect on the quality of bark that is produced, in terms of bark damage and the dimensions of the bark. The quality of the bark was assessed for each of the five strippability classes. Annexure 1 contains pictures that give a visual indication of the bark quality levels achieved. The quality results of the bark as analysed at the UCL processing facility's laboratory, are shown in Annexure 2 and are summarised in Table 4 below.

Table 4: Bark quality analyses results for the Demuth debarker for each strippability class.

	Strippability class					
	1	2	3	4	5	Averages
%Tannin (dry)	35.86	36.11	38.59	38.09	41.96	38.122
%Non-tannin (dry)	17.28	14.99	14.91	13.43	15.22	15.166
%Insolubles	0.18	0.17	0.33	0.17	0.11	0.192
% Moisture	48.39	48.23	47.22	47.46	45.05	47.27
% Extractives	27.64	26.69	28.56	27.29	30.02	28.04
% Fibre	23.97	25.09	24.22	25	22.93	24.242
Index of Quality	1.16	1.07	1.18	1.09	1.39	1.178
Tannin:Non-tannin	2.15	2.46	2.59	2.85	2.76	2.562

When looking at each of the factors considered (as explained in Chapter 3), there is not a great difference between the different strippability classes. The percentage tannins on a dry basis increase slightly with an increasing strippability class due to a lower moisture content. The average is 38.12% which is acceptable, as it should be between 30 to 40% (Kristan, personal communication, 2010). The percentage non-tannins on a dry basis varied throughout the strippability classes and has an average of 15.2% which is a little higher than the recommended 10 to 15%. The percentage insolubles are very low with the average being 0.19%. The moisture content decreases with an increasing strippability class, therefore causing the stronger wood-bark bond strength. The average is 47.3%, a little higher than the recommended 40 to 45%. Neither the extractives nor the fibre percentage vary greatly between the strippability classes, averaging 28% and 24.2% respectively. The index of quality has an average of 1.18, which is near the required 1.2. The ratio of tannin to non tannin has an average of 2.56, very close to the desired 2.6. The averages shown in Table 4 for the Demuth bark analysis results are compared to the averages of the manual debarking results in Figure 16. The manual bark that was used as a comparison was obtained from the same compartment, where a small sample of trees was manually debarked under the same strippability conditions as the bark from the Demuth debarker.

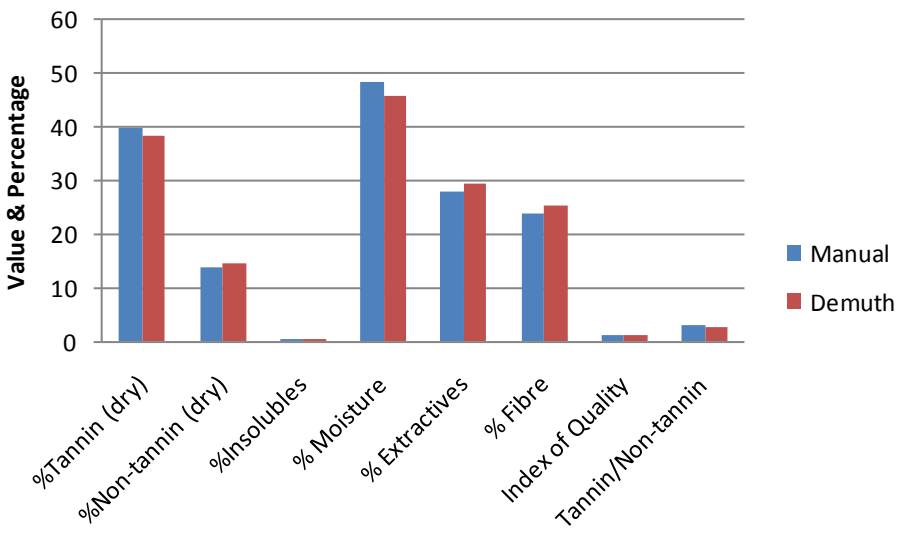

Figure 16: Comparison of bark analyses results between the Demuth debarker and manually debarked samples.

The results from Figure 16 show the comparison of the two debarking technologies. The manual debarking method currently being used in the industry is therefore an indication of the bark quality that is currently produced. The results obtained from the Demuth bark samples are very close to those obtained from the manually debarked samples. In terms of tannin percentage, both are acceptable, but the manually produced bark has a higher percentage of tannins, and is therefore better. The manually produced bark is also better than the bark produced by the Demuth Debarker as it has a lower percentage of non-tannins. The percentage insolubles are very similar. The manually produced bark has a higher moisture content due to the bigger dimensions of the bark produced, and will therefore dry out slower. The Demuth has a higher percentage of extractives and fibre, but has a lower tannin content than the manually produced bark. The index of quality is very similar for both methods. The manually produced bark has a higher, and therefore better, tannin to non-tannin ratio.

The results shown in Table 4 and Figure 16 indicate that the Demuth produces acceptable bark for the processing facility. There is a variation between the bark produced manually and the bark produced by the Demuth debarker, but they are both within the acceptable limits as described in Chapter 3.

CHAPTER 5:
HYENA MK3 DEBARKING HEAD

5.1 INTRODUCTION

The Hyena debarking head is a head manufactured in South Africa. It has two angled rollers and debranching arms on either side of the head. The Hyena debarking head can be attached to a wheeled or excavator-based carrier as shown in Figure 17. It weighs 1,140kg and has two driven angled rib rollers which feed the tree lengths through the head at seven metres per second (Küsel, personal communication, 2010). The rollers exert pressure on the stem causing the bark to pop off in strips depending on the wood-bark bonding strength. The Hyena head has two pairs of moving delimbing knives which can handle a maximum tree diameter of 400mm. According to Küsel (personal communication, 2010) the Hyena was specifically designed and built to process *E.nitens*, *E.macarthurii* and *E.smithii* but, has worked in *A.mearnsii* compartments. No modifications were made on the head while processing *A.mearnsii*.

Figure 17: Hyena head debarking an *A.mearnsii* tree.

Once the trees had been felled for the trials, the larger branches were removed by chainsaw (greater than 3cm diameter), and the debarking would then take place. Three lines of trees were felled at a time, with all the trees felled in the same direction. The operator would pick up the tree at the butt end using the delimbing knives and pull it through the head using the rollers. The amount of passes that were needed to remove all the bark depended on the wood-bark bond strength. This ranged from a single pass, removing the bark in tree length strips, to four or more passes, removing the bark in smaller chip lengths. When the wood-bark bond strength is high, more roller passes are required to remove the bark. This causes more damage to the bark, influencing the amount of oxidation that occurs. The only way to overcome this is to decrease the time between the debarking and processing of bark at the mill. Once debarking has been completed, the bark needs to be collected, bundled manually and transported to the factory within 24 hours. The debranching was conducted to the side of the machine and the debarking was done directly in front of the machine. This was done to try and separate the brush and the bark to enable easier collecting and bundling of the bark. The debarked tree lengths were then placed on top of the brush for crosscutting.

Due to the debarking occurring in front of the machine, the excavator would drive over the bark each time it would move further up the line to the unprocessed trees. This would cause the bark to get damaged as well as collecting sand and debris. The collection of the bark is not easy, due to it being of varying lengths and often being covered by brush and at times even tree lengths. A great deal of these problems can be overcome by changing operating techniques and planning.

5.2 HARVESTING SYSTEM

The system that was used with the Hyena debarker was as follows:

Felling: The trees were felled motor-manually by a chainsaw operator who had an assistant to help with the felling direction.

Debranching: Branches, with a diameter of larger than 3cm, were removed manually with a hatchet.

Debarking: The Hyena debarker would then grab the tree lengths at the base of each tree (thick-end) and debark them.

Cross-cutting: The chainsaw operator did the cross-cutting into 2.4m lengths.

Stacking: Once the crosscutting had been completed the log lengths were manually stacked for extraction.

Collecting Bark: After debarking, the varying lengths of bark were manually collected and bundled and stacked for extraction.

Extraction: A tractor with a self loading trailer was used to load and transport the log lengths to a central landing. The bark was collected and extracted in the same way.

5.3 RESEARCH SITE

The Hyena debarking trials were conducted on a Mondi plantation in the Iswepe region of Mpumalanga. Once the selected trees had been measured and felled, the Hyena debarker was brought in to carry out the debarking operation. The Hyena head that was used belonged to Eckart Küsel of Ihlathi Logging, and is manufactured by E&H Debarkers. The research site is indicated in Figure 18.

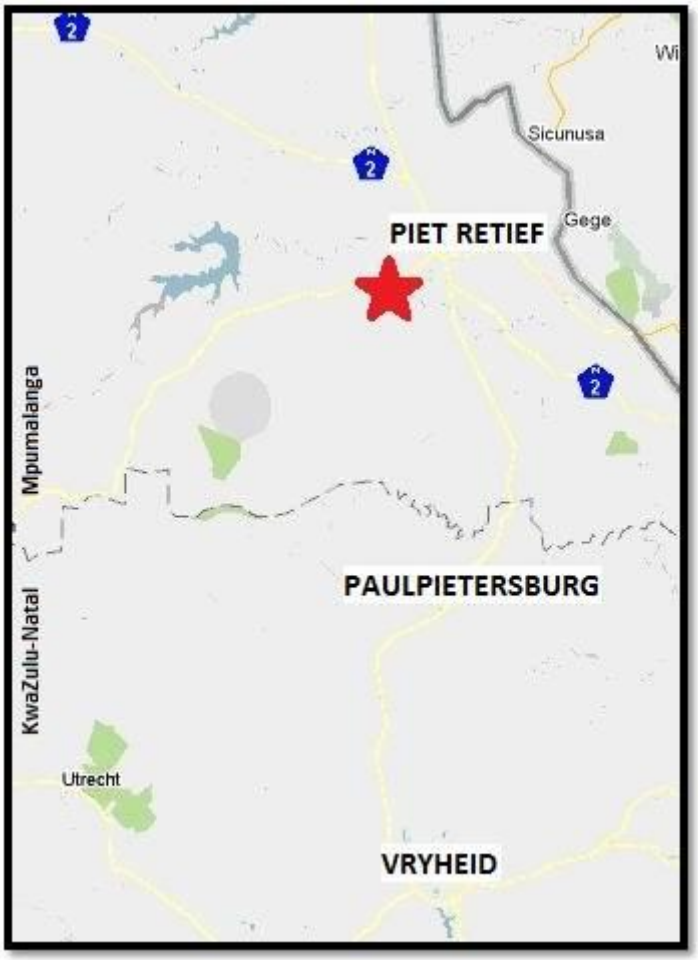

Figure 18: Hyena research site near Piet Retief in Mpumalanga (source: Google maps).

The trees processed in the trials had an average DBH of 15.8cm, an average height of 17.6m and an average volume of 0.152m³ per tree. A total of 386 trees were processed in the Hyena trials.

5.4 FACTORS AFFECTING THE PRODUCTIVITY OF THE HYENA DEBARKER

The three factors that were analysed to determine their effect on the productivity of the Hyena debarker were strippability, form and tree volume. Table 5 shows the average tree volume in cubic metres for each of the strippability and form classes. The table shows the fluctuating average tree volumes for each of the strippability and form classes. For the different strippability classes, the average tree volume

increases from class one to class two and the highest average tree volume of 0.174m³ occurs in class three. The tree volume then decreases again for class four and five. For the different form classes, the average tree size increases from form class one to two, where the highest average tree size of 0.164m³ occurs and it then decreases again in form class three. If there are any variances in the average productivity of each of the strippability and form classes, it could be related to this average tree volume.

Table 5: Average tree volume (m³) for each strippability and form class for the Hyena debarker.

	Tree volume class				
	1	2	3	4	5
Strippability	0.110 m³	0.162 m³	0.174 m³	0.161 m³	0.137 m³
Form	0.142 m³	0.164 m³	0.144 m³		

5.4.1 Results of strippability on productivity

When a strong wood-bark bond strength is experienced, the tree lengths need to pass through the head more often in order to remove the bark effectively. When all other element times such as moving and reaching for the tree remain constant, these extra passes will affect the productivity of the Hyena debarker negatively. The strippability was divided into five classes as described in Chapter 3. Figure 19 shows the distribution of sample sizes between these strippability classes.

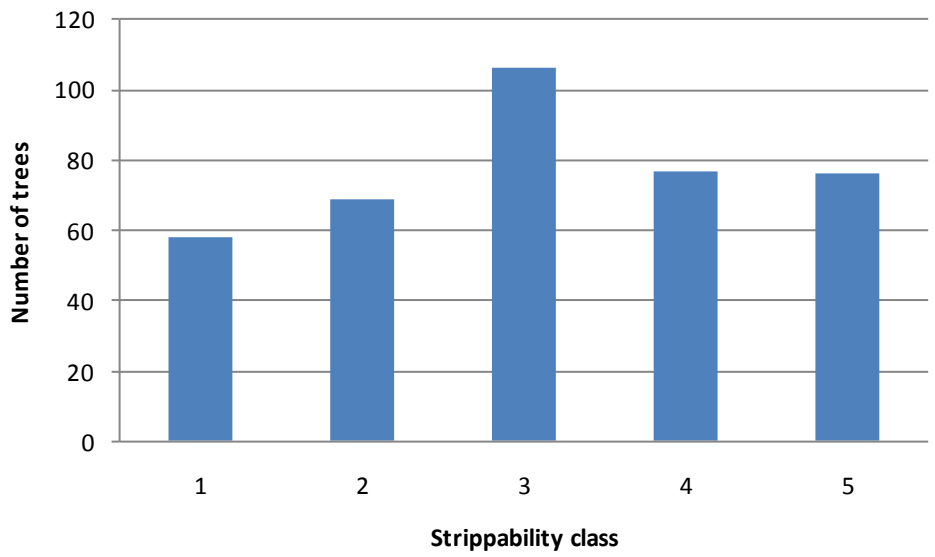

Figure 19: Strippability sample size distribution for the Hyena debarker.

The strippability sample size shows the distribution curve between the five classes for the Hyena debarker. The highest sample size occurs in the strippability class three with 106 trees, class one and two have a sample size of 58 trees and 68 trees respectively, and class four and five have a sample size of 77 trees and 76 trees respectively. There is therefore a good distribution of trees with very strong and very weak wood-bark bond strengths. The effect that these strippability classes have on productivity is shown in Figure 20.

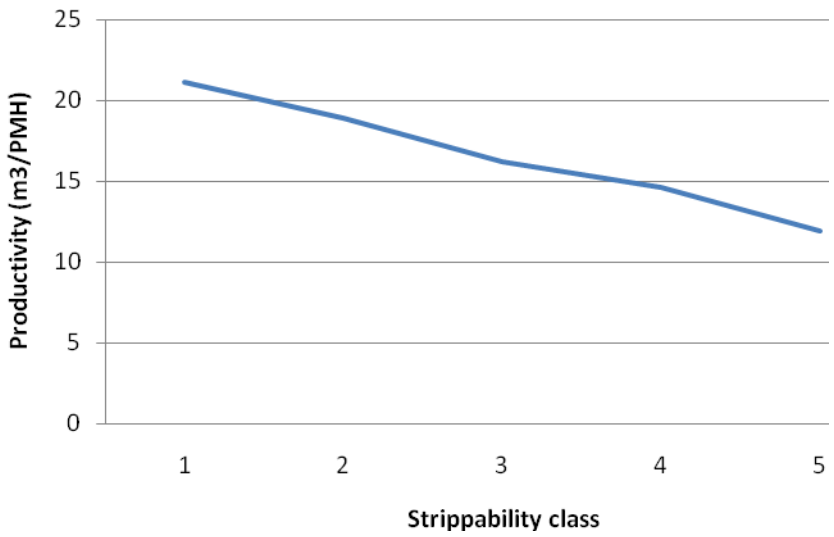

Figure 20: Effect of strippability on the productivity of the Hyena debarker.

Figure 20 clearly indicates that an increase in strippability class causes a decrease in the productivity of the Hyena debarker. When there is very low wood-bark bond strength, the debarker needs fewer passes to remove the bark; this therefore results in a high productivity due to reduced cycle times. A strong wood-bark bond strength, as experienced in strippability class five, results in much lower productivity (12.3m³ per PMH), when compared to strippability class one (21.4m³ per PMH), due to multiple passes needed to remove the bark from the stem. Strippability classes two, three and four had resultant productivities of 18.6m³ per PMH, 16.7m³ per PMH and 14.5m³ per PMH respectively. The steep decrease in productivity with an increasing strippability class shows that the strippability has a marked effect on the productivity of the Hyena debarker.

5.4.2 Results of form class on productivity

The form could influence the productivity of the Hyena debarker by hindering the movement of the tree through the head. The rollers and the debranching arms hold the tree tightly. If the tree has a good form, it will run smoothly through the head. If it is crooked however, it will get jammed on the rollers and arms, resulting in the head needing to be repositioned on the tree length in order to get more momentum or a different angle allowing the head to move over the bad area. If the form is poor, the head also has to process the tree with the delimbing knives slightly open. This reduced contact with the tree reduces debranching quality and decreases productivity as the knives do not remove the bark as easily. This is partially overcome by altering the angle of the rollers, therefore spinning the tree while moving through the head. A larger contact area between the rollers and the roof of the debarking head decreases delay time by increasing the available movement space for poor form trees. When the trees have a sharp crook or bend, there is usually a small amount of bark that remains on the stem on the inside of the crook, therefore also reducing debarking quality, as not all the bark is removed from the stem.

The sample size distribution of the three strippability classes is shown in Figure 21.

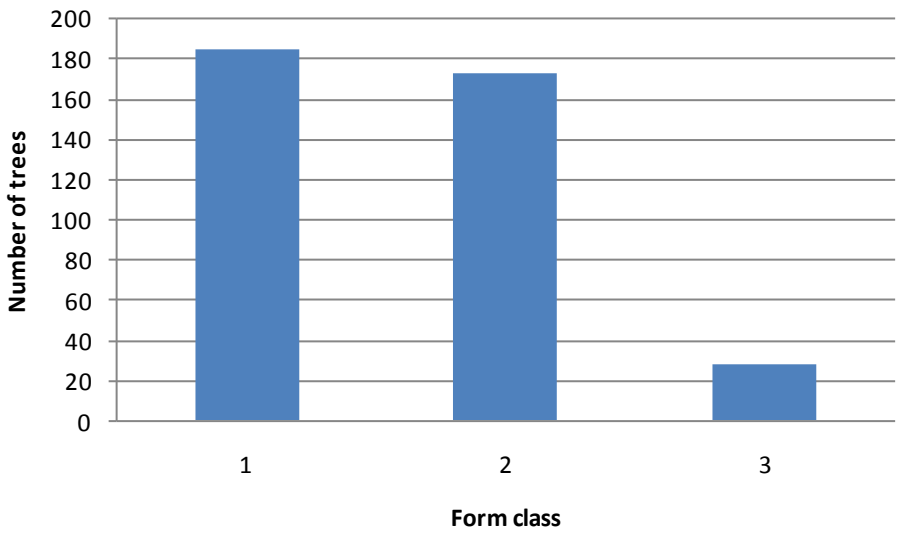

Figure 21: Form sample size distribution for the Hyena debarker.

The form class distribution is skewed to the left, and a high percentage of sampled trees occur in form classes one (183 trees) and two (174 trees). Form class three had a small sample size with 28 trees occurring in this class. The effect of each of these form classes on the productivity of the Hyena debarker is shown in Figure 22.

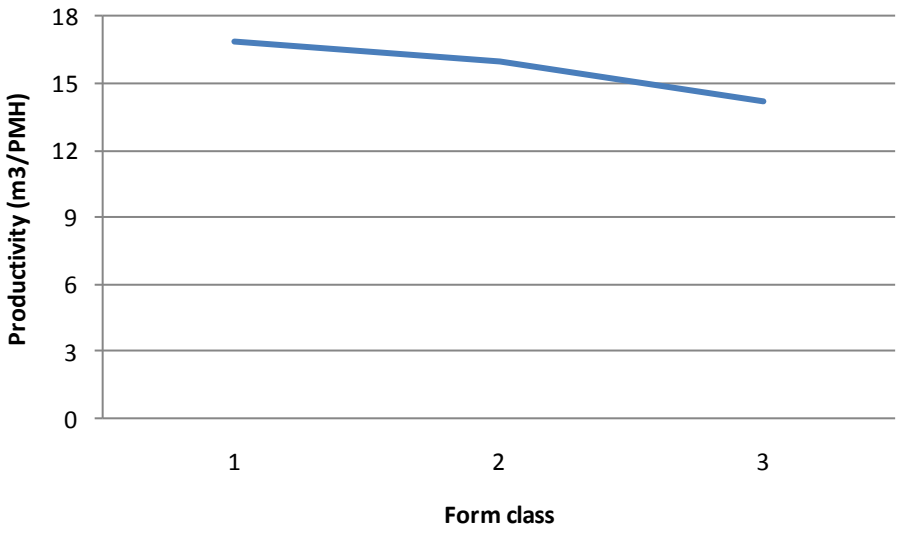

Figure 22: Effect of form on the productivity of the Hyena debarker.

Figure 22 shows the expected decrease in productivity with an increasing form class. The trees in form class one have the highest productivity of 16.9m³ per PMH. This is mainly due to fewer delays caused by poor stem form, and time required to re-position the debarking head on the stem. The productivity achieved for form class two and three was 15.9m³ per PMH and 14.2m³ per PMH respectively. The decrease over the different form classes is not very large, with a difference of less than 3m³ per PMH between form class one and three.

5.4.3 Results of tree volume on productivity

When processing large trees, more time might be taken to debark these trees than smaller trees, but the volume per time would be greater. The different tree sizes were divided into five tree volume classes as described in Chapter 3. The sample sizes of each of these volume classes are shown in Figure 23.

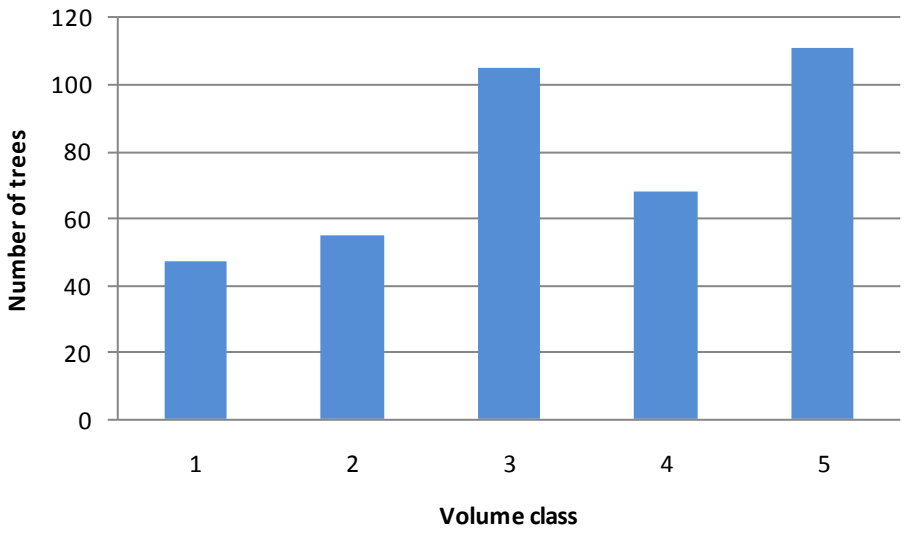

Figure 23: Volume sample size distribution for the Hyena debarker.

The sample size distribution shown in Figure 23 provides a good representation of the trees that were processed in the research trials. All of the volume classes had a sample size of larger than 45 trees. Fewer trees were debarked in the smaller volume classes, with the lowest number debarked in volume class one (46 trees).

The largest samples occurred in volume classes three and five, with 104 trees and 111 trees being processed respectively. Tree volume class two and four had a sample size of 53 trees and 67 trees respectively. The effect that each of these volume classes individually had on the productivity of the Hyena debarker is shown in Figure 24.

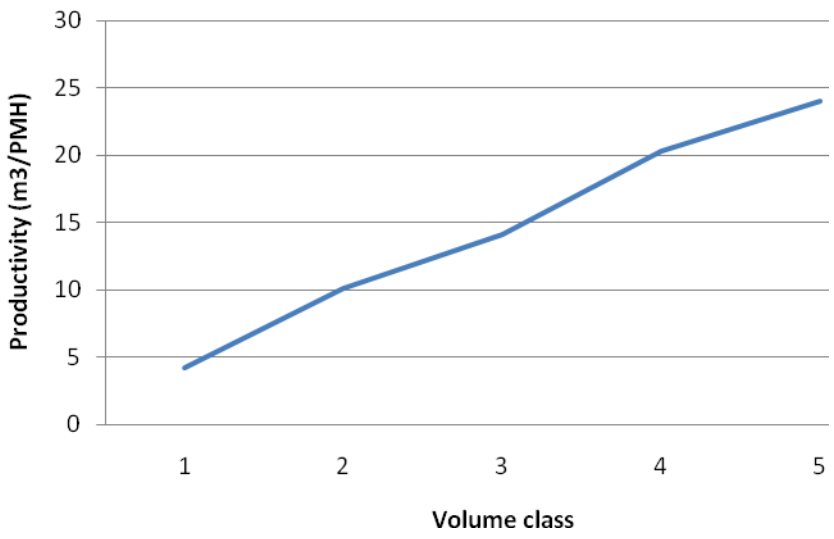

Figure 24: Effect of volume on the productivity of the Hyena debarker.

The steep gradient of the graph in Figure 24 shows the importance of volume on the productivity of the Hyena debarker. With a small tree volume as in volume class one, a low productivity of 4.3m³ per PMH is achieved, while a higher productivity per PMH is achieved in volume classes two (10.1m³ per PMH), three (14.2m³ per PMH), four (20.9m³ per PMH) and five (24.1m³ per PMH). Due to feed speeds remaining constant even when processing larger diameter trees, the average productivity for larger tree sizes was greater than those for smaller tree sizes. The wood-bark bond strength is usually lower with larger trees than with smaller trees, therefore less passes are needed to debark the entire tree. This is usually due to the trees being suppressed by the larger trees. This also contributes positively towards higher productivity in the higher tree volume classes.

5.4.4 Results of volume, strippability and form combined on productivity

The individual effects of strippability, form and volume class on the productivity of the Hyena debarker have been discussed in detail. An increase in volume class increased productivity per PMH, while an increasing strippability and form class reduced productivity per PMH. Figure 25 shows the effect that the three factors combined had on the productivity of the debarker. The x-axis is the combination of the three factors studies; first tree volume class, then strippability class then form class.

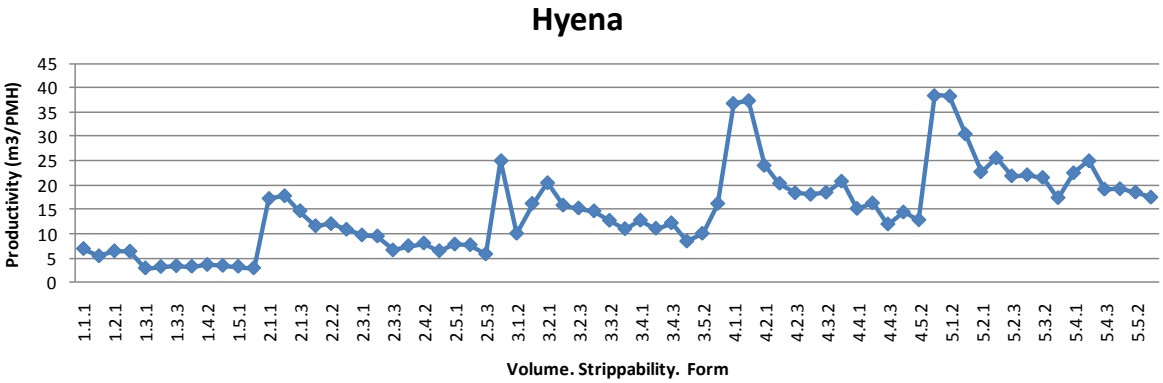

Figure 25: Productivity levels achieved by the Hyena debarker under various tree volume, strippability and form categories.

Figure 25 shows a general increase in productivity over the different strippability, form and tree volume class combinations. The tree volume increases with an increase in tree volume class, and this has shown an increase in productivity. Tree form and strippability showed a decrease in productivity with an increase in tree form and strippability class. Each of the volume classes therefore starts with a good strippability (weak wood-bark bond strengths) and form (straight trees), and at the end of each volume class it has a low strippability (strong wood-bark bond strength) and poor form (malformed trees). At the beginning of each tree volume class, there is therefore a spike in productivity, with a decrease thereafter. This is due to increasing strippability and form classes which have already been demonstrated as reducing productivity. For tree volume class one, there is a total decrease in

productivity of 3.2m³ per PMH, in tree volume class two a decrease of 12.4m³ per PMH, in tree volume class three a decrease of 14.1m³ per PMH, in tree volume class four a decrease of 23.7m³ per PMH and in tree volume class five a decrease of 23.2m³ per PMH. The increased productivity at the start of each volume class, and the sudden decrease shown with increasing strippability and form classes per tree volume class shows that strippability and form have a large effect on the productivity of the Hyena.

The productivity of the Hyena debarker ranges from the lowest productivity of 1.437m³ per PMH to a highest value of 61.702m³ per PMH. The average productivity for the research was 16.269 m³ per PMH. The above mentioned productivity figures are based on the full range of tree volume, strippability and form classes.

5.5 ANALYSES RESULTS

Firstly descriptive statistics were used to determine sample means, standard deviation, variance and sample sizes. The data was then transferred to STATISTICA to conduct both factorial ANOVAs and one-way ANOVAs. This was used to analyse the difference in productivity of the three technologies, for each of the different factors (volume, strippability and form). For both the factorial and one-way ANOVAs, the assumptions are that the error terms are normally distributed and there is an equal variance. Therefore a test for normality was done to determine if the error terms were normally distributed, homoscedasticity of the error terms was also checked, to see if there was equal variance. If the ANOVA results were significant, then a Duncan's pairwise comparison was used to determine if there were any statistically significant differences in mean productivity of each of the different factor versus technology combinations. The means and sample sizes as obtained from the descriptive statistics are shown in the figures and tables throughout this chapter.

5.5.1 Tree volume

Both tests were first conducted using the raw data for the normality test. The points were not lying along the line in the normal probability plot and therefore the

assumptions of normality were not met. A plot of the residuals against the predicted values suggested that the assumption of homoscedasticity was also not met. The outliers were then determined and removed as explained in Chapter 3. The assumptions were still not met. The productivity was then ranked, and both the assumptions were met as shown in Figure 26.

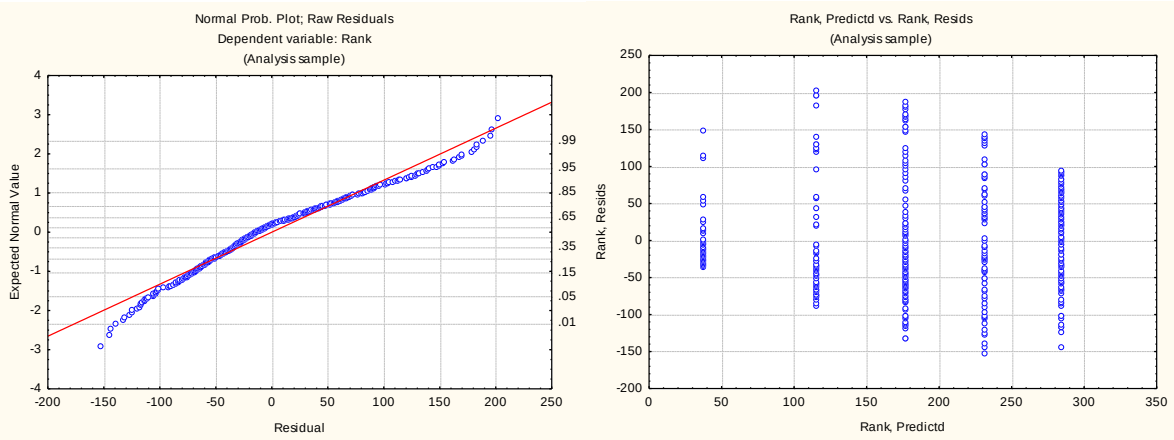

Figure 26: Results of Normality and Homoscedasticity tests of the Hyena debarker for tree volume.

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that there were statistically significant differences between the productivity of all the different volume classes with all of them having a $p < 0.05$ value.

5.4.2 Tree form

Both tests were first conducted using the raw data for the normality test. The points were not lying along the line in the normal probability plot and therefore the assumptions of normality were not met. A plot of the residuals against the predicted values suggested that the assumption of homoscedasticity was also not met. The

outliers were then determined and removed as explained in Chapter 3. The assumptions were met as shown in Figure 27.

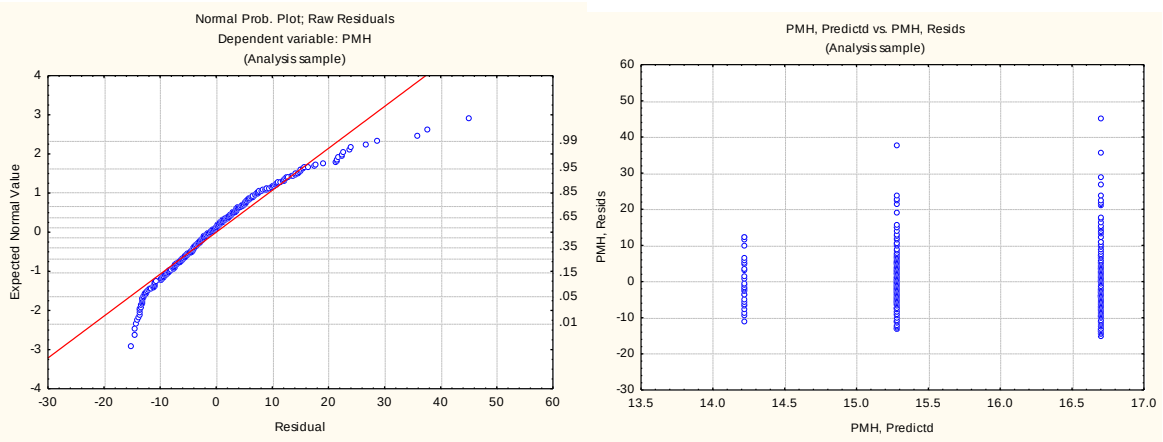

Figure 27: Results of Normality and Homoscedasticity tests of the Hyena debarker for tree form.

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that there were statistically significant differences between the productivity of all the different form classes with all of them having a $p < 0.05$ value.

5.4.3 Strippability

Both tests were first conducted using the raw data for the normality test. The points were lying along the line in the normal probability plot and therefore the assumptions of normality were met. A plot of the residuals against the predicted values suggested that the assumption of homoscedasticity was also met as shown in Figure 28.

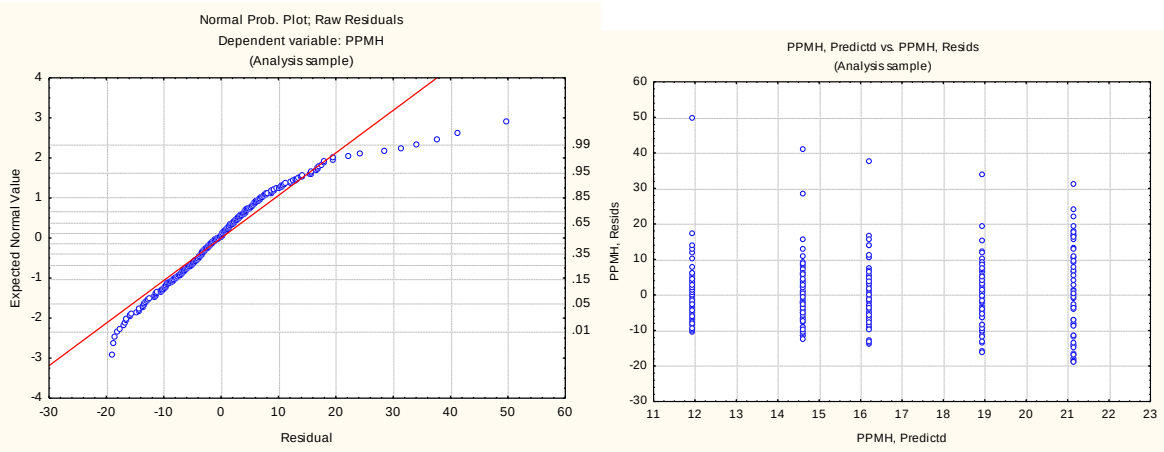

Figure 28: Results of Normality and Homoscedasticity tests of the Hyena debarker for strippability.

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that strippability class one had a significant difference in productivity with class three, class four and class five. Strippability class two showed a significant difference in productivity with class four and class five. Strippability class three showed a significant difference in productivity with class one and class five. Strippability class four showed a significant difference in productivity with class one and class two. Strippability class five showed a significant difference in productivity with class one, class two and class three.

5.6 BARK QUALITY RESULTS

The effects that tree volume, form and strippability have on the productivity of the Hyena debarker have been discussed in detail. Each of these factors could also have an effect on the quality of bark that is produced, in terms of bark damage and the dimensions of the bark. The quality of the bark was assessed for each of the five strippability classes. Annexure 1 contains photographs that give a visual indication of the bark quality levels achieved by each of the debarking technologies. The quality of

the bark as analysed at the UCL processing facility's laboratory, are shown in Annexure 2, as well as summarised below in Table 6.

Table 6: Bark quality analyses results for the Hyena debarker shown for each strippability class.

	Strippability class					
	1	2	3	4	5	Averages
%Tannin (dry)	33.08	37.99	40.405	39.915	40.11	38.3
%Non-tannin (dry)	12.41	15.27	15.935	14.665	14.08	14.472
%Insolubles	0.06	0.02	0.41	0.165	0.11	0.153
% Moisture	52.5	51.385	46.445	41.11	37.78	45.84
% Extractives	28.84	31.38	30.58	27.12	25.85	29.48
% Fibre	33.38	27.51	22.975	21.495	21.65	25.4
Index of Quality	0.864	1.14	1.33065	1.2516	1.194	1.15
Tannin:Non-tannin	2.73	2.49	2.54	2.725	2.85	2.667

When looking at each of the factors considered, there are not large differences between the different strippability classes. The percentage of tannins on a dry basis increase slightly with an increasing strippability class due to a lower moisture content. The average is 38.3% which is acceptable, as it should be between 30 to 40% (Kristan, personal communication, 2010). The percentage of non-tannins on a dry basis varies throughout the strippability classes and has an average of 14.5% which is within the recommended 10 to 15%. The percentage of insolubles is very low with the average being 0.15%. The moisture content decreases with increasing strippability class, therefore resulting in a stronger wood-bark bond strength. The average moisture content is 45.8%, which is within the recommended 40 to 45%. Both the extractives and fibre percentage do not vary greatly between the strippability classes, averaging 29.5% and 25.4% respectively. The index of quality has an average of 1.15, which is near the required 1.2 and therefore still acceptable. The ratio of tannin to non-tannin has an average of 2.67, and is sufficiently close to the desired 2.6. The averages obtained from the analysis of the Hyena bark as shown in Table 6, are compared to the averages of the manual debarking results in Figure 29.

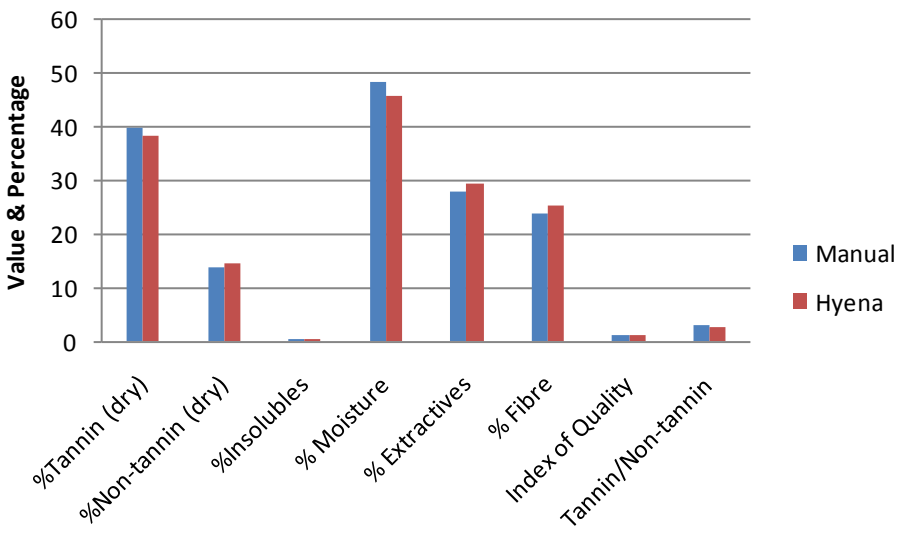

Figure 29: Comparison of bark analyses results between the Hyena debarker and manually debarked samples.

The results from Figure 29 show the comparison of the two debarking technologies. The manual debarking method currently being used in the industry is therefore an indication of the bark quality that is currently produced. The results obtained from the Hyena bark samples are very close to those obtained from the manually debarked samples. In terms of tannin percentage, both are acceptable, but the manually produced bark has a higher percentage of tannins, and is therefore better. The bark produced by the Hyena debarker is better than the manually produced bark as it has a lower percentage of non-tannins. The percentage of insolubles is very similar. The manually produced bark has a higher moisture content due to the bigger dimensions of the bark produced, and will therefore dry out slower. The Hyena has a higher percentage extractives and fibre, but this has a lower tannin content than the manually produced bark. The index of quality is very similar for both methods. The manually produced bark has a higher, and therefore better, tannin to non-tannin ratio. The results shown in Table 6 and Figure 29 indicate that the Hyena produces acceptable bark for the processing facility. There is a variation between the bark produced manually and the bark produced by the Hyena debarker, but they are both within the acceptable limits as described in Chapter 3.

CHAPTER 6:
HYPRO 765 TRACTOR MOUNTED DEBARKER

6.1 INTRODUCTION

The Hypro 765 is a tractor-mounted processor, which is produced in Sweden. It has the ability to debranch, debark and cross-cut tree lengths into logs. For the research that was conducted, no cross-cutting took place; the Hypro was purely used as a debarker. The debarker is mounted on the three point linkage of a tractor of 78kW or higher, used to power and carry the debarker, as shown in Figure 30. The Hypro has a 280 degree slewing capacity and a crane with a reach of seven metres. This allows the debarker to process trees that are felled up to 3.3 metres on either side of it (Chapman, 2006).

Figure 30: Hypro debarker mounted on the three point linkage of a tractor.

During the research, the trees were felled motor-manually; all branches greater than 3cm in diameter were removed manually with a hatchet. The trees were then processed on either side of the debarker. The bark is removed from the stem with

pressure applied by the feed rollers. The debranching knives also aid in scraping the loose bark off the stem. The debarker removes the bark in varying lengths, determined by the wood-bark bond strength. The stronger the wood-bark bond strength, the shorter the resultant bark strip lengths were, as seen visually in Annexure 1. The bark must then be collected and bundled manually. A large amount of bark gets caught around the debranching arms, which needed to be removed by the operator causing delays.

6.2 HARVESTING SYSTEM

The system that was used with the Hypro debarker was as follows:

Felling: The trees were felled motor-manually by a chainsaw operator who had an assistant to help with the felling direction.
Debranching: Branches, with a diameter of larger than 3cm, were removed manually with a hatchet.
Debarking: The Hypro debarker would then grab the tree lengths at the base of each tree (thick-end) and debark them.
Cross-cutting: The chainsaw operator cross-cut the tree lengths into 2.4m lengths.
Stacking: Once the crosscutting had been completed the log lengths were manually stacked for extraction.
Collecting Bark: After debarking, the varying lengths of bark were manually collected and bundled and stacked for extraction.
Extraction: A tractor with a self loading trailer was used to load and transport the log lengths to a central landing. The bark was collected and extracted in the same way.

6.3 RESEARCH SITE

The research trials were conducted on a Masonite forestry estate. The plantation was situated in the Greytown area on the road linking the towns of Greytown and Mooi River. The research trials were conducted over two different field visits. As explained in Chapter 3, one of the field visits was conducted during summer and the other during winter when debarking does not usually take place. The bark was then sent to the UCL processing plant in Dalton for analyses to be conducted. The Hypro

belonged to a contractor who was conducting the harvesting. The research site for the Hypro trials is shown in Figure 31.

Figure 31: Hypro debarking research site near Greytown in KwaZulu-Natal.

The research site had an average tree volume of 0.099m³, average diameter of 13.24cm and an average height of 16.38m. A total of 278 trees were debarked during the research.

6.4 FACTORS AFFECTING THE PRODUCTIVITY OF THE HYPRO DEBARKER

The three factors that were investigated to determine their effect on the productivity of the Hypro debarker were the effect of tree volume, strippability and form.

Table 7 shows the average tree volume in cubic metres for each of the strippability and form classes. For the different strippability classes, the average tree volume fluctuates, it decreases from strippability class one (0.104m³) to the lowest tree volume in class three of 0.086m³. The average tree volume then increases to the

highest tree volume of 0.117m³ in strippability class four and decreases again to a tree volume of 0.088m³ in class five. For the different form classes the average tree volume increases from form class one to three. Form classes one, two and three have an average tree volume of 0.096m³, 0.105m³ and 0.162m³ respectively. Table 7 distinguishes if any of the variances in productivity in Figure 6 are caused by differing average tree volume sizes of the sample.

Table 7: Average tree volume (m³) for each strippability and form class for the Hypro debarker.

	Tree volume class				
	1	2	3	4	5
Strippability	0.104	0.101	0.086	0.117	0.088
Form	0.096	0.105	0.162		

6.4.1 Results of strippability on productivity

The strippability was divided into five different classes which are differentiated by the wood-bark bond strength as described in Chapter 3. The stronger the wood-bark bond strength (higher strippability class), the more time is needed to debark each tree length, and this therefore has a negative effect on productivity. The sample sizes for each of these classes for the Hypro debarker are shown in Figure 32.

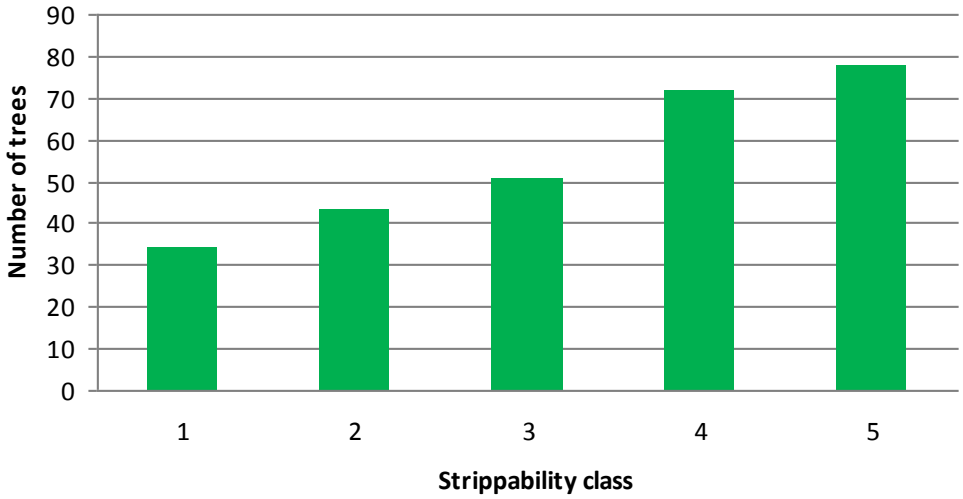

Figure 32: Strippability sample size distribution for the Hypro debarker.

The sample size distribution shown in Figure 32 is skewed to the right, with the largest sample size occurring in strippability class five, and the lowest in strippability class one. There is an increase in sample size from the smallest to the largest strippability class. Therefore more trees were debarked with very strong wood-bark bond strengths. Strippability class one had a sample size of 34 trees, strippability class two of 43 trees, strippability class three of 51 trees, strippability class four of 72 trees and strippability class five of 78 trees. The effect that each of these classes individually has on the productivity of the Hypro debarker is shown in Figure 33.

Figure 33: Effect of strippability on the productivity of the Hypro debarker.

Figure 33 shows a general trend of decreasing productivity per PMH with an increasing strippability class. The productivity curve is not uniformly shaped and has a sharp drop in productivity for strippability class three. When looking at Table 7 it is clear to see that the average volume for the different strippability classes fluctuates. This contributes to the drop and rise in the productivity of the strippability line. There is a large difference in average tree volume between strippability classes two (0.101m³), three (0.086m³) and four (0.117m³). Strippability class three has the lowest average tree volume, and therefore the lower productivity. Strippability class one has the highest productivity of 4.6m³ per PMH, strippability class two has a productivity of 4.4m³ per PMH, strippability class three has a productivity of 3.3m³ per PMH, strippability class four has a productivity of 3.8m³ per PMH and strippability class five has the lowest productivity of 3.1m³ per PMH. The decreasing productivity caused by an increasing strippability class is expected, due to longer debarking times required per tree when there is a strong wood-bark bond strength.

6.4.2 Results of form on productivity

The form was divided into three different classes based on the physical form of the tree as discussed in Chapter 3. Tree form was identified as one of the factors that could have an effect on the productivity of the Hypro debarker. The debarking time

between the different tree form classes would vary, due to longer times needed to handle and re-position trees with poor form in the debarking head, and therefore have an effect on the productivity of the Hypro debarker. The sample sizes of the three different form classes are shown in Figure 34.

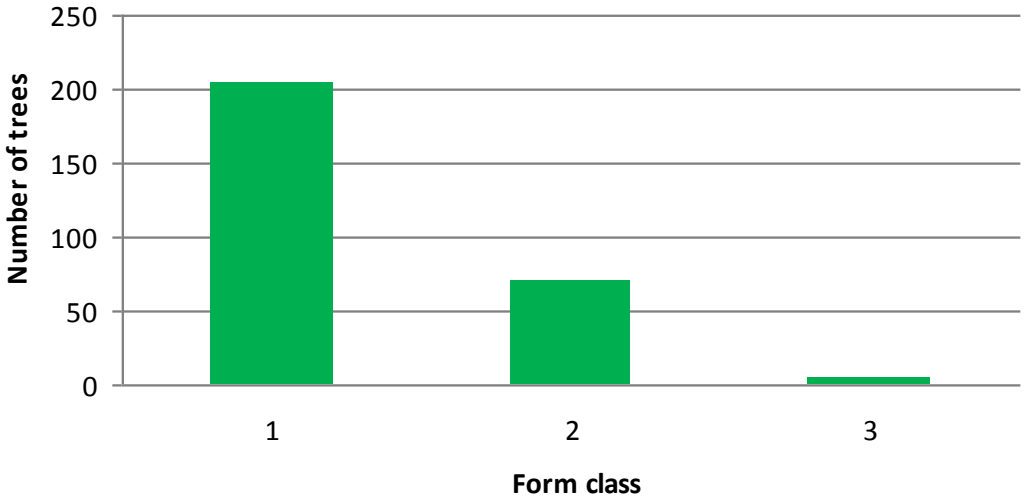

Figure 34: Form sample size distribution for the Hypro debarker.

The distribution of sample size is skewed to the left mainly in form class one with few trees occurring in form class three. Form class one has a sample size of 206 trees and form class two has a sample size of 69 trees. Form class three has very few trees, with a sample size of only eight trees, and this shows that the compartment used in the research had good stem form. The effect that each of these individual form classes has on the productivity of the Hypro debarker is shown in Figure 35.

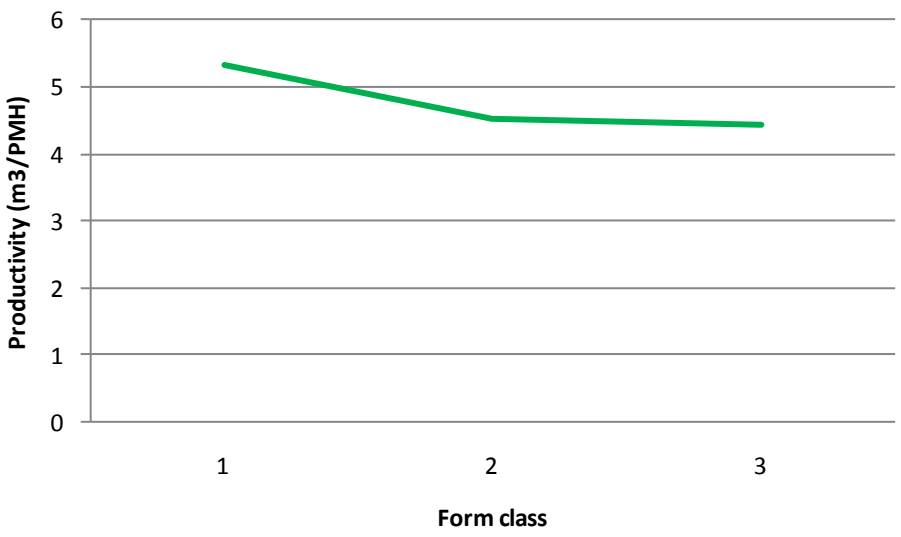

Figure 35: Effect of form on the productivity of the Hypro debarker.

The productivity curve in Figure 35 shows a decrease in productivity with an increase in tree form class. Form class one has a productivity of 5.3m³ per PMH, form class two of 4.5m³ per PMH and form class three of 4.4m³ per PMH. The productivity is expected to decrease when the tree has bad form, compared to those with a straight stem. The time taken to open the rollers, re-positioning the tree with the grab and then closing the rollers again to continue processing are all factors that would cause the productivity to decrease. The decrease for form class three is marginal which is caused by the small sample size and the higher average tree volume.

6.4.3 Results of volume on productivity

The tree volume was divided into five different classes as described in Chapter 3. The sample size distribution for each of the five classes is shown in Figure 36.

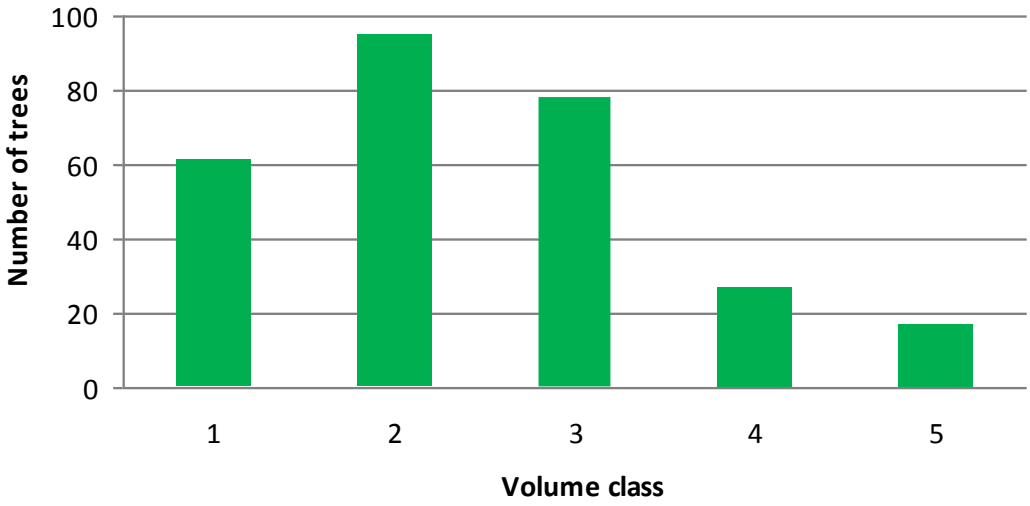

Figure 36: Volume sample size distribution for the Hypro debarker.

The sample size distribution is skewed to the left, with the majority of the sampled trees falling in the tree volume one (61 trees), two (95 trees) and three (79 trees) classes. Volume class four (27 trees) and five (17 trees) have low sample sizes. The effect that each of these individual volume classes had on the productivity of the Hypro debarker is shown in Figure 37.

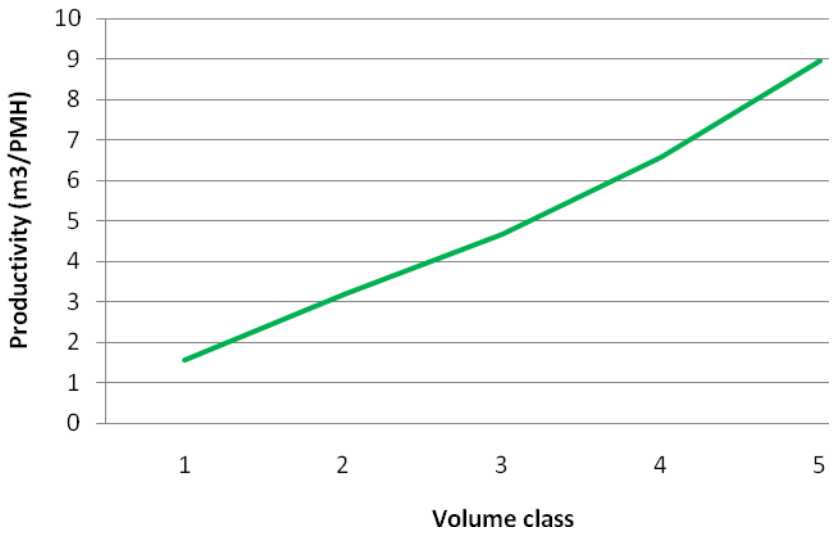

Figure 37: Effect of volume class on the productivity of the Hypro debarker.

The productivity curve shown in Figure 37 shows a steep increase in productivity with an increasing volume class. Due to most of the work element times, for example reaching for the tree and positioning it for the rollers, remaining fairly constant for the different tree sizes: the larger the piece size, the higher the productivity. Tree volume class one has the lowest productivity of 1.6m³ per PMH, tree volume class two of 3.1m³ per PMH, tree volume class three of 4.6m³ per PMH, tree volume class four of 6.6m³ per PMH and tree volume class five has the highest productivity of 8.9m³ per PMH. This productivity therefore shows the importance of tree size and its effect on the productivity of the Hypro debarker.

6.4.4 Results of volume, strippability and form combined on productivity

The individual effect of strippability, volume and form on the productivity of the Hypro debarker, have each been discussed. Figure 38 shows the effect that the three factors combined had on the productivity of the machine. The x-axis is the combination of these three factors; first tree volume class, then strippability class and then form class.

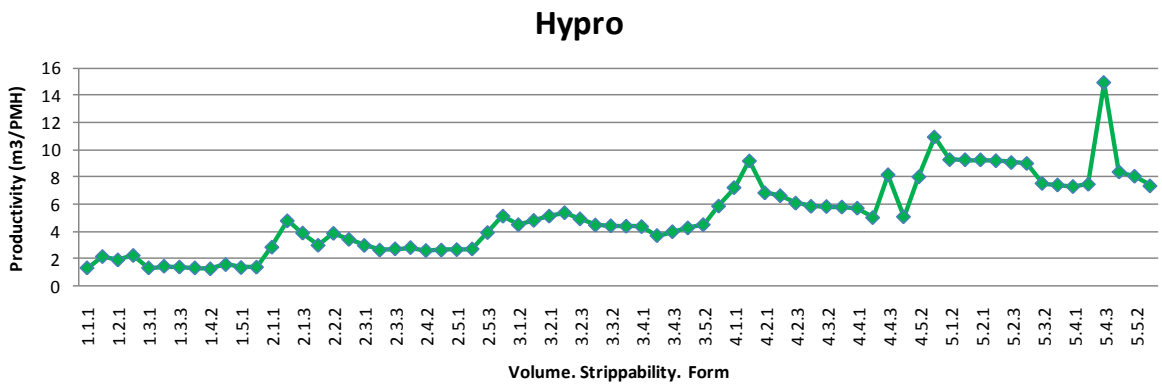

Figure 38: Productivity levels achieved by the Hypro processor under various tree volume, strippability and form situations.

The graph shows a general increase in productivity over the research sample. Tree form and strippability showed a decrease in productivity with an increase in tree form and strippability class. Each of the volume classes therefore starts with a good

strippability (weak wood-bark bond strengths) and form (straight trees), and at the end of each volume class it has a low strippability (strong wood-bark bond strength) and poor form (malformed trees). At the beginning of each tree volume class, there is therefore a spike in productivity, with a decrease thereafter. This is due to increasing strippability and form classes which have already been demonstrated as reducing productivity. For tree volume class one, there is a total decrease in productivity of 0.3m³ per PMH, in tree volume class two a decrease of 2.5m³ per PMH, in tree volume class three a decrease of 0.4m³ per PMH, in tree volume class four a decrease of 3.5m³ per PMH and in tree volume class five a decrease of 3.7m³ per PMH. The increased productivity at the start of each volume class, and the sudden decrease that is demonstrated by increasing strippability and form classes per tree volume class shows that strippability and form have a negative effect on the productivity of the Hypro.

The productivity of the Hypro debarker ranges from 0.771m³ per PMH to 14.939m³ per PMH. The average productivity for the research was 3.717m³ per PMH. The above mentioned productivity figures are based on the full range of tree volume, strippability and form classes.

6.5 ANALYSES RESULTS

Firstly descriptive statistics were used to determine sample means, standard deviation, variance and sample sizes. The data was then transferred to STATISTICA to conduct both factorial ANOVAs and one-way ANOVAs. This was used to analyse the difference in productivity of the three technologies, for each of the different factors (volume, strippability and form). For both the factorial and one-way ANOVAs, a test for normality was done to determine if the error terms were normally distributed, homoscedasticity of the error terms was also checked, to see if there was equal variance. Duncan’s pairwise comparison was used to determine if there were any statistically significant differences between each of the different factor versus technology combinations. The means and sample sizes as obtained from the descriptive statistics are shown in the figures and tables throughout this chapter.

6.5.1 Tree volume

Both tests were first conducted using the raw data for the normality test. The points were not lying along the line in the normal probability plot and therefore the assumptions of normality were not met. A plot of the residuals against the predicted values suggested that the assumption of homoscedasticity was also not met. The outliers were then determined and removed as explained in Chapter 3. The assumptions were then met as shown in Figure 39.

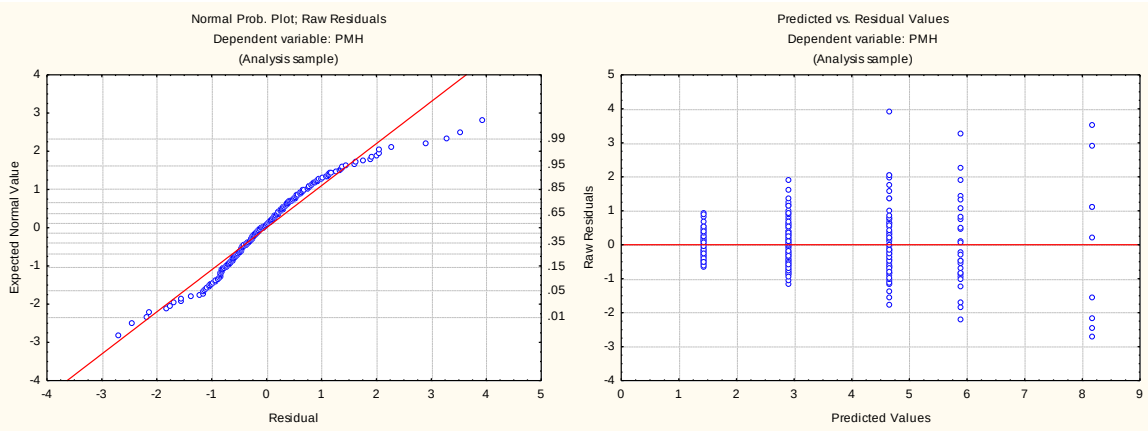

Figure 39: Results of Normality and Homoscedasticity tests of the Hypro debarker for tree volume.

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that there were statistically significant differences between the productivity of all the different volume classes with all of them having a $p < 0.05$ value.

6.5.2 Tree form

Both tests were first conducted using the raw data for the normality test. The points were lying along the line in the normal probability plot and therefore the assumptions of normality were met. A plot of the residuals against the predicted values suggested that the assumption of homoscedasticity was also met as shown in Figure 40.

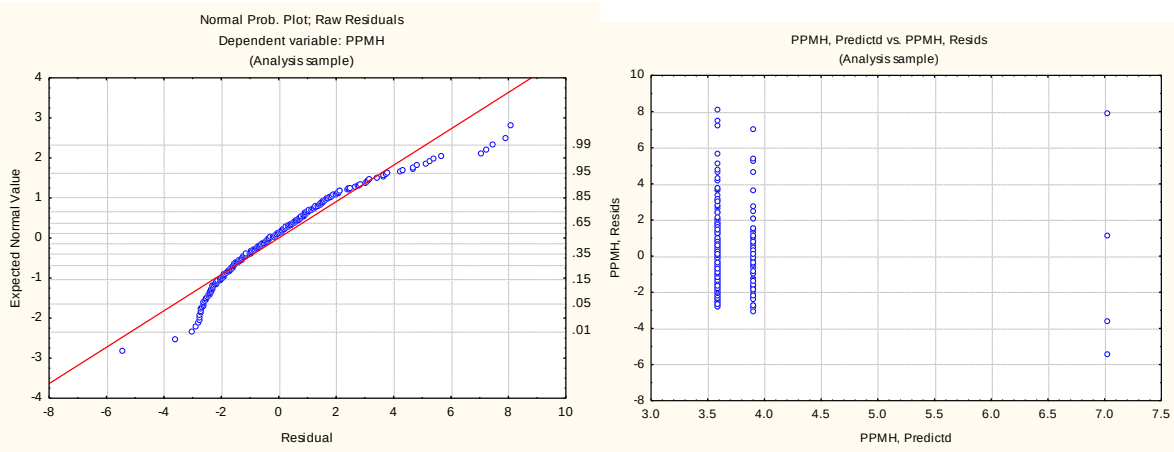

Figure 40: Results of Normality and Homoscedasticity tests of the Hypro debarker for tree form.

The univariate results showed that there was a statistically significant difference in mean productivity within the different volume classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that for the form classes, form class three had a significant difference in productivity when compared to class one and class two. The productivity of form class one and class two did not differ significantly from one another.

6.5.3 Strippability

Both tests were first conducted using the raw data for the normality test. The points were lying along the line in the normal probability plot and therefore the assumptions of normality were met. A plot of the residuals against the predicted values suggested that the assumption of homoscedasticity was also met as shown in Figure 41.

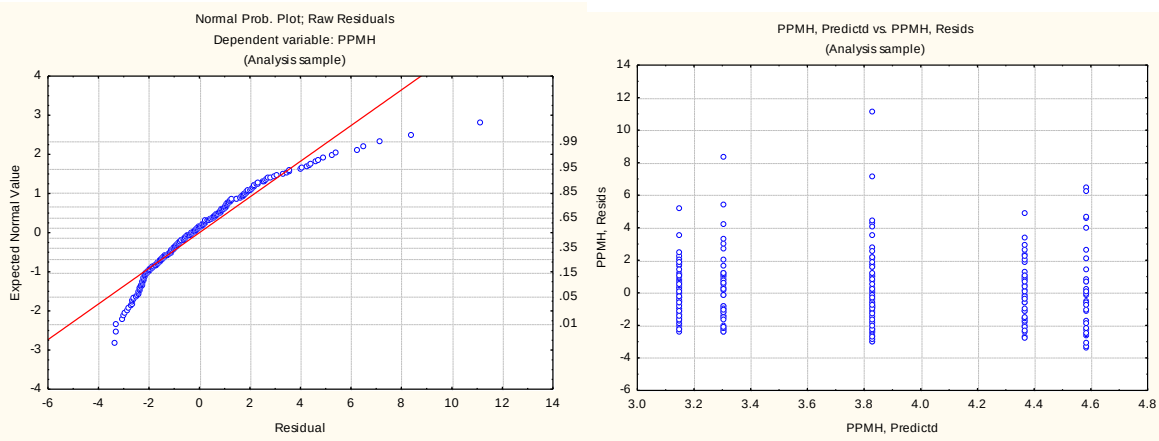

Figure 41: Results of Normality and Homoscedasticity tests of the Hypro debarker for srippability.

The univariate results showed that there was a statistically significant difference in mean productivity within the different strippability classes; therefore Duncan's pairwise comparison was used to determine which classes showed a significant difference. Duncan's pairwise comparison showed that strippability class one showed a significant difference in productivity with class three and class five. Strippability class two showed a significant difference in productivity with class three and class five. Strippability class three showed a significant difference in productivity with class one and class two. Strippability class four showed no significant difference in productivity with any of the other strippability classes. Strippability class five showed a significant difference in productivity with class one and class two.

6.6 BARK QUALITY RESULTS

The effects that tree volume, form and strippability have on the productivity of the Hypro debarker have been discussed in detail. Each of these factors will also have an effect on the quality of bark that is produced, in terms of bark damage and the size of the bark. The quality of the bark was assessed for each of the five strippability classes. Annexure 1 shows the visual quality of the bark produced by each of the debarking technologies. The quality of the bark as analysed at the UCL processing facility's laboratory, is shown in Annexure 2, and summarised in Table 8 below.

Table 8: Bark quality analyses results for the Hypro debarker shown for each strippability class.

	Strippability class					
	1	2	3	4	5	Averages
%Tannin (dry)	36.13	36.65	37.16	31.46	38.92	36.06
%Non-tannin (dry)	10.65	11.33	10.25	9.88	10.90	10.60
%Insolubles	0.13	0.19	0.19	0.31	0.25	0.21
% Moisture	36.59	27.96	45.80	36.42	39.49	37.25
% Extractives	30.08	34.75	25.88	26.58	30.41	29.54
% Fibre	33.33	37.30	28.32	37.01	30.11	33.21
Index of Quality	0.90	0.93	0.91	0.72	1.01	0.90
Tannin:Non-tannin	3.40	3.29	3.63	3.19	3.57	3.42

When looking at each of the factors considered, there is little difference between the different strippability classes. The percentage of tannins on a dry basis increased slightly with increasing strippability class due to lower bark moisture contents, except for strippability class four. The average is 36.06% which is acceptable, as it should be between 30-40% (Kristan, personal communication, 2010). The percentage of non-tannins on a dry basis varies throughout the strippability classes and has an average of 10.6% which is within the recommended 10-15%. The percentage of insolubles is very low with the average being 0.21%, which is good. The moisture content varies for each strippability class, with an average of 37.25%, slightly lower than the recommended 40-45%, which is still acceptable. Both the extractives and fibre percentage do not vary greatly between the strippability classes, averaging 29.54% and 33.21% respectively. The index of quality has an average of 0.9, which is near the required 1.2. The ratio of tannin to non-tannin has an average of 3.42, higher than the desired 2.6. The averages shown in Table 8 for the Hypro bark analysis results are compared to the averages of the manual debarking results in Figure 42.

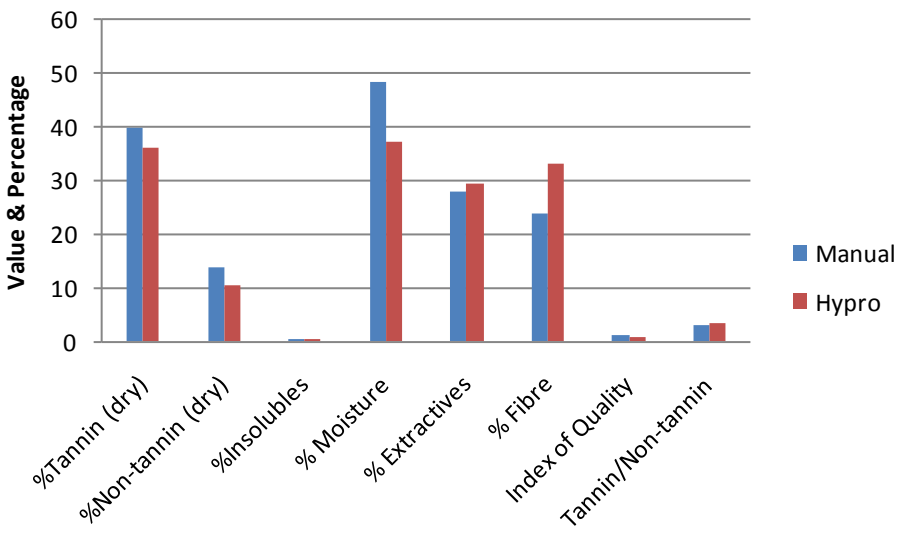

Figure 42: Comparison of bark analyses results between the Hypro debarker and manually debarked samples.

The results from Figure 42 show the comparison of the two debarking technologies. The manual debarking method currently being used in the industry is therefore an indication of the bark quality that is currently produced. The results obtained from the Hypro bark samples are very close to those obtained from the manually debarked samples. In terms of tannin percentage, both are acceptable, but the manually produced bark has a higher percentage of tannins, and is therefore better. The manually produced bark is better than the bark produced by the Hypro debarker as it has a lower percentage of non-tannins. The percentage of insolubles is very similar. The manually produced bark has a higher moisture content due to the bigger dimensions of the bark produced, and will therefore dry out slower. The Hypro has a higher percentage extractives and fibre, but this has a lower tannin content than the manually produced bark. The index of quality is very similar for both methods. The bark produced by the Hypro debarker has a higher, and therefore better, tannin to non-tannin ratio. The results shown in Table 8 and Figure 42 indicate that the Hypro produces acceptable bark for the processing facility. There is a variation between the bark produced manually and the bark produced by the Hypro debarker, but they are both within the acceptable limits as described in Chapter 3.

CHAPTER 7: COMPARISON OF MACHINES

7.1 INTRODUCTION

The effect of strippability, form and tree size on the productivity of the Demuth, Hyena and Hypro debarkers have been discussed in Chapters 4, 5 and 6 respectively. The way in which these individual factors affect the productivity of each of the machines varies. This chapter will show the effect of each of these factors on all three of the machines in order to compare the productivity. This will enable the identification of debarking technologies that are influenced more by either of the factors than any of the other machines.

7.2 RESULTS OF STRIPPABILITY ON PRODUCTIVITY

The effect that a stronger wood to bark bond strength has on productivity is shown in Figure 43. As would be expected, there is a general decline in productivity with an increase in strippability class (increasing difficulty of strippability). It is interesting, however, to see that there is an increase in productivity with an increase in strippability class for the Demuth debarker as explained in Chapter 4. The Hyena has the highest productivity over all the different strippability classes, but has the steepest decline angle, showing that the productivity of this machine is affected more than the others by strippability. This was also confirmed in Chapter 5. The Demuth and Hypro debarkers are also affected negatively by an increasing strippability class, but not to the extent of the Hyena debarker.

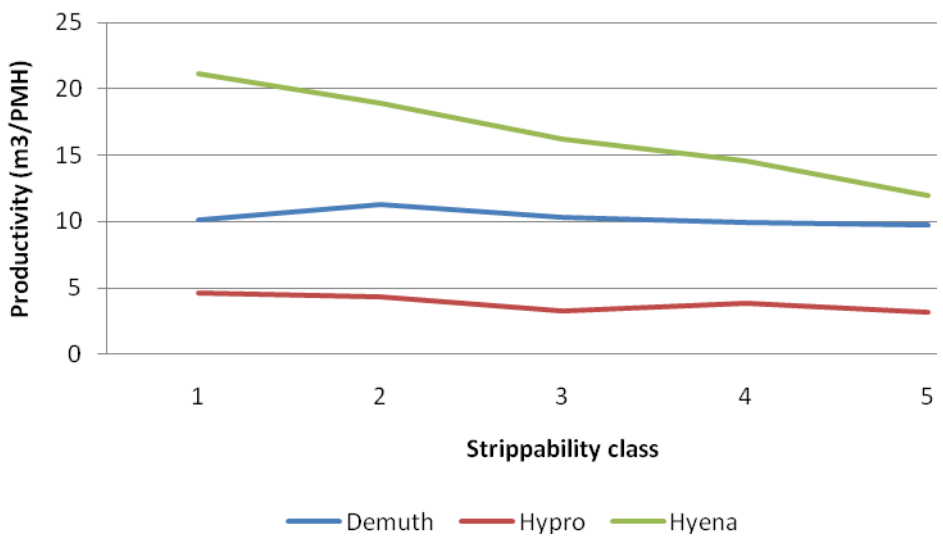

Figure 43: The effect of strippability on productivity for the three debarking technologies.

7.3 RESULTS OF FORM ON PRODUCTIVITY

Figure 44 illustrates the influence on productivity caused by the physical form of the tree. As would be expected, there is a decrease in productivity with an increase in stem form class (deteriorating stem form) for all three debarking technologies. There is not a great decline in productivity between the different form classes, showing that the machines were able to handle poor form. The Hyena debarker shows the biggest decrease in productivity, with deteriorating stem form, when compared to the Demuth and Hypro debarkers. Once again the Hyena is the most productive with the Hypro being the least productive of the three machines.

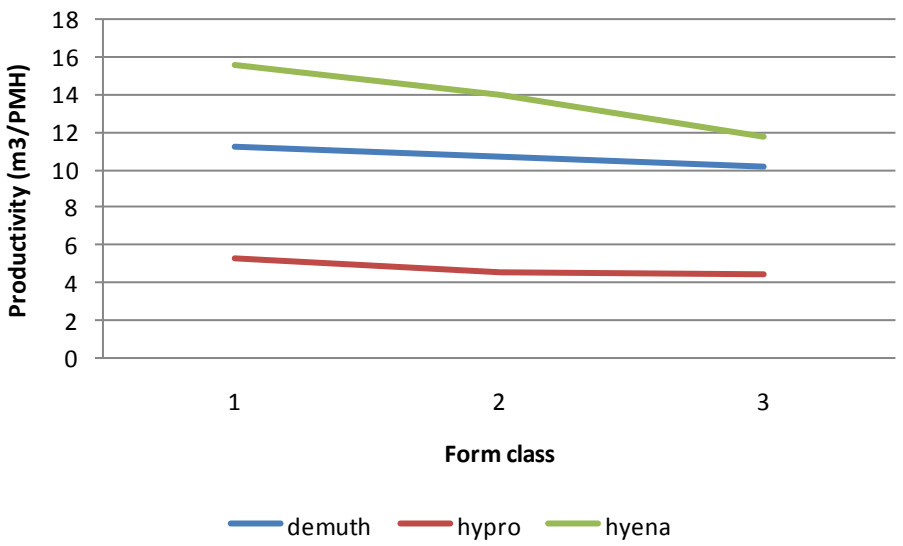

Figure 44: The effect of form on productivity for the three debarking technologies.

7.4 RESULTS OF VOLUME ON PRODUCTIVITY

The effect of tree volume on the productivity of the different debarking technologies is shown in Figure 45. The productivity points plotted for the five tree volume classes are the average for each class. In the smaller tree volumes, the Demuth is the most productive, with the Hyena becoming more productive with an increase in tree size. The Hypro is the least productive over all the volume classes, but does show a steady increase with increasing tree size. Both the Demuth and the Hypro debarkers show a gradual increase in productivity while the Hyena has a larger productivity increase with increasing tree volume.

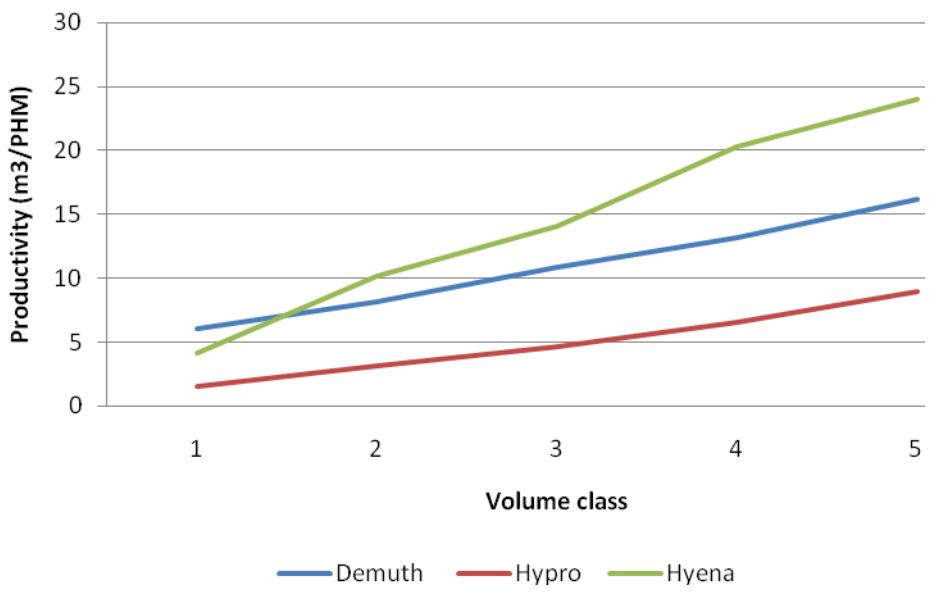

Figure 45: The effect of tree size on productivity for the three debarking technologies.

7.5 RESULTS OF VOLUME, STRIPPABILITY AND FORM COMBINED

In Figure 46, a trend line is drawn to show the productivity trend affected by tree volume, strippability and form. Due to the x-axis not being a scale, this line only indicates the trend of the productivity, and is not a regression line.

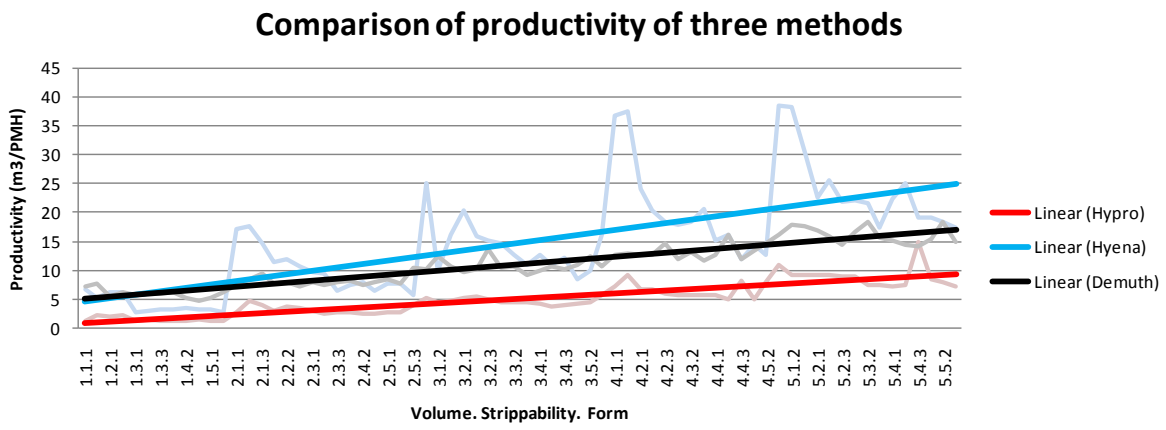

Figure 46: Trend line of productivity levels for the three debarking technologies under various volume, strippability and form combinations.

Figure 46 plots the productivity levels for the different methods over different tree volume, strippability and form classes. As was expected, there is a direct correlation between the influence of increasing tree volume and increasing productivity. When dealing with only tree volume class one, and then looking at the effect of decreasing form and strippability classes, it is clear that these have a negative effect on productivity. Each time there is a change in volume class, a clear spike is noticed in the productivity which then slowly decreases again with the decrease in form and strippability classes. The productivity spikes of the Hyena debarker at the beginning of each of the volume classes with a good form and good strippability are clearly noted. The steep decline of the Hyena productivity also shows the negative effect of form and strippability on the debarker's productivity. The Demuth shows the best productivity in the smallest tree volume class, while the Hyena achieves the greatest productivity in the larger tree volume classes (class two-five).

7.6 CONCLUSION

Table 9 shows the most productive machine for each tree volume class, influenced by strippability and form. The strippability and form are divided into three classes, good (strippability class one and two, and form class one), average (strippability class three and form class two) and poor (strippability class four and five and form class three).

Table 9: Most productive machine for each tree volume, strippability and form class.

Volume class	Strippability and form	Most Productive machines (m3/PMH)	
		1st	2nd
1	Good (1+2)	Demuth (6.674)	Hyena (6.198)
	Average (3)	Demuth (5.899)	Hyena (3.076)
	Poor (4+5)	Demuth (5.565)	Hyena (3.207)
2	Good (1+2)	Hyena (14.609)	Demuth (8.224)
	Average (3)	Hyena (8.529)	Demuth (7.794)
	Poor (4+5)	Demuth (8.417)	Hyena (7.137)
3	Good (1+2)	Hyena (17.083)	Demuth (11.161)
	Average (3)	Hyena (12.731)	Demuth(10.136)
	Poor (4+5)	Hyena (11.723)	Demuth (10.867)
4	Good (1+2)	Hyena (27.366)	Demuth (13.142)
	Average (3)	Hyena (19.059)	Demuth (12.246)
	Poor (4+5)	Hyena (14.074)	Demuth (13.813)
5	Good (1+2)	Hyena (29.541)	Demuth (16.499)
	Average (3)	Hyena (20.305)	Demuth (16.875)
	Poor (4+5)	Hyena (20.267)	Demuth (15.412)

It is clear from Table 9 that the Demuth debarker is the most productive in the smaller tree volume class (class one) as well as the end of class two when there is a poor form and strippability class. The Hyena debarker becomes more productive in the bigger tree classes. The productivity of the Hypro debarker is lower than the Demuth and Hyena debarkers as was shown in previous graphs. In the good strippability and form classes, the Hyena is more productive than the Demuth debarker, but the productivity in the poor strippability and form is very similar. When looking at volume class three, in the good form and strippability classes, the Hyena out performs the Demuth debarker by 5.922m³ per PMH, in the average strippability and form classes by 2.595m³ per PMH, and in the poor strippability and form classes by only 0.856m³ per PMH. This trend occurs throughout the different volume classes.

Figure 47 shows the productivity of the Demuth and Hyena debarkers as in Table 9, but also includes the productivity of the Hypro debarker. The scale used on the x-axis of Figure 47 is the same as the one used in Table 9.

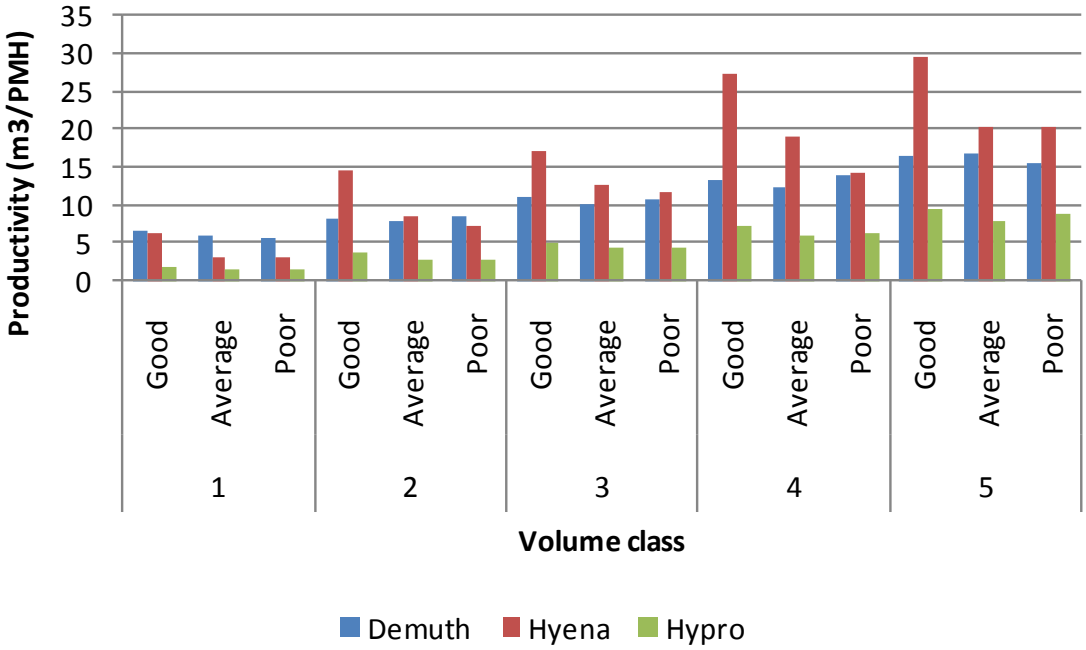

Figure 47: Machine productivity influenced by tree volume, strippability and form.

It is clear from Figure 47, that the productivity of the Hypro is lower than that of the Demuth and the Hyena. The figure clearly shows the sharper decrease in productivity of the Hyena over the three strippability and form classes, compared to the steady decrease of the Demuth and Hypro debarkers.

CHAPTER 8: MACHINE/SYSTEM COSTS

8.1 INTRODUCTION

In the previous chapters, all the different factors affecting productivity were discussed. This chapter will determine the costs associated with each of the machines to achieve the previously mentioned productivity figures. In order to determine the costs of each of the debarking technologies, the tree sizes to be used were determined. The costs associated with each of the machines were determined at three productivity levels, these were determined at tree sizes 0.1m³, 0.15m³ and 0.2m³. A manual debarking system costing was also conducted for the three productivity levels. Figure 48 below shows the sample distribution for each of the debarking technologies over the different tree volume classes. The green line is for the Hypro debarker, the blue line the Hyena debarker and the red line the Demuth debarker.

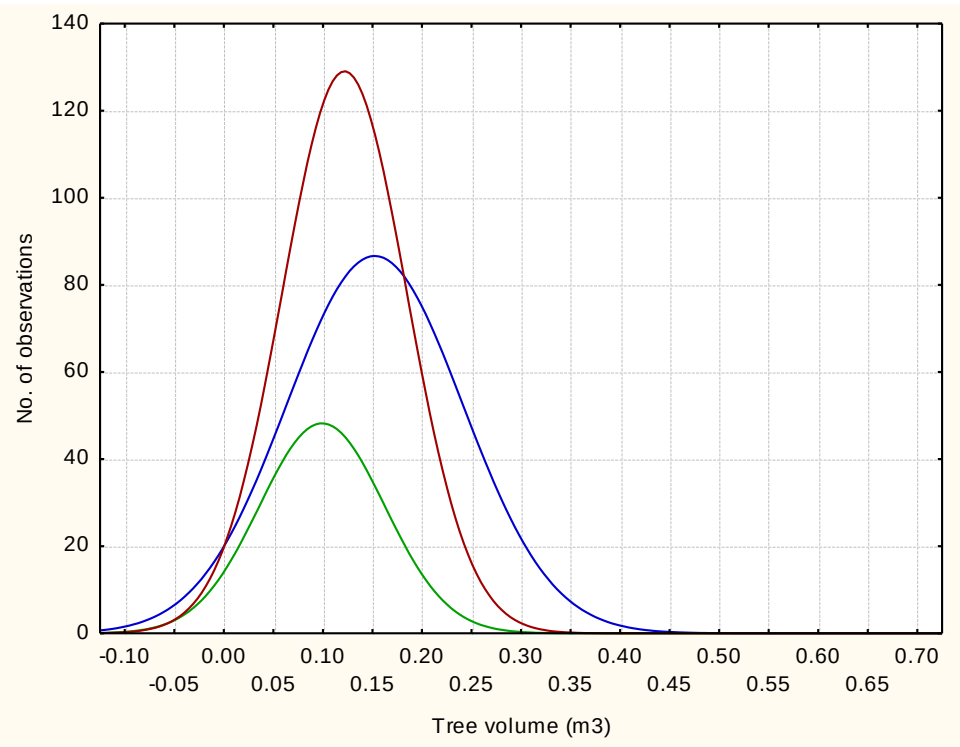

Figure 48: Tree volume sample size distribution for the Hyena, Demuth and Hypro debarkers.

8.1.1 Productivity modelling

Once it was determined that there was a large enough sample size occurring in each of the three tree volume classes (0.1m³, 0.15m³ and 0.2m³) for the three technologies, the productivity equations were modelled. Regression models were constructed in STATISTICA that described the effect that tree volume has on productivity. Tree volume was used as an independent variable and was related back to machine productivity as m^3 per PMH. In order to ensure that the models were valid and accurate, the resultant productivities obtained from the models were compared to actual data from the research trials and they were found to be accurate.

The coefficient of determination (R^2 value) of each regression model was examined. The R-squared value is an indicator of precision of fit. It measured whether the estimated regression line fits the observed machine productivities. These estimated coefficients are given in Table 10 below. The model equation for all processing technologies is presented below.

Productivity (m³/PMH) = β0 + (β1*Ave tree vol) + (β2*(Ave tree vol)²)

Table 10: Coefficients of the productivity model for each debarking technology.

Effect	**Hyena**	**Demuth**	**Hypro**
Intercept (β0)	2.4638	3.7732	0.1409
Avg tree vol (β1)	109.3928	56.0234	38.9843
Avg tree vol^2 (β2)	-94.0974	-19.4628	-17.7133
R^2 Value	0.468174	0.733946	0.836051

The R-squared value for both the Demuth and Hypro debarkers is very high, and therefore indicates that the regression model was a good fit for the observed productivity. The R-squared value of the Hyena debarker is a substantially lower, which is caused by a higher standard deviation of the sample size. When the resultant regression line results of the Hyena debarker were compared to the actual

attained productivity, they were similar with all differing by less than 0.07m³ per PMH. This renders the resultant productivity to be valid.

The coefficients from Table 10 were imported into the productivity equation to determine the resultant productivities that would be used in the machine and system costings. The productivity levels attained by the three debarking technologies at a tree size of 0.1m³, 0.15m³ and 0.2m³ are shown in Table 11 below. For the productivity figures of each of the debarking technologies, only tree volume was used. The average tree form and strippability for each of the research samples was calculated to determine if they are similar or not, and if they could have an effect on the resultant productivity. The results were very similar. The average values for form were 1.3 for the Demuth debarker, 1.5 for the Hyena debarker and 1.3 for the Hypro debarker. The average values for strippability were 2.9 for the Demuth, 3.1 for the Hyena and 3.2 for the Hypro.

Table 11: Productivity (m³ per PMH) achieved by the three debarking technologies at the different tree volume levels.

Tree volume (m³)	**Hyena**	**Demuth**	**Hypro**
0.1	12.4867	9.37554	3.89843
0.15	16.810	12.17671	5.847645
0.2	20.677	14.97788	7.79686

The productivity figures for the manual systems as well as any machines that were not researched, were obtained from the Forestry Solutions website (Forestry Solutions, 2010), as this is where information from extensive productivity studies for various machines and labour is obtained. Some of the figures were obtained from companies that are currently debarking *A. mearnsii* manually. The productivity per PMH that was used in the costing model is shown in Table 12 below. The labour productivity is shown in m³ per labour hour (PLH), based on an eight hour shift length.

Table 12: Productivity shown in m³ per PMH/PLH achieved by the manual operations and machines for the three tree volumes.

OPERATION	Tree volume (m³)		
	0.1	**0.15**	**0.2**
Fell and crosscut	3	4.5	5.7
Stack	1.5	2.3	2.8
Debranch and debark	0.3	0.5	0.6
Extended primary transport	11.99	12.93	13.46
Three-wheel loader on Depot	30	30	30
Collect and bundle bark	0.2	0.2	0.2

8.1.2 Cost assumptions

In order to determine the total operating costs (R/m³) of each of the systems, the cost of running the machine for a given period (one hour) is divided by the productivity achieved during the same period. The total cost for each of the systems is determined by various cost inputs. The productivity for this time period was determined as explained above for each of the three tree volume classes.

To determine the total costs of owning and operating a machine per PMH, information is required on the ownership costs (depreciation, interest, insurance, licensing and schedule operating time), operating costs (maintenance, fuel, lubricants, tyre or track replacement costs) and labour or machine operator costs (wages, salaries, legislated costs and other labour overheads) (Brinker et al., 2002). Costing information was placed into a Microsoft Excel mechanised harvesting system costing model which was designed by Forestry Solutions (Forestry Solutions, 2010).

The costs and assumptions used in the costing model were obtained from various sources. The machine prices used in each of the costings were obtained directly from the manufacturers and suppliers. The industry norm for operator and labour wages and machine life hours were used. They were obtained from contractors, private growers and companies. The fuel consumption, insurance, repair and maintenance costs, residual values and utilisation figures were obtained from Brinker et al., 2002. Overhead costs and oil and lubrication costs were obtained from Grobbelaar, 2000 in the South African forestry handbook.

The research trials conducted were not sufficient enough to determine machine utilisation figures; therefore an assumed utilisation rate of 65%, as suggested by Brinker et al., 2002 was used for each of the machines. A residual value (machine value after depreciation period) of 20% was used for each of the machines (Brinker et al., 2002). A machine life of 15,000 PMH was used for the carrier for the Hyena debarker and for the Hyena debarking head (Küsel, 2010). A machine life of 15,000 PMH was used for the Demuth debarker and carrier, as they were both used on a depot, and were not used infield. A machine life of 10,000 PMH was used for the Hypro debarker and tractor as well as for the tractors used for extracting the timber. The machines were depreciated over their total expected life hours. The prime interest rate in South Africa of 8%, obtained from the South African Reserve Bank at the time of the research was used. A diesel price of R8.30 per litre was used in the costings, which was the valid price in South Africa at the time of the research. The fuel consumption of each of the machines were actual figures obtained from the machine owners and are shown in Table 13 below.

Table 13: Fuel consumption for each of the machines used in the research.

Fuel consumption rates (litres/PMH)	Demuth tractor: 5 Hyena carrier: 18 Hypro tractor: 8 Tractor for extraction: 9 Three wheel loader: 9 Chainsaw: 2

The cost of lubricants is shown in Table 14, and is determined as a percentage of fuel consumption, and then multiplied by the lubricant's cost per litre. The cost is based on the amount of hydraulic oil that is used in the operating of the machine. The amounts were obtained and calculated from Grobbelaar, 2000. The cost used for two-stroke chainsaw oil was R26.75 per litre; cutter bar oil was R24.75 per litre and for hydraulic oil R19.68 per litre. These costs were obtained from a supplier (UCL stores) in Dalton, KwaZulu-Natal, and were the same for each of the machines.

Table 14: Lubricants consumption as a percentage of fuel consumption.

Consumption of lubricants (Percentage of fuel consumption)	Demuth tractor: 7% Hyena carrier: 11% Hypro tractor: 9% Tractor for extraction: 8% Three wheel loader: 9% Chainsaw: 12%

The insurance rates that were used for each machine were obtained from Brinker et al (2002) and altered for the machines that were used in the research trials. The rates are shown in Table 15 below, and are shown as a percentage of purchase price.

Table 15: Insurance rates for the machines used in the research.

Insurance (Percentage of purchase price)	Demuth: 4% Tractors: 2% Three wheel loader: 2% Hyena: 5% Hypro: 4%

The repair and maintenance cost used in the costings include the costs of daily infield maintenance on the machines, as well as the total cost of owning and operating a full workshop. The Hypro and Hyena are similar technologies and therefore have the same repair cost factor of 120 percent. The tractor used with the Demuth has a lower repair cost factor, as it sits on a depot and is stationary. The tractor with the Hypro does more work than the Demuth, but still less than the extraction tractors, and therefore a repair cost factor of 90 percent was used. There are no research results on this, and it is based on the researcher's assumption after consulting machine owners. The repair and maintenance cost factors shown below in Table 16 are obtained from Brinker et al (2002) and machine owners.

Table 16: Repair and maintenance cost factors.

Repair and maintenance cost factors	Extraction tractors: 100% Hypro tractor: 90% Demuth tractor: 80% Hypro: 120% Hyena carrier: 100% Hyena head: 120% Demuth: 80% Three wheel loader: 100%

The daily operator wages and general labour wages were averaged rates obtained from two forestry companies, who wished to remain anonymous, and are shown in Table 17.

Table 17: Operator and labour wages.

Wage rates per day	General labourer: R 90 Chainsaw operator: R100 Tractor / Bell driver: R120 Supervisor: R140 Hyena and Hypro operator: R370

A New Holland TT75 tractor was used to power the Demuth debarker, and a New Holland 8030 was used to power the Hypro debarker as well as for extracting the timber to a depot. The extraction units were equipped with a self-loading crane. An average extraction distance, for the extended primary transport, of 1.5 kilometres was used for each of the costings. The extraction units were used to extract both the timber and the bark. For the manual operations, only five days were used per week, a further 41 days were put aside for sick leave, annual leave and productive days lost per year. A figure of 221 days per year was therefore used in the costings for the manual operations. For the machines, six days were used per week, and 31 days for annual leave, sick leave and productive days lost per year. A figure of 292 productive days per year was therefore used in these costings. These figures were used for all

the costings for each of the different debarking technologies. The costs used for the manual operations are shown in Table 18 below and were used for all the manual inputs into the costings. All the prices used in the costing model exclude value added tax (VAT).

Table 18: Manual equipment and safety clothing costs.

Labour equipment costs	Husqvarna 365 Chainsaw: R 5280 Chainsaw bar: R 276 Chainsaw chain: R 134 Shin Guards: R 120 Safety pants: R 603 (Umvoti Repairs, 2010) Hatchet: R 83 Gloves: R 12 Safety shoes: R 213 Files: R 13 Hardhat: R 20 Stacking tool: R 120 (UCL Stores, 2010)

The costs that were used in the costings for each of the machines and carriers used are shown below in Table 19. The costs were obtained from the machine suppliers, dealers, owners and managers.

Table 19: Machine costs used.

	Demuth DDM 420	**Hypro 765**	**Hyena Mk3**
Capital outlay	R 900 100.00	R 630 000.00	R 495 000.00
Carrier	R 270 000.00	R 420 000.00	R 1 250 000.00

Once the costings were completed, the systems were balanced. The annual timber volume for each of the systems was divided by five to obtain the annual bark volume. The ratio for timber:bark of 5:1 is currently used in the industry (Eggers, personal communication, 2010). For the Hyena and Hypro debarkers, only 60 percent of this

bark volume was utilizable. This utilisation figure was obtained from research done by Ramantswana (2010) where bark removed by a harvester was collected and weighed and compared to the theoretical total bark volume. The results of the machine costings are included in the sections below.

8.2 DEMUTH MACHINE/SYSTEM COSTS

The cost per m³ for the Demuth debarker for the three different tree volumes is shown in Table 20. The table also shows the cost of each of the operations and the annual system production.

Table 20: Demuth system costs description.

OPERATION	TREE SIZE (m³)		
	0.1	**0.15**	**0.2**
Fell and crosscut	R 21.32	R 14.73	R 12.14
Stack	R 12.59	R 9.45	R 6.49
Extended primary transport	R 30.34	R 28.13	R 27.03
Three-wheel loader on Depot	R 16.97	R 14.27	R 12.39
Demuth debarking	R 45.61	R 35.36	R 30.77
TOTAL system cost per m³	**R 126.83**	**R 101.94**	**R 88.82**
Annual volume required (m³)	15890	20498	25463

The Demuth system was balanced around the productivity of the Demuth debarker for each of the three tree volumes. When the tree volume increases, there is a general decrease in the cost per m³, due to the fixed costs being diluted by higher annual volumes. The lowest cost of R88.82 per m³ is achieved with a tree volume of 0.2m³ and the highest cost of R126.83 per m³ is achieved with a tree volume of 0.1 m³. A tree volume of 0.15m³ achieves a cost of R101.94 per m³.

The total number of people needed for the system for each of the tree volume classes is shown in Table 21.

Table 21: Labour numbers for each tree volume class for the Demuth debarker.

Tree size	Fell	Demuth	Three wheeler	Stackers	**Total**
0.1	6	5	1	6	**18**
0.15	6	5	1	6	**18**
0.2	6	5	1	7	**19**

The people needed for tree volumes of 0.1m³ and 0.15m³ are the same. Three chainsaw operators and three assistants are used to fell, debranch and crosscut the trees. Six stackers are then used to collect and stack the timber for extraction. Only one extraction unit is needed to extract the timber and transport it to a depot. One three wheeled loader is used to load the timber onto the feed table of the Demuth and stack the debarked timber. Five labour units are used to feed and operate the Demuth debarker. The number of people needed for a tree volume of 0.2m³ is one more than the other two tree volumes, due to another stacker needed with the higher annual volume.

8.3 HYENA MACHINE/SYSTEM COSTS

The cost per m³ for the Hyena debarker for the three different tree volumes is shown in Table 22. The table also shows the cost of each of the operations and the annual system production.

Table 22: Hyena system costs description.

OPERATION	**TREE SIZE (m³)**		
	0.1	**0.15**	**0.2**
Fell and crosscut	R 23.19	R 16.16	R 10.85
Hyena carrier	R 44.93	R 32.37	R 26.55
Hyena head	R 10.54	R 7.59	R 6.39
Collect and bundle bark	R 14.35	R 14.24	R 13.90
Stacking	R 12.66	R 8.97	R 6.39
Extended primary transport	R 30.34	R 28.13	R 27.03
TOTAL system cost per m³	**R 136.01**	**R 107.46**	**R 91.11**
Annual volume required (m³)	18404	25543	31146

The Hyena system was balanced around the productivity of the Hyena debarker for each of the three tree volumes. When the tree volume increases, there is a general decrease in the cost per m³, due to the fixed costs being diluted by higher annual volumes. The lowest cost of R91.11 per m³ is achieved with a tree volume of 0.2m³ and the highest cost of R136.01 per m³ is achieved with a tree volume of 0.1 m³. A tree volume of 0.15m³ achieves a cost of R107.46 per m³.

The total number of people needed for the system for each of the tree volume classes is shown in Table 23.

Table 23: Labour numbers for each tree volume class for the Hyena debarker.

Tree size	Fell	Hyena	Collect bark	Stackers	**Total**
0.1	8	1	8	7	**24**
0.15	8	1	11	7	**27**
0.2	6	1	13	8	**28**

The number of people needed for the three tree volumes varies. Four chainsaw operators and four assistants are used to fell, debranch and crosscut the trees for three volumes of 0.1m³ and 0.15m³. For a tree volume of 0.2m³, three chainsaw operators and assistants are needed. For a tree volume of 0.1m³ seven stackers were used, for 0.15m³ seven stackers and 0.2m³ eight stackers were used to collect and stack the timber for extraction. The largest number of people are required to collect and bundle the bark. For a tree volume of 0.1m³ eight people were used, for 0.15m³ 11 people and 0.2m³ 13 people were used to collect and bundle the bark for extraction.

8.4 HYPRO MACHINE/SYSTEM COSTS

The cost per m³ for the Hypro debarker for the three different tree volumes is shown in Table 24. The table also shows the cost of each of the operations and the annual system production.

Table 24: Hypro system costs description.

OPERATION	TREE SIZE (m³)		
	0.1	**0.15**	**0.2**
Fell and crosscut	R 30.45	R 20.31	R 22.83
Hypro tractor	R 69.72	R 46.48	R 34.86
Hypro debarker	R 43.86	R 43.05	R 21.93
Collect and bundle bark	R 16.14	R 14.76	R 13.95
Stacking	R 15.94	R 10.63	R 8.18
Extended primary transport	R 30.34	R 28.13	R 27.03
TOTAL system cost per m³	**R 206.45**	**R 163.36**	**R 128.78**
Annual volume required (m³)	5915	8870	11831

The Hypro system was balanced around the productivity of the Hypro debarker for each of the three tree volumes. When the tree volume increases, there is a general decrease in the cost per m³, due to the fixed costs being diluted by higher annual volumes. The lowest cost of R128.78 per m³ is achieved with a tree volume of 0.2m³ and the highest cost of R206.45 per m³ is achieved with a tree volume of 0.1 m³. A tree volume of 0.15m³ achieves a cost of R163.36 per m³.

The total number of people needed for the system for each of the tree volume classes is shown in Table 25.

Table 25: Labour numbers for each tree volume class for the Hypro debarker.

Tree size	Fell	Hypro	Collect bark	Stackers	**Total**
0.1	4	1	3	3	**11**
0.15	4	1	4	4	**13**
0.2	6	1	5	4	**16**

The number of people needed for the three tree volumes varies. Two chainsaw operator and two assistants were used to fell, debranch and crosscut the trees with tree volumes of 0.1m³ and 0.15m³. For tree volume 0.2m³, three chainsaw operators and three assistants were used. For a tree volume of 0.1m³ three stackers were used, for 0.15m³ four stackers and 0.2m³ four stackers were used to collect and

stack the timber for extraction. For a tree volume of 0.1m³ three people were used to collect and bundle the bark, for 0.15m³ four people and 0.2m³ five people were used. More labourers were needed in the larger tree sizes due to the system having a higher annual volume requirement.

8.5 MANUAL SYSTEM COSTS

The cost per m³ for manual debarking, for the three different tree volumes is shown in Table 26. The table also shows the cost of each of the operations and the annual system production.

Table 26: Manual system costs description.

OPERATION	TREE SIZE (m³)		
	0.1	**0.15**	**0.2**
Fell and crosscut	R 28.13	R 19.09	R 16.04
Debranch and debark	R 55.90	R 37.22	R 28.07
Stacking	R 12.92	R 8.91	R 7.04
Extended primary transport	R 30.34	R 28.13	R 27.03
TOTAL system cost per m³	**R 127.29**	**R 93.35**	**R 78.18**
Annual volume required (m³)	20487	22093	22995

The manual system was balanced around the productivity of the extraction unit for each of the three tree volumes. When the tree volume increases, there is a general decrease in the cost per m³, due to the fixed costs being diluted by higher annual volumes. The lowest cost of R78.18 per m³ is achieved with a tree volume of 0.2m³ and the highest cost of R127.29 per m³ is achieved with a tree volume of 0.1 m³. A tree volume of 0.15m³ achieves a cost of R93.35 per m³.

The total number of people needed for the system for each of the tree volume classes is shown in Table 27.

Table 27: Labour numbers for each tree volume class for the manual system.

Tree size	Fell	Debark	Stackers	**Total**
0.1	8	39	8	**55**
0.15	6	28	6	**40**
0.2	6	22	5	**33**

For tree volumes of 0.1m³, four chainsaw operators and four assistants are used to fell and crosscut the tree lengths. For a tree volume of 0.15m³ and 0.2m³, three chainsaw operators and three assistants are used. For a tree volume of 0.1m³, 39 people are used to debranch and debark the trees and eight to stack the timber, for a tree volume of 0.15m³, 28 people to debranch and debark and six to stack and for a tree volume of 0.2m³, 22 people to debranch and debark and five to stack the logs.

8.6 COST COMPARISONS

The system costs for each of the debarking machines and the manual debarking have been individually discussed above. This section compares the system costs of each of the debarking technologies against one another. Comparisons are made for each system when the bark is utilised, as well as when the bark in not utilised. The system costs of the different technologies when the bark is utilised are shown in Table 28 and Figure 49.

Table 28: System costs for the four systems when the bark is utilised.

	TREE SIZE (m³)		
	0.1	**0.15**	**0.2**
Hypro	R 206.45	R 163.36	R 128.78
Manual	R 127.29	R 93.35	R 78.18
Hyena	R 136.01	R 107.46	R 91.11
Demuth	R 126.83	R 101.94	R 88.82

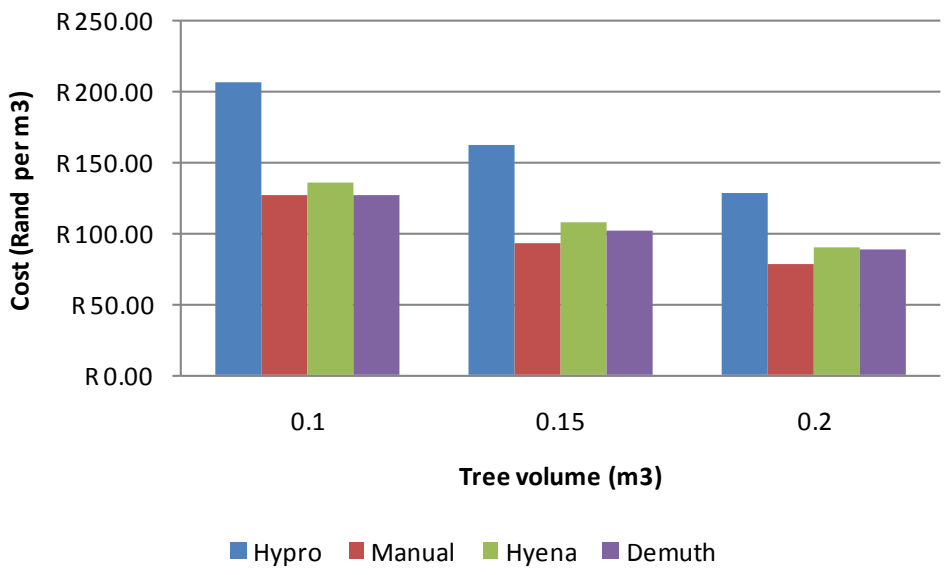

Figure 49: Cost comparisons for the four systems when the bark is utilised.

The manual system costs are the lowest for tree volumes 0.15m³ and 0.2m³, with costs of R93.35 and R78.18 per m³. For a tree volume of 0.1m³, the Demuth Debarker obtained the lowest cost of R126.83 per m³. The Demuth is the second lowest cost for tree volumes 0.15m³ and 0.2m³ with costs of R101.94 and R88.82 per m³ respectively. The Hypro has the highest cost per m³ for all three tree volumes. The Demuth has the best cost per m³ when compared to the other two mechanical options. This is mainly due to the bark being removed on the depot and there is no need to collect and bundle the bark infield. If the bark is a waste product, and there is no need to incur the cost of collecting and bundling the bark infield, then the Hyena debarker becomes more viable than the Demuth debarker for each of the tree volumes as shown in Table 29 below.

Table 29:System costs for the four systems when the bark is not utilised.

	0.1	**0.15**	**0.2**
Hypro	R 190.31	R 148.60	R 114.83
Manual	R 121.32	R 88.85	R 75.11
Hyena	R 121.66	R 93.22	R 77.21
Demuth	R 126.83	R 101.94	R 88.82

When the bark is not utilised, the manual system has the lowest costs for each of the tree volumes. The Hyena achieves the best system cost compared to the Demuth and the Hypro debarkers. The Demuth debarker achieves the second best system cost. The Hypro still has the highest costs. The percentage utilisable bark for each of the different debarking technologies will not affect the system costs, but will have an effect on the income for the grower. The Demuth and manual systems had the best bark utilisation, followed by the Hypro and Hyena debarkers.

The resultant costs per m^3 that were attained for each of the systems, were influenced by the assumptions that were used. The costs would therefore vary when different assumptions or cost inputs are used in the model. Users of costing models must ensure that their assumptions are relevant to their particular situation. The resultant costs obtained for the four debarking technologies, were for the timber and the bark to be stacked at a depot.

CHAPTER 9: CONCLUSION AND RECOMMENDATIONS

This chapter deals with the concluding remarks and some system recommendations for each of the debarking technologies

9.1 CONCLUSION

A growing demand for *A. mearnsii* bark and a shortage of manual labour has prompted the *A. mearnsii* industry stakeholders to investigate mechanised options for removing bark.

This research identified three mechanised debarking technologies and compared them against one another in terms of productivity and costs. For the costs, the machines were compared against a manual system, which is currently the most prominent system used to debark *A. mearnsii*.

The three factors that effected productivity (tree volume, strippability and form), all showed interesting results. Tree form class showed a decrease in productivity with an increase form class. All three of the debarking technologies took longer to debark trees that had a bad form. For the Demuth debarker, this was due to longer times needed to feed the logs into the debarker. For the Hyena and Hypro debarkers, it was due to the tree lengths getting stuck in the head, and therefore needing to reposition the tree and the head. The Hypro debarker was affected the most by trees with a bad form. The setup of the rollers on the Hyena head, cause the tree to spiral whilst moving through the head. This, along with a large gap between the rollers and the top of the head, gives the tree movement space without causing it to get stuck.

An increase in strippability class produced a general decrease in productivity for all three machines. The Hyena was affected the most by an increasing strippability class. When a stronger wood-bark bond strength was experienced, the Hyena debarker showed the largest decrease in productivity. The Demuth showed an increase in productivity for strippability class two, and then decreased again for the remaining classes. This showed that the Demuth debarker achieved a better

productivity when the wood-bark bond strength was a little higher. The Hypro debarker showed a steady decrease with an increasing strippability class.

An increasing tree volume class caused an increase in the productivity of all three machines. For tree volume class 1, the Demuth debarker achieved the highest productivity followed by the Hyena and then the Hypro. For tree volumes 2-5, the Hyena was the most productive followed by the Demuth and then the Hypro debarker. When the system element times such as moving, reaching for the tree and feed speeds remained constant, the higher the piece size debarked, the higher the resultant productivity achieved was. The debarking time for trees with a higher volume is longer than those with a smaller volume, but the productivity or time per volume (m^3) is less.

The effect of tree volume, form and strippability combined on the productivity of all three of the debarking technologies was also determined. Tree volume has the greatest effect on the productivity of each of the machines. The form and strippability each have a negative effect on the productivity. Of the three debarking technologies the Hyena was the most productive, followed by the Demuth and lastly the Hypro.

One of the most significant factors determining the success or failure of these debarking technologies is the effect of the bark produced on the extraction efficiency at the bark processing plants, thereby affecting the end product produced. It was found that the samples of bark that were analysed at the processing facility all varied from one another, but all the samples were at an acceptable standard for the processing facilities. The bark samples were all sent on the same day as the trees were debarked, therefore they were fresh. Further research should be carried out to determine the effect of delaying the sending of the bark to the processing facilities, and determining the subsequent bark quality. Due to the bark produced by the machines varying in size, but generally being smaller sizes than manually removed bark, it will oxidise faster, resulting in a rapid decrease in quality. This would mostly be the case in the higher strippability classes, where the bark needed more effort to be removed. Further research should also be conducted on the percentage of utilisable bark produced by each of the three debarking technologies. When

debarking with the Hyena debarker, it is important that the operator does not debark directly in front of the machine, as he will then drive over the bark and damage and contaminate it. The logs and branches must not be placed on top of the bark as it will prevent the labour from being able to access and bundle the bark. When debarking with the Hypro debarker, a great deal of bark collects around the debranching arms. This must be removed regularly, as it decreases the quality of debarking and also damages the bark that collects around the arms. For the Demuth debarker, the pressure of the knives and scrapers as well as the sharpness of the knives must be checked at regular intervals. The planning of the time delay between felling and debarking must also be carefully planned, as these factors affect the chip dimensions produced, and therefore the quality of the bark.

System costings were carried out for the three mechanised systems as well as for a manual system. The results showed that when the bark is utilised, the manual system has the lowest cost per m^3 for tree volumes of $0.15m^3$ and $0.2m^3$ and the Demuth had the lowest cost for a tree volume of $0.1m^3$. The Demuth had the second lowest costs for tree volumes $0.15m^3$ and $0.2m^3$, followed by the Hyena and Hypro debarkers respectively. When the bark is not utilised, and is a waste product, the manual system achieves the lowest costs for all three tree volumes, followed by the Hyena and then the Demuth debarker. The Hypro has the highest system costs. The manual system had the highest number of people, followed by the Hyena, Demuth and Hypro. The reason for the Hyena and Hypro having such a high number of people is due to them needing to collect and bundle the bark. When the bark is utilized, the Demuth is the most cost effective option of the mechanised systems, but if the bark is a waste product then the Hyena debarker becomes cheaper for all three tree volumes. When the bark is not utilised, the competitiveness in terms of cost per m^3 for the Hypro increases. The Hyena achieves the highest annual volumes for each of the tree volumes, followed by the Demuth debarker and then the Hypro debarker. The cost per m^3 for the Demuth, Hyena and the manual system is very similar for all three tree volumes, with the Hypro being more expensive.

The research results have proven that mechanical debarking is a viable option for timber growers and forestry companies, as the costs are very close when compared

to the manual system; and in the current and expected difficulty of recruiting manual forestry labour as cited by Steenkamp (2007). The bark that was produced was of sufficient quality to be accepted by the processing facilities, when it was sent within a day of the debarking taking place. The productivity of the three machines varied and was affected by form, strippability and productivity. The higher strippability classes did have a negative effect on the productivity of each of the debarking technologies, but the productivity results of some of the machines were still satisfactory. This could result in the debarking of *A. mearnsii* during the winter months, and the debarking season could therefore be extended, to the benefit of the timber and *A. mearnsii* bark industry through the improved seasonal utilization of labour, timber and bark.

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Annexure 1

Mechanical debarking quality

Debarking quality

Strippability 1

Demuth

Hyena

Hypro

Strippability 2

Demuth

Hyena

Hypro

Strippability 3

Demuth

Hyena

Hypro

Strippability 4

Demuth

Hyena

Hypro

Strippability 5

Demuth

Hyena

Hypro

Annexure 2

Bark sample analysis results

Mechanically Debarked Hyena Bark Sample Analyses

Date	25/11/2010	25/11/2010	26/11/2010	26/11/2010	27/11/2010	27/11/2010	28/11/2010
Sample id	HYNA/DAY1	HYNA/DAY2	HYNA/DAY3	HYNA/DAY4	HYNA/DAY5	HYNA/DAY6	HYNA/DAY7
% Tans	21.06	22.37	24.36	18.97	25.59	14.07	19.05
% Non Tans	7.72	8.99	9.23	7.78	8.21	6.04	6.69
% Insol	0.06	0.02	0.53	0.29	0.17	0.16	0.11
% Moist	37.78	41.11	40.30	52.59	43.74	59.03	52.50
% Extractive	28.84	31.38	34.12	27.04	33.97	20.27	25.85
%Fibre	33.38	27.51	25.58	20.37	22.29	20.70	21.65
Reds	-	-	-	-	-	-	-
Yellows	-	-	-	-	-	-	-
I.Q	0.8640	1.1407	1.3339	1.3274	1.5240	0.9792	1.1940
T/NTR	2.73	2.49	2.64	2.44	3.12	2.33	2.85
Strippability	83% is class 1	88% is class 2	67% is class 3	78% is class 3	67% is class 4	54% is class 4	95% is class 5

% Tannin (dry)	33.85	37.99	40.80	40.01	45.49	34.34	40.11
% Non-Tan (dry)	12.41	15.27	15.46	16.41	14.59	14.74	14.08

Mechanically Debarked Hypro Bark Sample Analyses

Date	26/06/2009	26/06/2009	27/06/2009	27/06/2009	28/06/2009	28/06/2009	29/06/2009	29/06/2009
Sample id	HYPRO/DAY1	HYPRO/DAY1	HYPRO/DAY 2	HYPRO/DAY 2	HYPRO/DAY 3	HYPRO/DAY 3	HYPRO/DAY 4	HYPRO/DAY 4
% Tans	21.03	21.48	26.40	28.50	24.54	26.13	19.88	20.40
% Non Tans	6.66	6.79	6.78	7.15	9.28	8.08	5.49	5.62
% Insol	0.04	0.18	0.17	0.17	0.22	0.17	0.15	0.22
% Moist	38.41	38.57	32.78	29.03	27.69	27.15	46.07	45.53
% Extractive	28.45	28.45	33.35	35.82	34.04	34.38	25.52	26.24
%Fibre	33.14	32.98	33.87	35.15	38.27	38.47	28.41	28.23
Reds	-	-	-	-	8.76	8.61	10.81	10.29
Yellows	-	-	-	-	20.37	21.05	26.66	25.25
I.Q	0.8585	0.8626	0.9846	1.0191	0.8895	0.8937	0.8983	0.9295
T/NTR	3.16	3.16	3.89	3.99	2.64	3.23	3.62	3.63
% Tannin (dry)	34.15	34.97	39.27	40.16	33.94	35.87	36.86	37.45
% Non-Tan (dry)	10.81	11.05	10.09	10.07	12.83	11.09	10.18	10.32

Mechanically Debarked Hypro Bark Sample Analyses continued

Date	02/07/2009	02/07/2009	03/07/2009	03/07/2009
Sample id	HYPRO/DAY 5	HYPRO/DAY 5	HYPRO/DAY 6	HYPRO/DAY 6
% Tans	19.06	20.93	24.52	22.60
% Non Tans	6.37	6.19	6.91	6.29
% Insol	0.46	0.15	0.30	0.19
% Moist	36.07	36.76	38.20	40.77
% Extractive	25.89	27.27	31.73	29.08
%Fibre	38.04	35.97	30.07	30.15
Reds	7.61	7.17	6.32	6.86
Yellows	15.74	15.29	13.05	14.16
I.Q	0.6806	0.7581	1.0552	0.9645
T/NTR	2.99	3.38	3.55	3.59

% Tannin (dry)	29.81	33.10	39.68	38.16
% Non-Tan (dry)	9.96	9.79	11.18	10.62

Mechanically Debarked Demuth Bark Sample Analyses

Date	11/11/2009	12/11/2009	13/11/2009	14/11/2009	22/06/2009	23/06/2009	24/06/2009
Sample id	DEMUTH/DAY1	DEMUTH/DAY2	DEMUTH/DAY3	DEMUTH/DAY4	Day 5	Day 6	Day 7
% Tans	16.97	19.30	17.27	17.05	20.64	20.32	23.36
% Non Tans	6.64	6.44	6.64	5.66	7.81	7.04	8.08
% Insol	0.14	0.22	0.29	0.11	0.26	0.17	0.09
% Moist	54.31	49.26	49.68	50.29	47.04	47.86	45.98
% Extractive	23.75	25.96	24.20	22.84	28.71	27.53	31.53
%Fibre	21.75	24.78	26.12	26.89	24.25	24.61	22.49
Reds	-	-	-	-	-	-	7.28
Yellows	-	-	-	-	-	-	15.63
I.Q	1.0920	1.0476	0.9265	0.8494	1.1839	1.1187	1.4020
T/NTR	2.56	3.00	2.60	3.01	2.64	2.89	2.89
% Tannin (dry)	37.14	38.04	34.32	34.30	38.97	38.97	43.24
% Non-Tan (dry)	14.59	12.69	13.20	11.39	14.75	13.50	14.96

Mechanically Debarked Demuth Bark Sample Analyses continued

Date	17/06/2009	18/06/2009	19/06/2009	20/06/2009	22/06/2009	23/06/2009	24/06/2009
Sample id	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
% Tans	20.95	17.29	19.79	18.09	20.10	19.69	22.73
% Non Tans	9.86	11.13	9.63	7.27	7.93	7.00	8.65
% Insol	0.22	0.19	0.12	0.15	0.39	0.17	0.13
% Moist	46.84	46.00	46.42	47.88	47.39	47.07	44.13
% Extractive	31.03	28.61	29.63	25.51	28.42	27.05	32.51
%Fibre	22.13	25.39	23.95	26.61	24.19	25.39	23.36
Reds	-	-	-	-	-	-	7.37
Yellows	-	-	-	-	-	-	16.01
I.Q	1.4022	1.1268	1.2372	0.9587	1.1749	1.0654	1.3917
T/NT Ratio	2.12	1.55	2.06	2.49	2.53	2.81	2.63
% Tannin (dry)	39.41	32.02	36.94	34.71	38.21	37.20	40.68
% Non-Tan (dry)	18.55	20.61	17.97	13.95	15.07	13.35	15.48

Mechanically Debarked Demuth Bark Sample Analyses continued

Date	17/06/2009	18/06/2009	19/06/2009	20/06/2009
Sample id	Day 1	Day 2	Day 3	Day 4
% Tans	19.85	16.57	19.67	20.39
% Non Tans	11.01	8.77	9.37	8.20
% Insol	0.14	0.17	0.17	0.16
% Moist	46.67	47.07	46.92	48.18
% Extractive	31.00	25.51	29.21	28.75
%Fibre	22.33	27.42	23.87	23.07
Reds	-	-	-	-
Yellows	-	-	-	-
I.Q	1.3883	0.9303	1.2237	1.2462
T/NT Ratio	1.80	1.89	2.10	2.49

% Tannin (dry)	37.22	31.31	37.06	39.35
% Non-Tan (dry)	20.65	16.57	17.65	15.82

Manually Debarked Bark Sample Analyses

Date	11/11/2009	12/11/2009	13/11/2009	14/11/2009
Sample id	MANUAL/DAY1	MANUAL/DAY2	MANUAL/DAY3	MANUAL/DAY4
% Tans	20.86	18.90	20.11	21.93
% Non Tans	7.61	6.66	6.98	7.30
% Insol	0.16	0.27	0.18	0.11
% Moist	48.69	49.71	49.75	45.71
% Extractive	28.63	25.83	27.27	29.34
%Fibre	22.68	24.46	22.98	24.95
Reds	-	-	-	-
Yellows	-	-	-	-
I.Q	1.2623	1.0560	1.1867	1.1760
T/NTR	2.74	2.84	2.88	3.00

% Tannin (dry)	40.65	37.58	40.02	40.39
% Non-Tan (dry)	14.83	13.24	13.89	13.45

Annexure 3

Sampling and analysis of green and spent bark

SAMPLING AND ANALYSIS OF GREEN AND SPENT BARK

ANALYSIS

A : DETERMINATION OF AMOUNT OF BARK TO BE USED

1. Select an amount of green or spent bark that will give a solution as nearly as possible of 4,0 gl^{-1} tannin. (in any case not less than 3,75g nor more than 4,25g).
2. Calculate the mass of previously dried green or spent bark in the following manner :
   t = approximate tans % green or spent bark

   a = moisture % green or spent bark

   M = mass of bark to be used

   Then $M = \frac{(200 - 2a)}{t}$ grams

NOTE : If extractives only are to be determined 10,0 g of sample may be used.

B : DETERMINATION OF MOISTURE IN GREEN BARK

1. Mass accurately about 100 g green bark. (if not ex choppers then chop to uniform size)
2. Dry in drying oven at 105 °C for at least 24 hours to constant mass. (± 2mg)
3. Calculate moisture as follows :

   $$\text{Moisture \%} = \frac{(\text{mass wet bark} - \text{mass dry bark})}{\text{mass wet bark}} \times 100$$

C : DETERMINATION OF EXTRACTIVES IN GREEN BARK

1. Grind the dried sample obtained from A : above so that the whole will pass a 20 mesh (841 µm) screen.
2. Transfer the appropriate amount of dried bark as calculated from A : above to an extraction thimble.
3. Pour ± 100ml hot distilled water through the bark and collect the eluent in a 1000ml volumetric flask. (use 250ml flask if extractives only to be determined)
4. Transfer 150ml distilled water to an extraction flask.
5. Insert extraction thimble and boil under reflux for 3 hours.
6. Transfer the extract to the 1000ml (250ml) flask, cool and make to the mark.
7. Filter 100ml through S & S 3000 filter paper.
8. Pipette 50ml of filtrate into an evaporating basin and evaporate to dryness over a steam bath (± 2hrs).
9. Dry in an oven for 2 hours.
10. Calculate as follows:

$$\text{Dry extractives \%} = \frac{\text{mass dry residue} \times 100}{\frac{50}{1000} \times \text{mass green bark}}$$

$$= \frac{\text{mass dry residue} \times 4000}{\text{mass green bark}} \quad \text{(for 1000ml flask)}$$

$$\text{Wet extractives \%} = \text{dry extractives \%} \times \frac{(100 - a)}{100}$$

Where a = moisture % green bark

D : DETERMINATION OF NON-TANS IN GREEN BARK

1. Filter ± 400ml solution from C : 6 above through S & S 3000 filter paper.
2. Pipette 100ml into a bottle containing 25,75g hide powder at 73% moisture and agitate mechanically for 10 minutes.
3. Pour the sample solution and hide powder through a liner cloth in a filter funnel. Squeeze as dry as possible and collect the filtrate.
4. Add ± 1g of kaolin. Swirl solution.
5. Filter through S & S 3000 filter paper returning the filtrate until perfectly clear.
6. Pipette 50ml to a tared evaporating basin and evaporate to dryness.
7. Dry in an oven at 105°C for 2,5 hours.
8. Cool in desiccator and mass.
9. Calculate non-tans % as follows :

g water added to soln. in hide powder =0,73 x 25,75 = 18,798

Total volume of soln. before filtration = 100 + 18,798 = 118,798

$$\text{Non-tans \%} = \frac{\text{mass dry residue}}{\text{mass g bark}} \times \frac{1000}{50} \times 1.188 \times 100$$

$$= \frac{\text{mass dry residue}}{\text{mass g bark}} \times 2376$$

simplified to = mass dry residue x 240 (for 10g sample)

$$\text{Non-tans \% wet} = \text{non-tans \% dry} \times \frac{(100 - a)}{100}$$

a = moisture % green bark

E : DETERMINATION OF SOLUBLES IN GREEN BARK

1. Grind the dried sample obtained from A : above so that the whole will pass a 20 mesh (841 µm) screen.
2. Transfer the appropriate amount of dried bark as calculated from A : above to an extraction thimble.
3. Pour ± 50ml hot distilled water through the bark and collect the eluent in a 1000ml volumetric flask. (use 250ml flask if extractives only to be determined)
4. Transfer 150ml distilled water to an extraction flask.
5. Insert extraction thimble and boil under reflux for 3 hours.
6. Transfer the extract to the 1000ml (250ml) flask, cool, make to the mark and shake well.
7. Using a 50ml syringe and 25ml glass micro fibre filter transfer 100ml solution into a 300ml glass beaker.
8. Pipette 50ml of the filtered solution into an evaporating basin and evaporate to dryness.
9. Place in an oven at 105°C for 2½ hours.
10. Cool in a desiccator and mass.

$$\text{Solubles \% dry} = \frac{\text{mass dry residue}}{\text{mass green bark}} \times \frac{1000}{50} \times 100$$

$$= \frac{\text{mass dry residue}}{\text{mass green bark}} \times 2000$$

$$\text{Solubles \% wet} = \text{solubles \% dry} \times \frac{(100 - a)}{100}$$

a = moisture % green bark

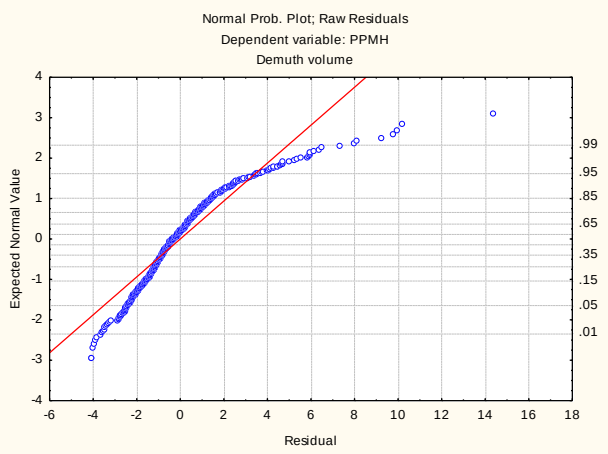
Annexure 4

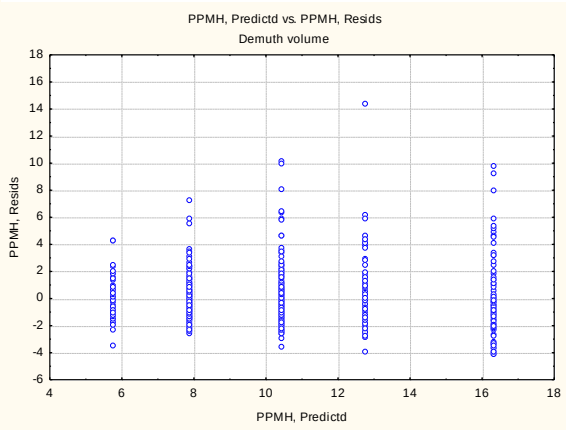
Graphs for Normality and Homoscedasticity

Demuth

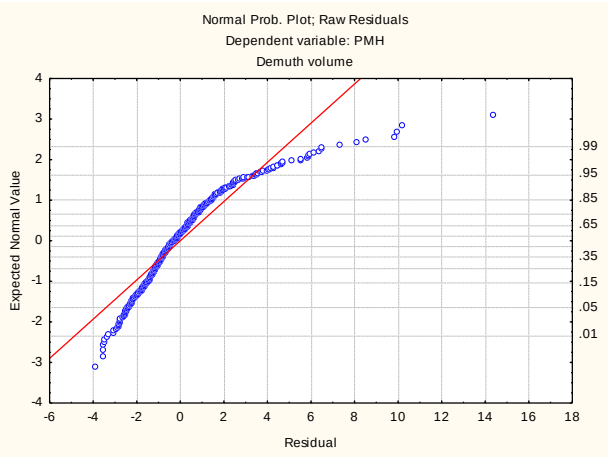
Volume

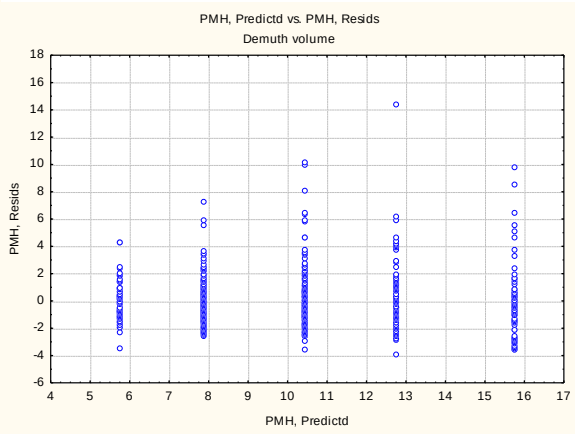
With productivity





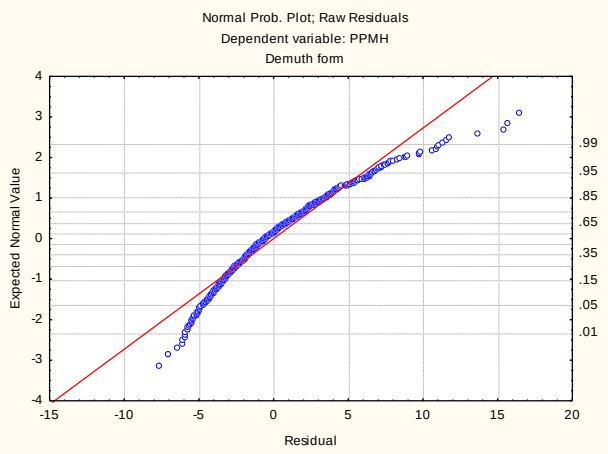
With outliers removed

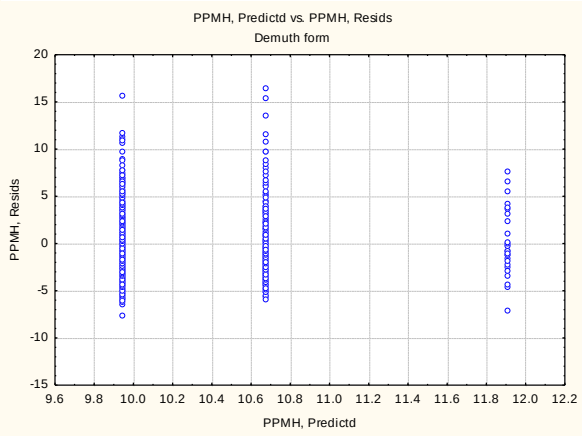




Form

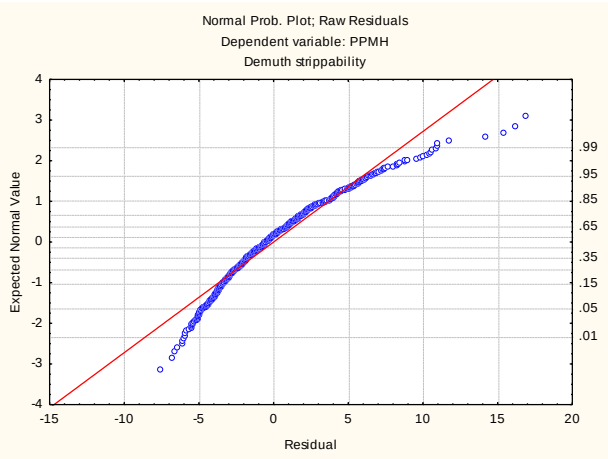
With productivity

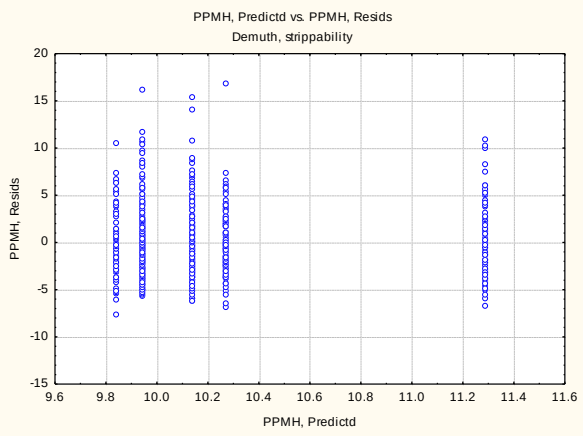




Strippability

<u>With productivity</u>

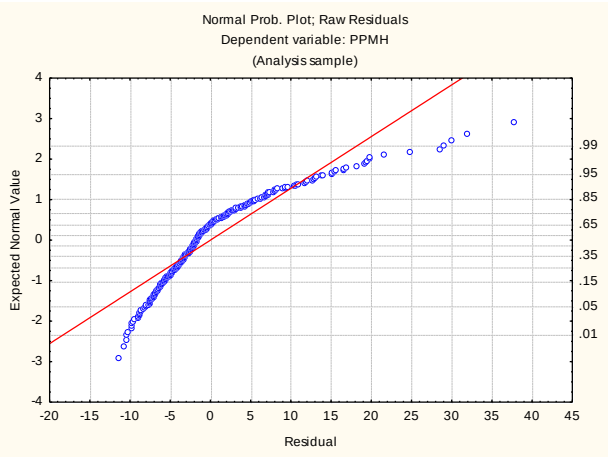


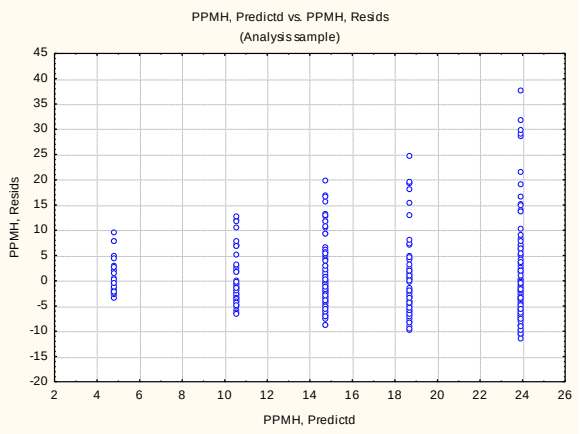


Hyena

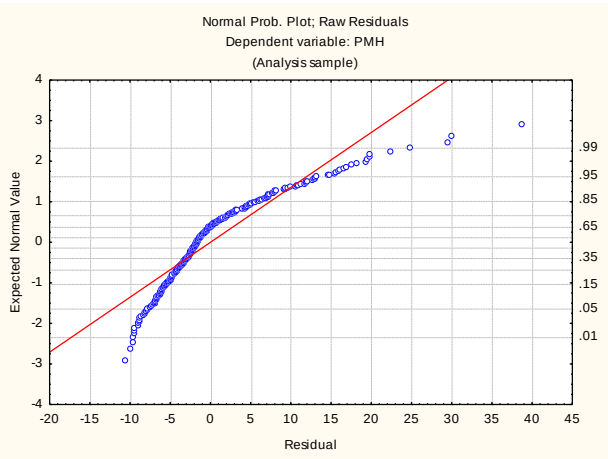
Volume

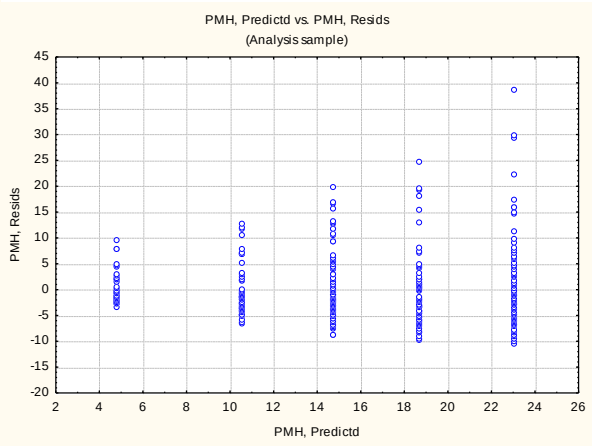
<u>Normal productivity</u>





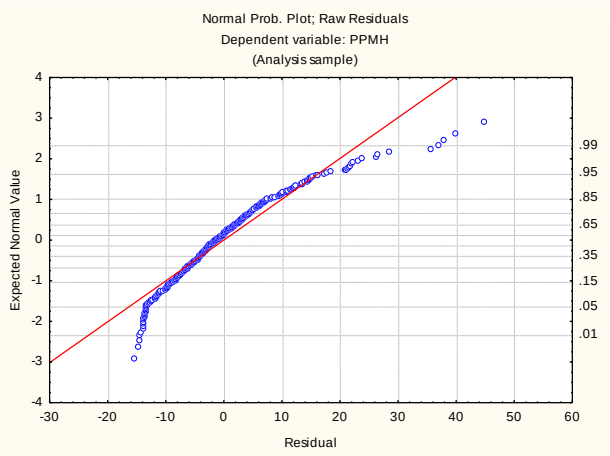
<u>Outliers removed</u>

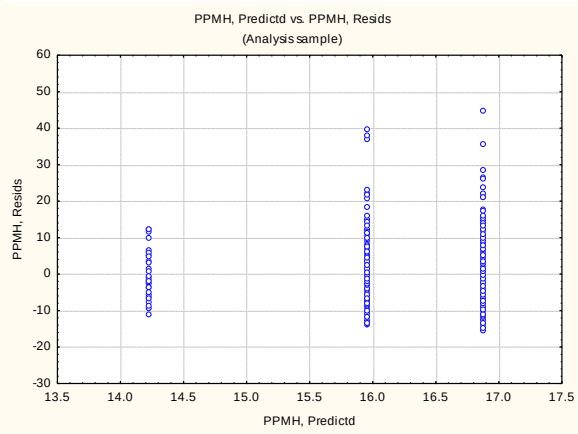




Form

Normal productivity

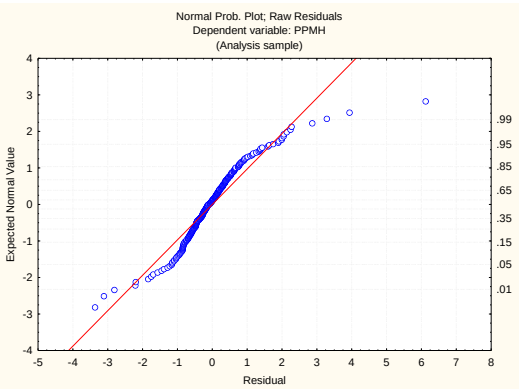


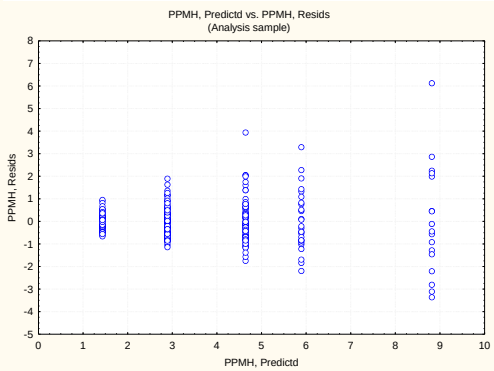


Hypro

Volume

Normal productivity





Annexure 5

Demuth costings

Tree volume 0.1m³

SYSTEM DESCRIPTION	:	Manual
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 21.32	15,890	3	1	6	220
Extract and stack						R 12.59	15,890	6	1	6	221
Bell 225 logger						R 16.97	15,890	1	1	1	292
Demuth DDM 420 Mobile Debarker						R 45.61	15,890	1	1	5	292
				Total (ex overheads)		R 96.50		11		18	
				TOTAL		R 96.50		11		18	

Tree volume 0.15m³

STUDY FOR : Masters Thesis
PREPARED BY : John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 14.73	20,498	3	1	6	221
Extract and stack						R 9.45	20,498	6	1	6	221
Bell 225 logger						R 14.27	20,498	1	1	1	292
Demuth DDM 420 Mobile Debarker						R 35.36	20,498	1	1	5	292
				Total (ex overheads)		R 73.81		11		18	
				TOTAL		R 73.81		11		18	

Tree volume 0.2m³

SYSTEM DESCRIPTION	:	Manual
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 12.14	25,468	3	1	6	221
Extract and stack						R 6.49	25,463	5	1	5	221
Bell 225 logger						R 12.39	25,463	1	1	1	292
Demuth DDM 420 Mobile Debarker						R 30.77	25,463	1	1	5	292
				Total (ex overheads)		R 61.79		10		17	
				TOTAL		R 61.79		10		17	

Annexure 6

Hyena costings

Tree volume 0.1m³

SYSTEM DESCRIPTION	:	Hyena debarker
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 23.19	18,404	4	1	8	221
Hitachi Excavator						R 44.93	18,404	1	1	1	292
Hyena debarker						R 10.54	18,404	1	1	0	292
Collect and bundle bark						R 14.35	2,208	8	1	8	221
Extract and stack						R 12.66	18,404	7	1	7	221
				Total (ex overheads)		R 105.67		4		24	
				TOTAL		R 105.67		4		24	

Tree volume 0.15m³

SYSTEM DESCRIPTION	:	Hyena debarker
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 16.16	25,543	4	1	8	221
Hitachi Excavator						R 32.37	25,543	1	1	1	292
Hyena debarker						R 7.59	25,543	1	1	0	292
Collect and bundle bark						R 14.24	3,065	11	1	11	221
Extract and stack						R 8.97	25,543	7	1	7	221
				Total (ex overheads)		R 79.34		4		27	
				TOTAL		R 79.34		4		27	

Tree volume 0.2m³

SYSTEM DESCRIPTION : Hyena debarker
OPERATION : Wattle debarking
STUDY FOR : Masters Thesis
PREPARED BY : John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 10.85	31,146	3	1	6	221
Hitachi Excavator						R 26.55	31,146	1	1	1	292
Hyena debarker						R 6.39	31,146	1	1	0	292
Collect and bundle bark						R 13.90	3,738	13	1	13	221
Extract and stack						R 6.39	31,146	6	1	6	221
				Total (ex overheads)		R 64.09		3		26	
				TOTAL		R 64.09		3		26	

Annexure 7

Hypro costings

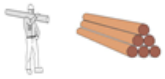
Tree volume 0.1m³

SYSTEM DESCRIPTION	:	Hypro 765
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 30.45	5,915	2	1	4	221
Hypro tractor						R 69.72	5,915	1	1	1	292
Hypro 765						R 43.86	5,915	1	1	0	292
Collect and bundle bark						R 16.14	710	3	1	3	221
Extract and stack	 					R 15.94	5,914	3	1	3	221
				Total (ex overheads)		R 176.12		2		11	
				TOTAL		R 176.12		2		11	

Tree volume 0.15m³

SYSTEM DESCRIPTION : Hypro 765
OPERATION : Wattle debarking
STUDY FOR : Masters Thesis
PREPARED BY : John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 20.30	8,870	2	1	4	221
Hypro tractor						R 46.48	8,873	1	1	1	292
Hypro 765						R 43.05	8,873	1	1	0	292
Collect and bundle bark						R 14.76	1,064	4	1	4	221
Extract and stack						R 10.63	8,873	3	1	3	221
				Total (ex overheads)		R 135.22		2		12	
				TOTAL		R 135.22		2		12	

Tree volume 0.2m³

SYSTEM DESCRIPTION	:	Hypro 765
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 22.83	11,830	3	1	6	221
Hypro tractor						R 34.86	11,831	1	1	1	292
Hypro765						R 21.93	11,831	1	1	0	292
Collect and bundle bark						R 13.95	1,419	5	1	5	221
Extract and stack						R 8.18	11,831	4	1	4	221
				Total (ex overheads)		R 101.75		3		16	
				TOTAL		R 101.75		3		16	

Annexure 8

Manual costings

Tree volume 0.1m³

SYSTEM DESCRIPTION	:	Manual
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 28.13	20,487	4	1	8	221
Debark and debranch						R 55.90	20,487	39	1	39	221
Extract and stack						R 12.92	20,487	8	1	8	221
				Total (ex overheads)		R 96.95		4		55	
				TOTAL		R 96.95		4		55	

Tree volume 0.15m³

SYSTEM DESCRIPTION	:	Manual
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 19.09	22,093	3	1	6	221
Debark and debranch						R 37.22	22,093	28	1	28	221
Extract and stack	 					R 8.91	22,093	6	1	6	221
				Total (ex overheads)		R 65.21		3		40	
				TOTAL		R 65.21		3		40	

Tree volume 0.2m³

SYSTEM DESCRIPTION	:	Manual
OPERATION	:	Wattle debarking
STUDY FOR	:	Masters Thesis
PREPARED BY	:	John

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/ton)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Chain Saw						R 16.04	22,994	3	1	6	221
Debark and debranch						R 28.07	22,995	22	1	22	221
Extract and stack						R 7.04	22,995	5	1	5	221
				Total (ex overheads)		R 51.15		3		33	
				TOTAL		R 51.15		3		33	