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ASSESSING TREE MORTALITY INTENSITY AT TWO DIFFERENT PERIODS OF RESIN TAPPING IN UGANDA

BY

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DECLARATION

I hereby declare that the work presented in this thesis is the result of my own effort and has never been presented for any award in this University or any of the institution of higher learning.

Signed..SAAD............ Date 21st/04/2022..

SSEBULIBA SAAD

The dissertation report has been submitted with approval of my supervisor

Signed: Syofunah. Date 21st/04/2022...

Dr. AGATHA SYOFUNA

DEDICATION

This thesis is dedicated to the almighty Allah as the source of wisdom. To my family whose love and support has continually inspired my life and academic life as a whole.

ACKNOWLEDGEMENT

I am so grateful to the almighty God for everything throughout my academic life, for without him I would not have made it. I thank you every day of my life.

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ABSTRACT

Resin tapping is an emerging alternative economic activity in Ugandan *Pinus* plantations despite the fact that they are mainly managed for timber production. During resin extraction at Kikonda forest reserve the outer layers of pine trees are incised over many years, leaving typical 'fish bone'-like patterns on the stem face. This mechanical damage inflicted by resin tapping incisions is likely to affect tree health. This makes tapped pine trees more susceptible to extreme weather events like strong winds leading to stem breakage, rotting, drying due to droughts and more susceptible to pests. In this study, diameter at breast height (DBH) of resin tapped trees was measured and observed for major causes of mortality at two different stages of resin tapping. More specifically, tree mortality intensity of pine trees tapped at four years was compared with those tapped for two years and the effect of resin tapping periods on DBH of tapped trees at two and four years period were assessed. 20 alternating square sample plots of $100m^2$ (at a spacing of 3mx3m) along the-transects from two compartment were established. A total of 1200 trees sampled from 40 plots were marked, DBH measured and observed for any causes of mortality. The results indicate that four-year tapped trees in F01 compartment had smaller stem diameter compared to stem tree diameter in F08 compartment tapped for two years. The influence of years of resin tapping on mortality of trees tapped for two and four years indicates that mortality occurred most in the four years tapped trees with 18% trees drying and 17% trees breaking. This indicates that mortality increases with years of resin tapping. Therefore, trees whose diameter is less than 20 cm must be tapped for maximum of 2 years since there is less damage.

Key words: Resin tapping, mortality, Resin, Tree diameter.

CHAPTER ONE

INTRODUCTION

1.1 Background

Africa is a relatively recent producer of resins, although large areas of pines have always been planted for timber or pulp for some time. Zimbabwe pioneered African resin production tapping from *Pinus elliottii* in the Eastern highlands of Zimbabwe which began in 1976 (Langenheim, 2003). Kenya also began resin tapping production in 1986 (Coppen and Hone 1995). Resin is produced from three pine species in Kenya, *Pinus elliottii* in the South provides most of the resin, *Pinus caribaea* is tapped in southern coastal areas, and *P. radiata* is tapped at higher elevations. Total resin production shows an upward trend although resin is converted to a modified form and sold locally to paper mills.

In South Africa, tapping is centered on extensive plantings of *P. elliottii* and *P. caribaea* in Northern KwaZulu - Natal, and it's resin production is the highest of the three leading African resin tapping countries, with its resin and turpentine being consumed domestically (Langenheim, 2003). Several other African countries have extensive areas of underexploited pines that have potential for resin production (Coppen and Hone 1995). For example, Malawi has large areas of pine, including *Pinus elliottii*, and resin production has been planned. Commercial tapping of *P. caribaea* began on a small scale in Uganda in 1994 (Langenheim, 2003).

Since tapping is a controlled wounding of the tree, the type of wounding is important for sustained yields and the health of the tree (Langenheim, 2003). It involves concentrating the wound only in the area where the secretory tissue is located in wood or bark (Trapp & Croteau, 2017). It's necessary to choose the most effective manner to refresh the wound and stimulate further flow of resin. Extensive tree mortality results not only as a direct consequence of the tapping procedure but by the indirect effects of insects, fire, and wind blowing down trees weakened by resin collection (Gaylosrd et al., 2015).

Studies on the effects of resin extraction on pine growth are scarce therefore there is need for research about effects of resin extraction. But possible effects of resin tapping on pine tree mortality are even less studied (Génova et al. 2014). However, it is hypothesized that the severe damage caused by resin tapping alters a trees' mechanical and physical properties. For example, it makes trees more susceptible to extreme weather events such as strong winds leading to stem breakage, rotting, drying due to droughts and more susceptible to insects (Maaten et al., 2017).

In Uganda, the extraction of resin as a non-timber forest product is entirely a new venture that not many companies and forest owners are engaged in. Currently resin is being tapped at Kikonda forest reserve under Nile Fibre Board Ltd and the species being tapped is *Pinus carribaea.* Since the activity is new, there is need for more research on the negative impacts of resin tapping such as mortality that induce stock reduction to enable tree farmers minimize effects to maximize output.

1.2 Problem statement

In Uganda, many pine plantations have been established by different individuals and organizations mainly for timber production (Kaboggoza, 2011). However, these trees take long to mature for harvest and the owners have to be patient before they can get any returns from these plantations. This has encouraged farmers to start extraction of non-timber forest products (NTFP's) as alternative source of income while the trees continue to mature. Among these NTFPs is resin which is obtained from various species of Pines. For this reason, resin tapping has become a very profitable business worldwide, but also the current technological advancements and international markets have contributed to extensive engagements (Cristine & Fett-neto, 2013). The fact that there is variation in tapping periods, a question on varying mortality rate of trees in a given plantation can be studied (Hadiyane et al., 2015). Basing on the stock reduction at the reserve, there is need for information about comparison in the stock variation intensity of trees tapped 4 years period with those tapped for 2 years to enable us understand the expected stock reduction with continuous resin tapping in pine plantations in Uganda. Also resin tapping is recommended when the tree reaches minimum DBH of 25.5 cm (Palma et al., 2012). Two tapping regimes are possible; long term tapping which begins early in the life of the tree and takes place until final cut and tapping before final cut, which occurs only in the last 3–4 years before final cut. Unfortunately in Uganda, resin tapping is done even on trees that are below 20cm in DBH. According to Cheng, (1997) and Ding et al., (1979), too early resin tapping of trees whose DBH is below 20 cm may severely affect the growth of trees. Studies by Rodrigues *et al., (*2008) on the effect of tree age and DBH on resin production yield of *Pinus elliottii* in

Brazil found out that bigger trees (22-23.5 cm DBH) gave 20-25% higher oleoresin yield than smaller trees of diameters 18.0- 19.5 cm DBH. Therefore, if resin tapping continues to be carried out on trees below 20 cm of diameter, this will negatively impact on commercial pine tree growers in the long run hence the need to understand the effect of tapping from small diameter trees.

1.3 Objectives

1.3.1 General objective

To compare tree mortality intensity of pine trees exposed to 4 years period of tapping and those tapped for 2 years.

1.3.2 Specific objectives

(i) To evaluate the effect of resin tapping on DBH in pine trees.

(ii) Assess the influence of years of resin tapping on pine tree mortality.

(iii) Assess the different causes of mortality and their intensity on pine trees.

1.4 Hypothesis

H_0: Pine tree mortality intensity does not increase with years of resin tapping.

H_0: DBH does not increase with years of resin tapping.

1.4 Justification

In Uganda, establishment of plantations especially for Eucalyptus and pine on both private and public depleted forest reserve land is increasing as a way of conservation, forest restoration and protection of land. Since pine plantations are mainly established for timber production, resin extraction is considered as an alternative source of income as trees mature. This practice of resin extraction has been reported to cause a significant negative impact on tree stock which needs to be regulated or further studied to minimize these impacts to ensure sustainable timber production.

The study will provide information on the extent at which tapping influences mortality. The information generated will guide decision makers on how best to minimize resin tapping tree mortalities in pine plantations. It is envisaged that information gathered during the study will be useful to local and commercial tree growers as well as research institutions and companies such as SPGS under FAO, Uganda Timber Growers Association (UTGA) to mention but a few that are promoting commercial plantation forestry.

Furthermore, information from the study will give an insight to deeper research on resin tapping in the country. In a broader sense, as a strategy to combat timber shortage, the information from this study will enable successful establishment of pine plantations which is essential as an immediate solution in combating wood shortage.

CHAPTER TWO

LITERATURE REVIEW

2.1 Resin tapping across the world

Resins are sticky, liquid, organic substances that usually harden upon exposure to air into brittle, amorphous solids (William, 2017). They are secreted by a number of plants, especially pines and other conifers and are a major non-wood product of forests. Present day annual world production of pine rosin is estimated to be 1.2 million tons per year and world production of pine turpentine is estimated to be about 330 000 tons (Giri et al., 2008).

China is by far the biggest world producer, consumer and exporter of resin with 70 % of the world production and controls efficiently the world market and prices (Palma et al., 2012). Pine resin is one of the valuable plant extracts which is popularly tapped from 12 different pine tree species around the world, the principal products of pine resin are rosin and turpentine oil that both could be obtained by distillation of Pine resin which are mainly used in paints, varnishes and soap manufacturing. Besides these, some medicinal value of resin where it can be used in stimulant, anti-spasmodic, astringent, diuretic and anti-pathogenic (Chhetri & Timilsina, 2021).

Pinus caribaea is a tropical pine tree native to the Caribbean and Central America. The plant has been introduced into many parts of the world including several countries in Africa. The species is further subdivided into three varieties namely *P. caribaea var caribaea, P. caribaea var bahamensis and P. caribaea var hondurensis. Masson* pine (*Pinus massoniana*) a native species of central and southern China, has long been used as a main source of pine resin and turpentine in China (Williams et al., 2021). In recent years, the world has witnessed a renewed interest in natural resins, fueled mainly by an increasing demand from China, which has pushed prices up to about USD 650/ton (FAO, 2018).

2.1.1 Status of resin tapping in Uganda

For the first time in the history of commercial forestry in Uganda, pine forests are being subjected to intensive resin tapping for commercial purposes. This comes as a relief to pine tree growers who were already facing prospects of low timber prices and a long rotation period (18 years) for saw log production. Resin tapping thus provides an additional income stream to pine tree growers before final harvesting can take place. Big commercial forest companies such as Global Woods AG under Nile fiberboard Limited are involved in resin tapping and are exporting resin tapped from their own plantations (FAO, 2018).

Currently, increased demand for natural resin in China has pushed up prices (> USD 650/ton) and several Ugandan tree farmers, previously reluctant to participate are engaging or expressing interest in resin tapping. The resin tapping business in Uganda is currently dominated by Chinese investors who export it to mainland China. Tree growers across the country are being paid an annual rental fee equivalent to UGX 1.6 Million (USD 420)/ha/ year, paid in two instalments.

Resin yield varies with site, from two to four kilograms per tree, per year with an average yield of three kilograms per tree and about two tons per hectare, per year. Variation can be caused by length of harvesting season, tree size and number of resin extraction faces worked on per tree at a time. Resin yield per hectare depends on stocking per hectare, age, tree diameter, accessibility of the compartment and steepness of terrain. Access cleaning is recommended in compartments that are to be tapped for resin. It is more difficult to work on steep terrain, carrying loads of resin during harvesting, than on flat terrain.

2.1.2 Effects of resin tapping in Ugandan pine plantations

Current resin tapping is ongoing on about 2000 ha of pine plantations in Uganda with no adverse effects reported. However, there is a likelihood of damaging the trees during the process of tapping, if clear safe guards are not put in place.

Since the yield of resin is dependent on number of trees being tapped in a hectare, there is risk of farmer's under-thinning or not thinning compartment at all for fear of disrupting the tapping exercise and wanting to tap more trees in their plantation which may in turn adversely affect the volume and quality of the saw logs obtained at final harvest (FAO, 2018).

Presently, growers are being paid a fixed rental fee per hectare of plantation irrespective of the amount of resin collected. Since resin tapping is relatively new undertaking in Uganda, the resin tapping business is unregulated which might cause further damages to the trees if not studied.

2.2 Origin of resins

The resins may be found in any part of the plant or may occur only in the inner tissue. Usually, resins do not exude unless there has been some injury. For this reason, tapping has to be resorted to in order to obtain free production of resin from the plant. Resins are secreted in plant tissues in special cavities or resin ducts. These ducts are connected with one another and when one of these passages is severed the resin flows to the wound (Vázquez-gonzález et al., 2020).

Two tapping regimes are possible: long term tapping, which begins early in the life of the tree and takes place until final cut, and tapping before final cut, which occurs only in the last 3–4 years before final cut (Palma et al., 2012).

The method of formation of resin is not fully known but it is believed that it forms through polymerization and reduction of carbohydrates particularly starches (Langenheim, 2003). As regards its function in the life of the plant, it is generally believed that it may not be of any use in the growth of the plant but may assist in preventing desiccation to the injured tissue. The three most important families for the bulk production of natural resins for the commercial purposes are the Pinaceae, Leguminosae and Dipterocarpaceae.

The family Burseraceae yields aromatic resins also known as oleoresins such as frankincense and myrrh (Langenheim, 2003). The natural resins as a group are very heterogeneous and are insoluble in water and this characteristic serves to distinguish them from the gums (Giri et al., 2008). They are however soluble in a large number of organic solvents. The color of resins vary from colorless through various shades of amber and brown to pink (Ciesla,).The natural resins do not usually have a definite melting point. It may vary according to the species. Essential oil is sometimes an important constituent of a resin (Langenheim, 2003).

2.2.1 Resins

Pines are the primary source and the most important commercial producers of resin, yielding rosin and turpentine although other conifers and some broadleaf trees are also commercial resin sources (William, 2017). Resins are amorphous solid or semisolid substances that are invariably water insoluble but mostly soluble in alcohol or other organic solvents (Getahun & Kebede, 2020)**.** Physically they are found to be hard, transparent and fusible in that upon heating they first get softened and ultimately melt. Chemically, they are complex mixtures of allied substances, such as: resin acids, resin alcohols (resinols), resino-tannols, resin esters and gluco-resins. Thus, Resins are amorphous products having an inherent complex chemical entity. Resins are normally produced either in schizogenous ducts or cavities and are regarded as the end products of metabolism. They are electrically non-conductive and combustible in nature (Mahendra, 2016).

2.2.2 Distribution of resins in plants

The resins and resinous substances are more or less extensively distributed throughout the entire plant kingdom, specifically the Spermatophyta i.e., the seed plants. Resin presence is almost rare and practically negligible in the Pteridophyta i.e., the ferns and their allies. However, the resins have not been reported in the Thallophyta i.e., the sea-weeds, fungi etc. These findings and observations lead to the fact that resins are the overall and net result of metabolism in the higher plants, since the majority of them belong to the phylum Angiosperm and Gymnosperm (Getahun & Kebede, 2020).

2.2.3 Occurrence and formation of resins in plants

In plants, resins usually occur in different secretory zones or structures.

(i) Resin Cells: Ginger–*Zingiber officinale* (Family: Zingiberaceae).

(ii) Schizogenous Ducts: Pine Wood–*Pinus polustris* (Family: Pinaceae).

(iii) Glandular Hairs: Cannabis–*Cannabis sativa* (Family: Moraceae) (Johnson, 1998).

The formation of resins in the plant is by virtue of its normal physiological functions. However, its yield may be enhanced in certain exceptional instances by inflicting injury to the living plant, such as Pines. Many resinous products are not formed by the plant itself unless and until purposeful and methodical injuries in the shape of incisions are made on them and the secretion or plant exudates are tapped carefully such as: Balsam of Talu and Benzoin. In other words, these resins are of pathological origin (Getahun & Kebede, 2020).

Natural resins are secreted by a number of plants, especially pines and other conifers, Pines are the primary source of resin although other conifers and some broadleaf trees are also commercial resin sources. Most resins are harvested by a process known as tapping, a fairly labor-intensive process that involves wounding live trees and collecting the resin. If done properly, there is little or no injury to the tapped tree but over tapping will weaken and kill trees (William, 2017).

The ecological meaning of resin synthesis in conifers is directly related to the plant defense mechanism against predatory insects of bark and pathogenic fungi (Cristine & Rodrigues, 2016). Resin extraction is expected to result in causes of mortality such as tree drying, breakage and insect infestation. Improper application of Chinese method in resin tapping involves incised removal of the outer layers of pine trees diagonally over many years, leaving typical ‘fish bone’-like patterns on the stem face behind (Maaten et al., 2017) as shown in Figure 1. To protect themselves against this mechanical damage, pines produce a highly viscous substance which is rich in organic hydrocarbons (Maaten et al., 2017). It is this resin that is collected and processed to obtain turpentine and rosin.

Tree tapped face. Remaining tree bark.

Figure 1: Typical ‘fish bone’-like patterns on the stem face of a tapped pine tree

2.3 Challenges of resin tapping

Resin tapping may negatively affect tree stock, especially when the tapping intensity is high and if trees being tapped are below DBH 20cm because too early resin tapping may severely affect the growth of tree (Hadiyane & Sulistyawati, 2015). Tree density at times depends on the initial density, thinning intensity and schedule, which are determined by silvicultural practice. Usually, a forest is thinned according to crown density; for instance, artificial first thinning is performed when the crown density reaches 0.8 (Seidl et al., 2007).

The tapping methods used are brutal and injurious to the plants, often leading to their death (Sharma, 2016). The available technology is old and the innovations are essential for sustainable yield and quality control. Resin yield is mainly determined by tree species, DBH, age, site condition, climatic condition and tapping methods, length of tapping season, as well as whether stimulants are used or not (Chhetri & Timilsina, 2021).

Resin tapping is also reported to result in discoloration and hardening of wood on the wounded tapped area. The oldest and most valuable part of a tree is the butt log (first log of the tree stem) where resin tapping is done. The injured portion of the stem therefore affects grade as well as financial value of wood products from that section while the rest of the stem has full financial and utilization value (FAO, 2018).

2.3.1 Environmental issues

There is high concentration of acid mixture applied as stimulant for resin extraction. The mixture of Dilute Sulphuric Acid and Dilute Nitric Acid (20%) can be applied to trees where rill is formed for resin tapping (MFSC, 2007). If mixture is concentrated, it may negatively affect the growth and development of pine tree tapped. Majority of resin collectors are poor, so they spray heavily with the hope of more resin extraction and hence making more money. The acid mixture flows from trees during rainfall and causes severe effects to soil as well as growing vegetation (Paudyal, 2008) there by influencing negatively on the environment. Small study carried out in some community forests reveals that about 0.2% of pine trees, from which resin is extracted, are dying (Paudyal, 2008). This could be attributed to intensive and regular bark removal which involves concentrating the wound only in the area where the secretory tissue is located and the transportation system of the tree.

2.3.2 Technical issues

Selection of trees to be tapped is a big issue where some under sized pine trees are also tapped. Tree age is identified as the main factor driving resin production (Vázquez-gonzález et al., 2020). Majority of pine trees below 20 DBH if selected for resin tapping are more prone to the drying and breakage and yet their resin productions are still low. Rodrigues *et al.,* 2008, studied the effect of tree age and DBH on resin production yield of *Pinus elliottii* in Brazil and found out that bigger trees (22-23.5 cm DBH) gave 20-25% higher oleoresin yield than smaller trees of diameters 18.0- 19.5 cm DBH (Nadiope, 2018).

Poor tapping techniques lead to the depletion of pine resources in the long term (Chhetri & Timilsina, 2021). People are saying that resin tapped trees yield low quality timber compared to none tapped trees. However, a thorough study in this aspect is lacking and is highly recommended (Paudyal, 2008).

2.3.3 Socio-economic issues

It has been argued from civil society that wage rate for labor on trees marking, resin tapping and transportation to depots is very low. Resin tapping companies claim that wages are increased per year as per mutual understanding made between company and labors. Labors are involved in clearing grounds 1m round from tapping trees, rill making, resin collection from trees to container, resin transportation to depots. Labors are also employed to transport resin tapping tools and containers to forest (Chhetri & Timilsina, 2021) but their wages are demotivating.

2.3.4 Opportunities

Resin collection and transportation activities need huge amount of man power. Therefore, there is a good opportunity of employment for the local, women and disadvantaged groups. Likewise, forest technicians could be employed by companies in order to monitor implementation of Environmental Impact Assessment and technical aspects of resin tapping. Similarly, a huge amount of revenue has been generated each year to local and central government from resin, which could be invested for sustainable forest management, poverty reduction and livelihood and infrastructure development activities (Paudyal, 2008).

Revenue generated from resin is becoming a major source of income for community forest user groups, which could be allocated for community forest management, income generating activities for poor and excluded user households for social and infrastructure development activities. There is also a great opportunity of sustainable management of pine forest for multiple benefits so that resin could be extracted for a longer period of time and after, trees could be felled for other benefits like timber, furniture and firewood (Paudyal, 2008).

2.4 Scope of improvement in resin tapping

Resin tapping is done by exposing the resin ducts by making suitable incisions on the stem of trees which is a tedious job and needs attention while working with available devices and techniques. Most of the natural resins are collected in small quantities by forest dwellers by adopting traditional tapping tools/methods and practices from selected trees. The available devices for tapping resins are less efficient, add more injury to the trees and drudgery to the tappers/collectors, time consuming and require more labor (Sharma, 2016). Reduction in drudgery of resin tappers/collectors and increase in efficiency of tapping techniques and devices with increase in yield could be materialized with suitable improvement in the existing techniques and devices (Prasad et al., 2018).

Similarly, improved tapping techniques and devices will minimize injury to the trees and help in sustainable production of resins. Concerted efforts are urgently needed to improve method of tapping and collection for sustainable production of resins and livelihood of rural people. The plant physiological aspects need to be considered while designing new method of resin tapping and tool used in different tapping methods (Prasad, 2018).

2.5 Pine resin tapping techniques used around the world

Resins are collected from pine trees through tapping using different methods that involve inducing resin flow by deliberately inflicting an injury to a tree. Consideration for the right method to use should be based on its ability to maximize resin yield while minimizing damage to the wood. The depth of the cut into the tree for resin taping must reach the cambium layer but not go beyond it, into the sapwood (FAO, 2018).

Around 1850, Pierre Hugues developed the first pine resin tapping technique in the Landes de Gascogne, France system that is applied even nowadays, for example, in Indonesia. In 1869, Steele was granted an US patent in which he describes the basis of the fish bone tapping technique. Later, the technique evolved, through some modifications performed in the 1950's by Mazek Fialla in Europe, and become known today as the Rill method, applied in India (Hadiyane & Sulistyawati, 2015).

1. Mazek or Rill method

This is an improved method, to overcome the disadvantages of the cup and lip method. In rill method, the bark of the tree over a surface area of about 45 cm in height and 30 cm in width is removed with the help of a bark shaver. The surface is made very smooth and the thickness of the bark left should not be more than 2 mm to facilitate freshening of the blaze. The blaze frame is kept on the stem in the vertical portion 15 cm above the ground level and the position of the blaze is marked with a marking gauge. The control groove is cut with a grove cutter by drawing it from top to bottom. The lip is then fixed in the tree with nails. For freshening of the blaze, the tapper stands near the tree on one side of the blaze and holds the freshening knife at the lowest point of the control groove. The tapper along with blaze line marked on the tree then pulls up the knife. The depth of the rill is about 2mm into the wood. After making a freshening on both arms of the blaze a 1:1 mixture of dilute sulphuric acid (20%) and dilute nitric acid (20%) is sprayed on the freshly cut rill with the help of spray bottle. Exudation of oleoresin starts soon after the rills are made. The pot containing the oleoresin is emptied into a collection can. The resin adhering to the pot is removed with the help of a scraper. The control groove is also increased to avoid accumulation of resin in it. The advantage of the rill method is that there is less damage to the timber as the cuts are made on the surface. This method is currently used in Indonesia and India (Nadiope, 2018)

2. Chinese method

Consists of a series of downward-pointing V-shaped narrow grooves (1.5mm wide) cut on the tree stem, deep enough to reach the secondary xylem. The first groove is cut about 1.7meters above the ground, and subsequent grooves are cut downwards after every two days. The groove reaches roughly half way around tree’s circumference. Resin oozes out of the newly created groove and flows down the stem to a collection container (plastic bag) fasted to a tree about 40-60cm from the end of the cut. No chemical stimulant is used in this method.

3. The Portuguese method

In this method, slices of the back measuring about 10x5cm are cut into the tree stem every 18-22 days. A stimulant paste with 18 to 24 percent sulphric acid ($H2SO4$) is applied to stimulate and maintain resin flow. Resin continually oozes out of the sliced portion of the stem and flows into a bag fasted to the tree trunk at about 10cm above the ground for a period of 18-22days before a new slice is cut upwards. The slices are cut upward, the first at 20 cm above the ground and gradually extends to about 1.8Meters after two years of extraction. The resin collecting bag is raised with each cut to minimize chances of resin drying before it enters the bag (FAO, 2018).

4. American method

A horizontal groove is cut every 15 to 18 days. The grooves are cut upward, the first at 20 cm above the ground. Only the bark and phloem are removed. The length of the grooves is about one third of the tree’s circumference and the height varies from 2 to 3 cm. A stimulant paste with 18 to 24 percent sulphuric acid (H2SO4) is applied. In the paste formulation, stimulants are also used as chemical adjuvants, such as, for example, CEPA (2-chloroethyl-phosphonic acid, an ethylene precursor) or salicylic acid. This method is used, for example, in Brazil, Argentina, Portugal and Spain (Cunningham, 2012). The method has less damage to the surface as a small face is cut to fit the polythene bag and several cuts can be made from the same site without necessary changing the face. However, the surface is left exposed to attack from pathogens.

5. Hugues or French method

Slices of 8 to 10 cm wide are cut into the trunk every 10 to 15 days, reaching the secondary xylem. The cut surface may extend to 1.8 m from the ground after two years of extraction. This method was developed in the mid-nineteenth century in France and is now used mainly in Indonesia. The lip covers the pot partially to prevent pieces of the bark and dirt from falling into the cone. It also minimizes the evaporation of resin that accumulates into it. The cup and lip method has disadvantages that the blazes very often their depth into the wood exceeds the prescribed limit. The deep holes results in loss of timber and make the trees less resistant to wind. The method can only be used for one cycle of tapping (Cunningham, 2012) .

6. Borehole method

In this method holes are made near the ground level with the help of a machine into tree's sapwood to open the resin ducts and exuding resin is collected in a closed container. The hole in 10 each tree is done approximately 10 cm above the ground. The holes are drilled straight into the tree stem with a slight slope towards the opening so that resin drains freely. Immediately after making the hole the stimulants/ chemicals are sprayed inside each freshly made hole.

Chemical treatment is done once only, immediately after boring holes. After treatment a spout is installed inside the hole by gently hammering with a small mallet or pushing with palm of the hand to achieve compression fitting in the hole. The spout is meant for joining the collection container tightened to each spout and once the container is filled with resin, it is removed from the tree and poured into a collection can and immediately a new container is tied for future collection of resin.

There is less stress due to small size (2.5 cm diameter) of the hole. The hole heals fast. The technique is very suitable for the protection of tree against fire, insect, pest and diseases. Prolong resin flow can be obtained from bore hole for a period of several months without wounding the stem. The holes are made with the help of a machine therefore the labor productivity of the technique is several folds greater than other method. The technique could be very effective in conservation and management of pine resources. And resin is collected in a closed recipient, but this method has been tested but not yet significantly applied at commercial scale (Giri S.K., Prasad. N & Prasad.m, 2008).

Figure 2: Showing the five techniques of resin tapping 1. Chinese method; 2. American method; 3. Hugues or French method; 4. Mazek or Rill method; 5. Borehole method (Alejandro, 2012)

CHAPTER THREE

STUDY AREA AND METHODS

3.1 Study area

The study was carried out at Nile Fibre-Board Limited, Kikonda forest reserve in Kyankwanzi district. It is situated along Kampala-Hoima highway. It is about 38 km East of Hoima and 40 km west of Kiboga towns respectively, and about 15 km to Kafu River along Hoima-Kiboga main road at latitudes and longitudes 31033’05.6’’E and 1013’38.2” N respectively. The study research was carried out on plantation compartments F01 and F08 found in blocks F. Both compartments were established in the same planting season and acquired similar silvicultural practices.

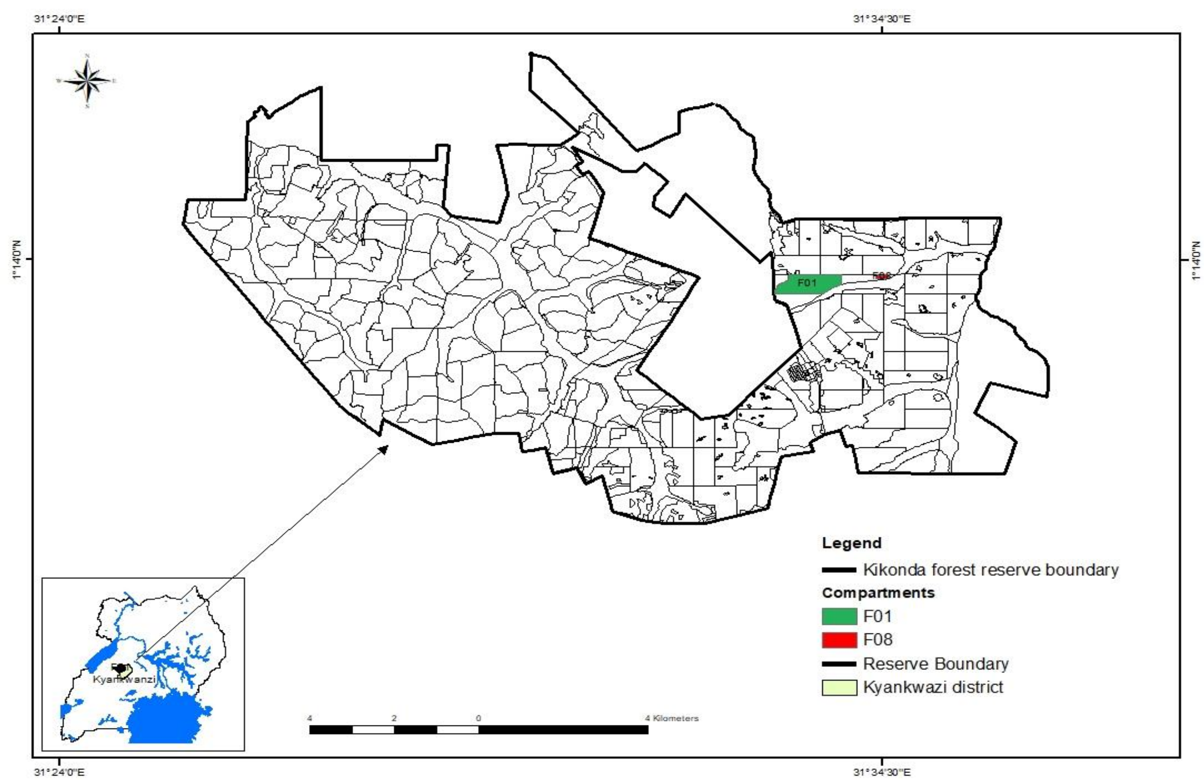

Figure 3: Location of Kikonda forest reserve in Uganda

3.2 Sampling design

The study was conducted in two tapped compartments of the same age. Fixed area sampling approach was used involving systematic establishment of 20 alternating square sample plots of 100 m^2 planting spot (at a spacing of 3mx3m) along the transects in each compartment. From each of the established sample plots, 30 trees were randomly selected, marked and assigned labels (numbered from 1 to 30) and then observed. A total of 1200 sample trees from all 40 sample plots in the study site were marked to identify any related causes of mortality such as insect infestation, resin tapping techniques, stem breakage, trees drying and rotting. Further examination was conducted to assess the effect of silvicultural management practices on mortality of resin tapped trees in contrast to the performance of un-tapped trees (Maaten et al., 2017).

3.3 Sampling intensity and data collection

In each compartment, established plots were explored to note the relationship between resin tapping and tree mortality. The diameter at breast height of all marked trees was measured using a caliper and recorded to enable assess the effect of size on mortality of the species (Hadiyane &. Sulistyawati, 2015).

Causes of mortality such as pest infestation, resin tapping techniques, stem breakages, tree drying, rotting, were observed and identified on the trees and the plots assessed for silvicultural practices in tapped and untapped compartments. Tree parameters such as DBH were measured using caliper and the number of dead, broken and pest infested trees were counted.

3.4 Data analysis

To test the relationship between resin tapping and tree mortality, comparison of causes of tree mortality in tapped trees in the sample plots was done. Stepwise multiple regression was applied to test the relationship between the various mortality causes (Vázquez-gonzález et al., 2020). Simple linear regression was used to test the relationship between resin tapping and tree mortality using R- software.

CHAPTER FOUR

RESULTS

4.1 Influence of years of resin tapping on diameter at breast height

Effect of resin tapping on pine tree diameter when all diameter at breast height were analyzed with resin tapping period indicate that in both compartments where resin tapping was carried out, tree diameters were highly significant ($P < 0.001$). From the P-value indicating that all measured DBH have acquired big diameters. From the estimate, the intercept of 24. 2968 of tree diameter tapped for a period of two years and -1.9603 of tree diameter tapped four years period indicate that since trees tapped for four years their diameter being -1.9603 means that it is less compared to 24.2968 diameter of trees tapped for a period of two (Table 1).

Table 1: Variation of pine tree DBH tapped for two and for four years

	Estimate	S E	T-value	P-value
DBH size (Intercept)	24.2968	0.1803	134.725	0.001
Period (4years – 2year)	-1.9603	0.2550	-7.686	0.001

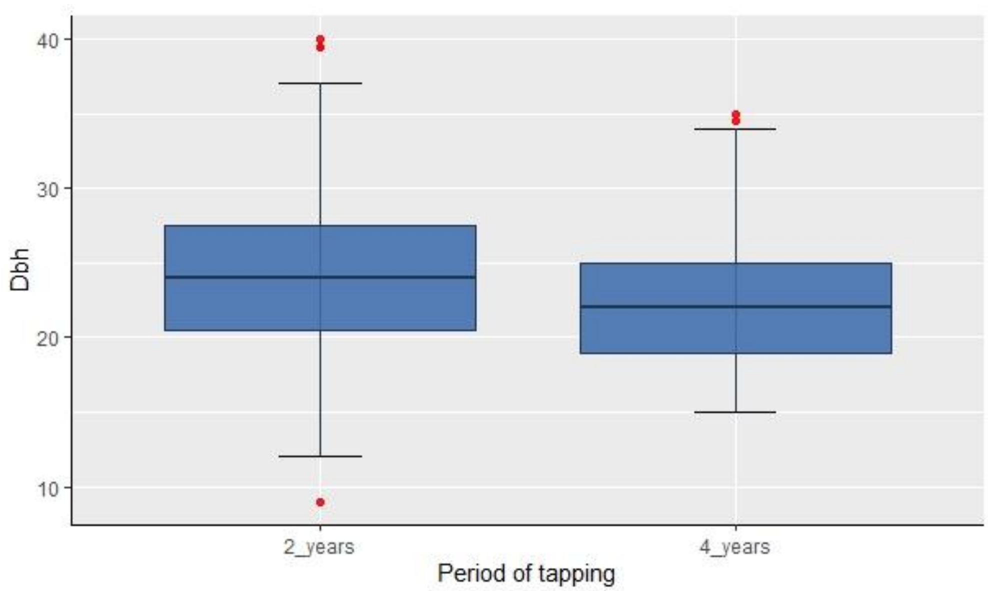

Figure 4: Comparison of length of two- and four-year's period of tapping on diameter at breast height of pine trees

The diameter at breast height of pine trees tapped for two years is larger compared to diameter at breast height of pine trees tapped for four years.

4.2 Influence of two and four years tapping period on pine tree mortality

From the results obtained, it was observed that the four years period of resin tapping had caused the most mortality forms in resin tapped trees at Kikonda forest reserve and with zero form of mortality in the two years tapped pine trees as shown in table 2.

Table 2: Mortality occurrences in the four and two year's period of resin tapping

Causes of mortality	Estimate	S E	Z-value	P-value
Drying-trees				
(Intercept)	-6.395	1.001	-6.390	1.66e-10 ***
Period(age4-age2)	4.858	1.007	4.827	1.39e-06 ***
Breakage				
(Intercept)	-5.7004	0.7083	-8.048	8.39e-16 ***
Period(age4-age2)	4.1286	0.7165	5.762	8.30e-09 ***
Insect-damage				
(Intercept)	-22.57	1967.60	-0.011	0.991
Period(age4-age2)	17.27	1967.60	0.009	0.993
Rotting				
(Intercept)	-21.57	1193.41	-0.018	0.986
Period(age4-age2)	17.97	1193.41	0.015	0.988

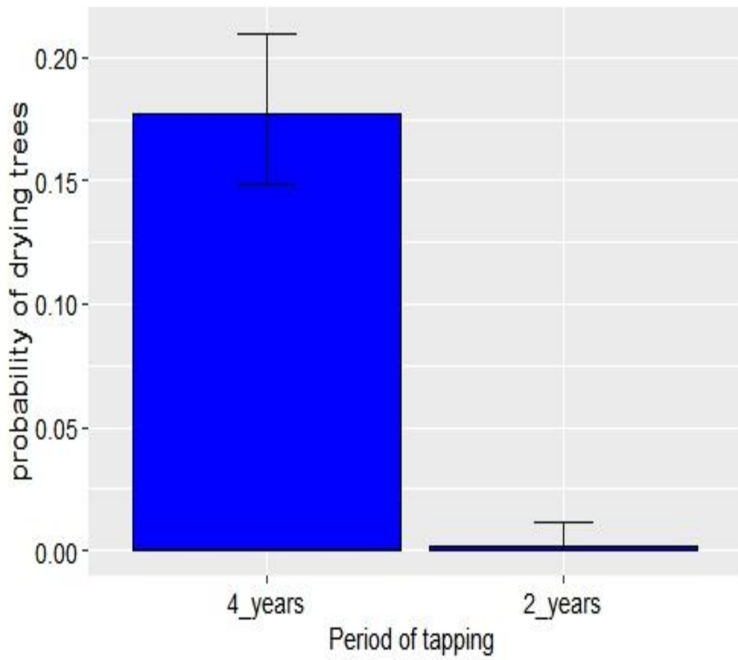

Figure 5: Probability of drying trees at two- and four-years tapping period

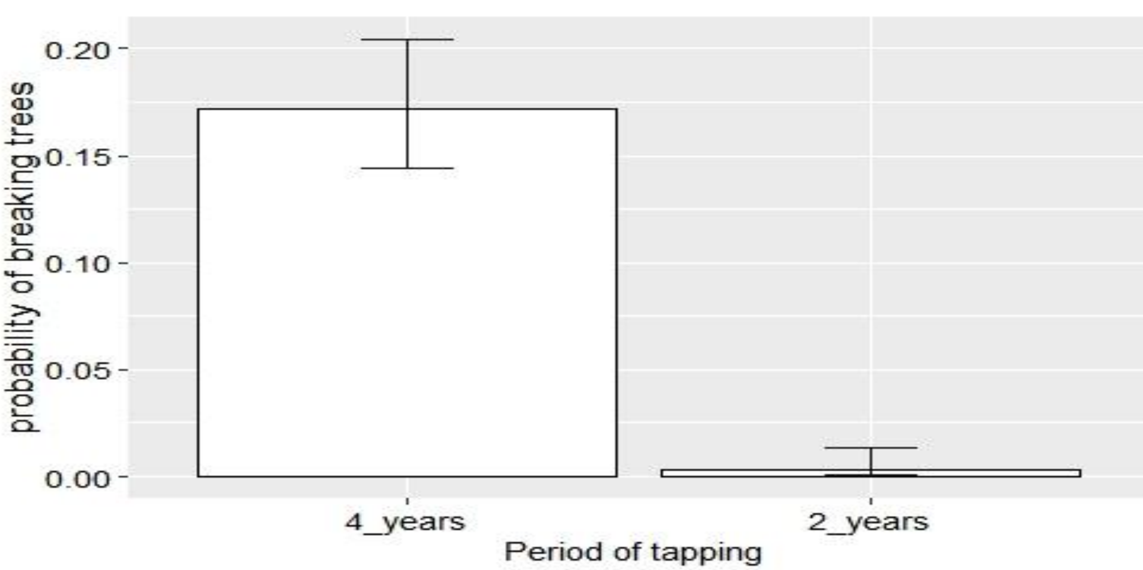

Figure 6: Probability of breaking trees at two and four years tapping period

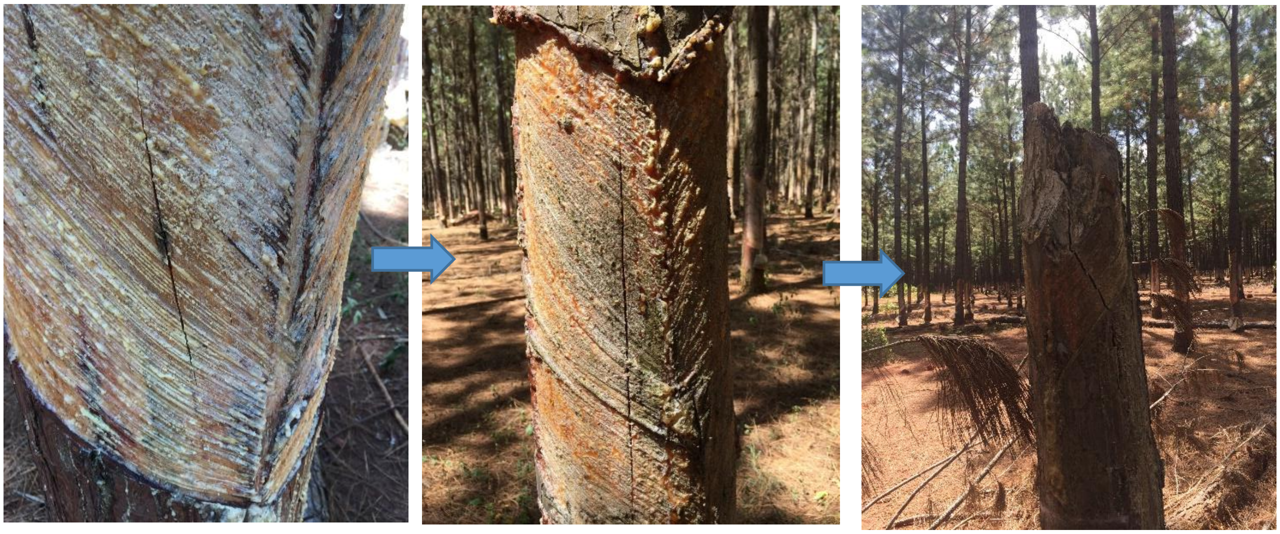

Figure 7: Line of weakness after incisions that induce tree breakage

Lines of weakness that develop on stems of tapped trees that later increase in length after removing tree bark making tapped trees more prone to wind breakage.

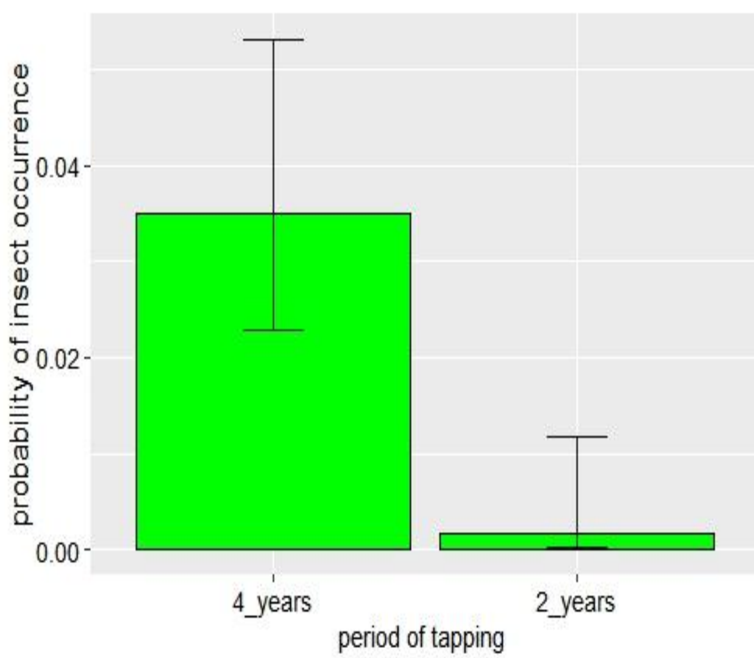

Figure 8: Probability of insect damage at two and four years tapping

Figure 9: Effect of insect infestation after years of resin tapping

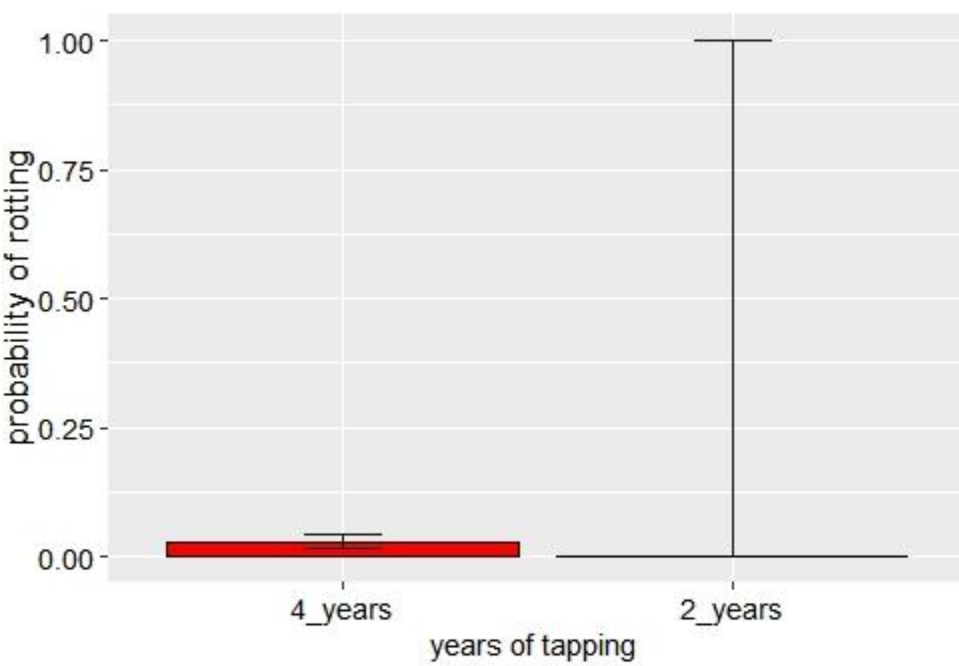

Figure 10: Probability of rotting at two and four years tapping

It is observed that with four years period of tapping, the mortality probability occurrences in terms drying, breaking, insect-damage and rotting were higher compared to mortality occurrences in the two years tapped period as indicated in figure 5, 6, 8 and 10 respectively.

4.3 Causes of mortality in resin tapped pine plantations

Mortality occurrence such drying trees, breaking trees, insect damage and rotting in resin tapped pine plantation in Kikonda forest reserve were assessed. Drying and breakage of pine trees, were highest amongst other causes of mortality in resin tapped trees and both of these causes were highly significant (P = 0.001). The probability of occurrence of insect damage and rotting was the same as in table 3.

Table 3: Probability of mortality occurrences in the two and four year's period of resin tapping

Causes of mortality	Estimate	S E	Z - value	P-value
(Intercept)	-3.9797	0.2152	-18.494	< 2e-16 ***
Breakage	1.6360	0.2382	6.868	6.50e-12 ***
Drying	1.6567	0.2378	6.966	3.26e-12 ***
Rotting	-0.3235	0.3311	-0.977	0.329

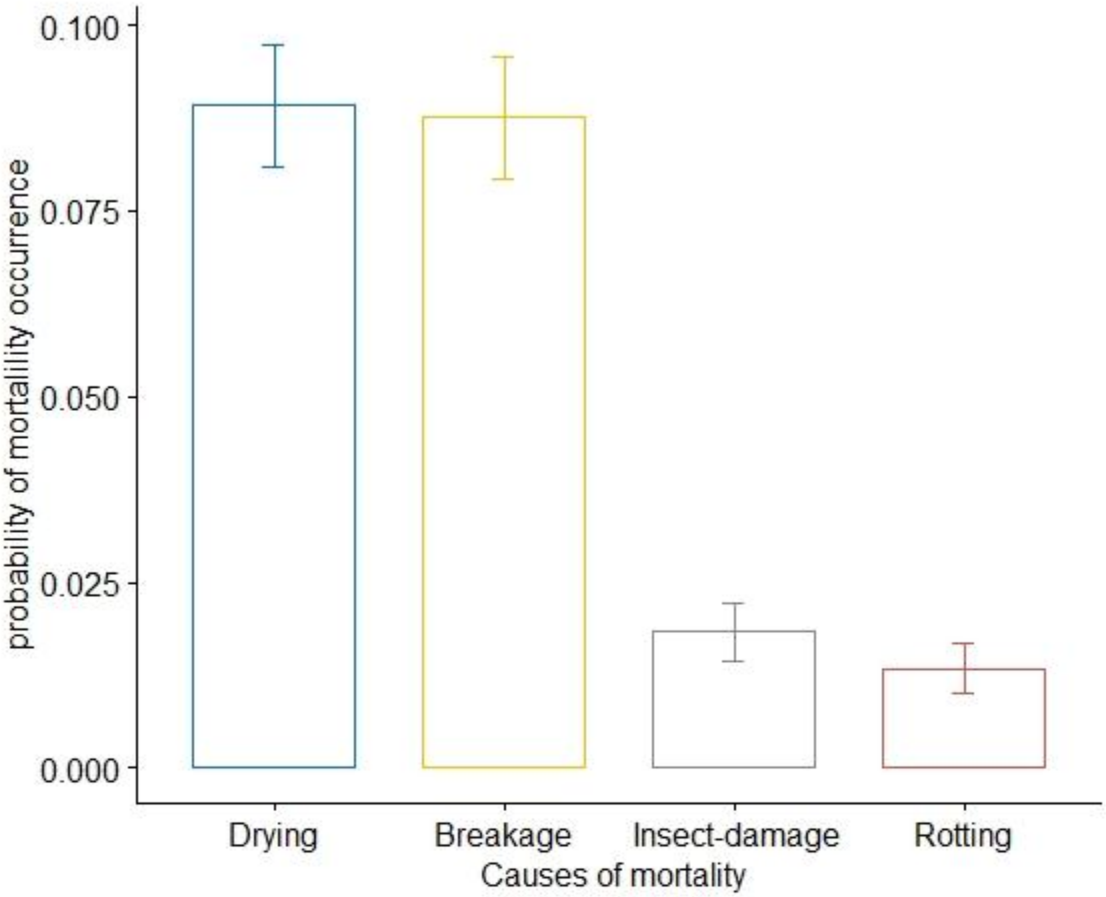

Figure 11: Probability of drying, breaking, insect-damage and rotting occurrences in resin tapped pine plantation in Kikonda forest reserve

From the results obtained below, it was observed that the major cause of mortality in resin tapped plantation in Kikonda forest reserve was drying trees, breaking trees, insect damage and least cause was rotting as shown in figure 11

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Influence of resin tapping years on diameter at breast height of resin tapped trees

The effect of resin tapping on diameter of pine trees tapped for four years period followed the trend of decrease in DBH growth of pine tapped trees (Williams et al., 2018). Williams et al., 2018 studied the effect of resin tapping on pine tree diameter in Guangxi in South China and found out that there is a decrease in DBH growth by 1.34% which resulted in a decrease in stem volume by 18.62%. Likewise another study found that tapping slash pine (*Pinus elliottii)* in South China resulted in reductions in tree diameters and stocking volume. Maaten et al., (2017) studied diameter of maritime pine (*Pinus pinaster Ait)* following wounding by resin tapping and observed a decrease in tree diameter close to the scars. The decrease in pine tree diameter of trees tapped for four years may likely be as a result of carbohydrates not being invested in tree growth but in excess resin production due to prolonged resin tapping.

Basing on figure 4, the results suggest that, there is a negative impact of resin tapping on pine tree diameter growth with trees tapped for four years. Magnuszewski & Tomusiak, (2013) found an increased radial response to tapping at 1.3 m in Scots pine with more years of resin tapping but at 3.0 m there was no effect. Sampled diameters in this study were only at 1.3 m from the ground and strictly of trees tapped for two and four year's period and it is possible that if DBH measurements were beyond the four years of resin tapping, results could have showed a positive effect. This would be attributed to an increase in the diameter growth due to the wood formation in the uninjured side of the tree, though in this study, diameter size of pine trees tapped for four years was not greater than that of pine trees tapped for two years.

5.2 The influence of tapping period on pine tree mortality

All mortality forms occurred in four years tapped tress. The major causes of mortality in the four year tapped pine trees were due to drying and breaking as indicated in figure 5 and 6 respectively. Occurrence of these forms in the four year tapped trees is because the current commercial resin tapping operations are performed on tree trunks through removing the bark and further tissues beneath it at variable depths according to the extraction method employed (Cristine & Fett-neto, 2013). Therefore, the physical injury weakens the cambium layer and sapwood of the trees after making incisions for four years to collect exuded resin therefore making stems of four years tapped trees prone to causes of mortality.

Resin yields are maximum and minimum during the hottest and coldest months, respectively and with the increase in frequency of freshening the incisions in hot seasons, tapped pine trees with four years of resin tapping become exposed to continuous dry seasons eventually making trees draught stressed as part of their water transport system is damaged eventually leading to drying (Maaten et al., 2017).

Occurrence of dried trees in the four years tapped trees is attributed to hydraulic failure, since the water transportation system is continuously damaged with four years of resin tapping (Gaylord et al., 2015).

Prolonged chipping of the pine tree stem for four years unless done carefully can lead to substantial damage to the butt log and in extreme chipping to freshen incisions for resin collection, tapping can kill the tree since it results in reduced vigor making trees susceptible to wind breakage after formation of lines of weakness (Johnson, 1998). Deeper and wider incisions induce a greater flow of resin, but can reduce growth of the tree and weaken the main stem , which ultimately causes falls due to the strong wind (Prasad, 2018). Breaking tree occurrences of resin tapped trees in the four years period is mainly attributed to strong winds which find already weakened trees stems due to many years of continuous incisions. Most trees cannot withstand strong winds and some of their diameter was below 20cm making them more prone to wind breakage according to Allan & Prasad, (2018). Therefore, with four-year period of resin tapping, trees are less able to attain enough volume to enable them withstand strong winds compared to those tapped for two years.

5.3 Causes of mortality in resin tapped pine tress

When trees become stressed with prolonged resin tapping, other factors such as moisture scarcity, strong winds and poor silvicultural practices and tapping trees whose diameters are less than DBH 20cm, makes tapped trees susceptible to drying, breaking, rotting and insect damage. At Kikonda forest reserve, the major cause of mortality in resin tapped pine trees is drying and breaking of trees. Resin tapped pine trees bear yield when they are in abnormal condition due to stress, such as prolonged incisions, moisture scarcity while resin yield increases with an increase in daily temperature and tapping intensity (Getahun & Kebede, 2020). An increase in frequency of freshening the incisions in hot seasons, moisture scarcity and prolonged tapping exposes tapped trees to various dry seasons. This eventually makes trees drought stressed as part of their water transport system is damaged leading to drying of resin tapped trees (Maaten et al., 2017).

The deep incisions or cuts in the trunk of the pine trees cause substantial damage and have been found to weaken the main stem, which ultimately falls due to the strong wind (Prasad, 2018). The other causes of mortality in Kikonda forest tapped trees was insect damage and rotting trees. Visually there was no incidence of bark beetles but termite damage occurred most in dried tapped pine trees that had been tapped for four years period. Rotting of resin tapped pine trees occurred mostly in trees that had been tapped for a period of four years and had been damaged by termites.

This is why there is a small difference between insect infestations and rotting of four year tapped trees.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Improper and prolonged tapping practices to harvest resins from pine trees has a detrimental effect on tree health and diameter at breast height of pine tapped trees.

Frequent and excessive extraction of resins from pine trees less than 20cm of DBH stresses the trees and makes tapped pine trees more vulnerable to drying, breakage insect damage and rotting.

Prolonged resin tapping leads to a decrease in growth of the diameter of pine tapped trees in long run leading to low timber volumes and yields.

Prolonged resin tapping may increase yield of resins temporarily, but reduces the long-term growth, productivity and increases susceptibility to drying, breakage, insect damage, rotting as forms of mortality in pine tapped trees.

6.2 Recommendations

Continuous resin tapping without rest and excessive resin tapping for more than 4 years period for tree less than 25 cm of DBH increases the susceptibility of these trees to drying, breakage rotting and insect damage and also negatively affects tree growth diameter at breast height. Therefore, trees below 20cm DBH shouldn’t be tapped for more than 2 years and prolonged resin tapping for more than four years should be carried out on pine trees above 25 cm of DBH since there is less damage.

Further research needs to be carried be carried out to compare mortality intensity of 4 and 6 years period of resin tapping on pine trees above 25cm of DBH with those tapped below 20cm DBH to determine mortality intensity of these trees and guide on the best minimum age to tap resin while avoiding tree mortality.

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