QUALITY, STOCKING AND YIELD OF PINUS PATULA AT MERU/USA FOREST PLANTATION

BY

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ABSTRACT

A study was conducted at Meru/Usa forest plantation to determine quality, stocking and yield of *Pinus patula* and factors influencing them. The Meru/Usa forest plantation compartments were categorized into affected and non – affected by root disease and insect defoliators. Systematic sampling method was used to align transect and plots in the compartment. 198 sample plots of 0.04ha were laid and measurements taken for estimation of stem quality, stocking, basal area and volume. The data collected were analysed by micro-soft excel and SPSS computer programmes. The weighted means of combined roundness and straightness for the affected compartments were 51.9 ± 5.0%, 32.7 ± 5.9% and 15.5 ± 4.9% in grades of good, medium and bad; while for the non – affected compartments were 60.9 ± 6.9%, 21.7 ± 6.4% and 17.2 ± 3.2% in grades of good, medium and bad. In this study it was found that the overall weighted means in the affected and non-affected compartments were 56.4%, 27.2% and 16.4% in grades of good, medium and bad respectively. The computed parameters for the affected compartments were 569 ± 137 stems/ha, 17 ± 4 m^2/ha and 129 ± 35 m^3/ha; while for the non – affected compartments were 709 ±184 stems/ha, 23 ± 2 m^2/ha and 153 ±37 m^3/ha. The study concluded that the compartments were affected with improper implementation of silvicultural practices, presence destructive agencies (wild animals and humans), root disease (*Armillaria mellea*), drought, grazing and insect defoliators (*Xanthisthisa tarspina*). It was also found that Meru/Usa forest plantation has suitable trees that may fetch good price at the markets if silvicultural practices are implemented accordingly. It is recommended that the Meru/Usa forest project should carry out proper silvicultural practices and local communities should be educated, encouraged to adopt and practice agroforestry.

DECLARATION

I, Anyandwile Asumwisye Mwasomola do hereby declared to the senate of Sokoine University of Agriculture that this dissertation has not been submitted to any other University and that it is my original work.

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The above declaration is confirmed

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LIST OF ABBREVIATIONS AND SYMBOLS

CAI	Current Annual Increment
FBD	Forestry and Beekeeping Division
FAO	Food and Agriculture Organization
FTI	Forestry Training Institute
G	Basal area (m^2/ha)
Ha	Hectare
MAI	Mean Annual Increment
m.a.s.l	Meters above sea level
MNRT	Ministry of Natural Resources and Tourism
N	Forest stocking (stems/ha)
SIDA	Swedish International Development Agency
SPSS	Statistical Package of Social Science
URT	United Republic of Tanzania
TTSA	Tanzania Tree Seed Agency

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Tanzania has about 33.5 million hectares of forests and woodlands (United Nations, 2005). About 13 million hectares of these forests have been gazetted as forest reserves under central and local government authorities. Forests under water catchment's management cover about 1.6 million hectares. The remaining area which is about 18.9 million hectares is covered by woodlands (URT, 1998). The value of Tanzania's forests is increasing with an expanding tourism portfolio and harvesting of organic forest products (United Nations, 2005). According to Chamshama and Malimbwi (1996) Tanzania forest plantations cover 98000 ha with *Pinus patula* as the major species. *P. patula* is among the exotic species of plantation forests constituting an important source of raw materials for different wood based industries in the country. Among the *P. patula* plantation projects in Tanzania are Sao Hill in Iringa, Kawetire in Mbeya, Meru/Usa forest project in Arusha and Rongai and west Kilimanjaro in Kilimanjaro regions.

1.2 Overview of Meru Forest Project

Meru/Usa forest project was established in 1923 for the purposes of producing raw materials for wood industries. It covers a total area of 5660 hectares (Mkumbo, 2001). Large scale planting of conifers commenced from early 1950's to 1970's when much of the plantable area had been covered, mainly with *Cupressus lusitanica* and *P. patula* under the form of 'taungya' system. The oldest conifer stands in the plantation forest dates back to 1953, but some hardwood stands of *Eucalyptus* sp, *Acacia melanoxylon* and *Olea capensis* were established earlier (Maeda, 2005). Currently *P. patula* plantations in the project cover about 36.4% (2060 ha.) of the total area (Maeda, 2005). The remaining area about

59.8% (3385 ha) is covered by other tree species, while unplanted area accounts to 3.8% (215 ha) of the total area. The working cycles are now focused on *P.patula, G. robusta, Eucalyptus* sp, *A. melanoxylon* and *O. capensis* with the long-term objective of producing sustainable yield of forest products. At present the status of *P.patula* plantations of age class 6-10 and 11-15 years, which is about 60 %, is affected in terms of quality, stocking and yield. Also these *Pinus patula* plantations are affected by root disease and insect defoliators. Most of the compartments are under stocked, unthinned, with high pruning not conducted and the logs which are currently harvested have numerous knots hence the poor lumber strength. In some compartments trees are crooked, fox tailed and have multiple leaders. Sometimes, the affected compartments have been forced to be harvested prematurely hence the objective of quality and quantity of wood to be produced is not met (Mkumbo, 2001).

1.3 Problem statement and justification

Currently at Meru/Usa forest plantations the quality, stocking and yield of *P. patula* is seriously affected and therefore declining. This is observed in the field and the wood produced from the plantations. In the field some trees are dead, dry, decayed and generally the appearance of leaves, boles and branches of the affected stands are not in good condition. In 2001, 1.5 hectares of *P. patula* in the Forestry Training Institute (FTI) and 38.6 hectares in the Meru/Usa forest project plantations were observed to have this health problem (Mkumbo, 2001). Since then, the effect has been increasing in such way that today over 100 hectares of FTI plantations and 421.7 hectares of Meru/Usa forest project plantations are affected (Maeda, 2005). This accounts about 25% of the total area planted with *P. patula*. Also some trees in the field and the logs brought to the FTI sawmill are of poor quality in terms of decay, straightness and roundness. The contributing factors to these problems probably may be;

- Silvicultural practices such as;
  - site selection: Tree species to be planted does not match with site,
  - improper taungya system practices,
  - seed sources are inferior genetically,
  - improper follow up of silvicultural practices.
- Diseases
- Inadequate supervision;
- Change of climate
- Insufficient funds

On these circumstances the government incurs high production costs, but the target of producing the intended materials is not met. According to FBD (2000) most of the compartments at Meru/Usa forest plantations are poorly stocked and the average volume is estimated at 250 – 300 m^3/ha. The plantation exhibits an uneven age class distribution because in some of the years replanting of harvested areas did not take place (URT, 1998). In *P. patula* plantations factors such as site class, growing stock, climate and management practices affected quality of wood to be produced (Mkumbo, 2001; Maeda, 2006). The management practices are not correctly done to improve yield; for example improper follow up of silvicultural practices like thinning and high pruning are not common at Meru/Usa forest project and in addition the quality of wood raw material supply is low (FBD, 2000). Therefore the results from the present study are expected to contribute towards sustainable management of the Meru/usa forest plantations and may be useful to other *P. patula* plantations in Tanzania.

1.4 Objectives

1.4.1 Overall objective

The main objective of the present study therefore was to determine quality, stocking and yield of *P. patula* and the factors that influence them.

1.4.2 Specific objectives

- To assess and compare qualitative parameters of two *P. patula* populations estimated from straightness, roundness and diseased trees.
- To assess and compare stocking parameters of two *P. patula* populations estimated from diameter distribution and number of stems per hectare.
- To assess and compare yield parameters of two *P. patula* populations estimated from basal area and standing volume.
- To establish the influence of management history on stand conditions

1.5 Research questions

(b) How is the quality of the growing stock reflected in terms of straightness, roundness and diseased trees?

(c) What is the status of stocking of growing stock as reflected in diameter distribution, number of stems per hectare?

(d) What is the status of yield of growing stock reflected in terms of basal area and volume?

(e) What is the effect of past management practices on growing stock?

(f) What are corrective measures can be instituted to improve quality, stocking and yield of growing stock?

1.6 Limitation of the study

This was constrained with poor accessibility, budget, time and harsh weather. Difficult field operating conditions like rough terrain, steep slopes, poor forest roads and heavy rains during the research period, these together affected the time that was allocated to the study. Accessibility to some of the compartments was too difficult due to bushy conditions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Assessment of stand quality

2.1.1 Diameter quality

Diameter is considered to be the fundamental characteristics of quality. Of all the factors which help to determine the value of the product, tree diameter is the one which can be appreciably modified by the forester (FAO, 1981). Tree of greater diameter are considered to be of high quality except for certain special uses such as pitprops, poles and others. Also a tree of large diameter lends itself to much greater variety of uses than small sizes trees. So it is important to describe a stand by its stem diameter distribution (Brazier, 2001).

2.1.2 Stem quality

The quality of the stem can be viewed in two ways i.e. the external and internal quality. External quality includes dimensions like diameter and height, roundness, straightness of the stem, branching diameter and branching density (Kellomaki, 1980). The internal quality characteristics include the structures of the growth rings, mechanical strength, and amount of heartwood, cellulose content, rotting or decay. Stem quality is an important factor when selecting stands to be felled for production of particular type of timber and for production recovery in the saw mill. Brown and Miller (1985) found that diameter and sweep were the characters which had most impact on recovery. Short and irregular crooks result in the loss of scale. The leaning of stems causes tension wood to develop. These are the limiting defects to many end uses. Crooked and logs with eccentric pith cause wastage in veneer and plywood industry. Extremely crooked bolts add to the costs of debarking and chipping in the pulp industry (Hans, 1982). Also crooked boles cause problem in transport due to poor packing. Therefore defective logs cause problems and losses in nearly all harvesting, transporting and processing operations (Bayley and Kietzka, 2004).

2.1.3 Stem straightness

Stem straightness is a quality requirement for poles. It contributes to superior grades of sawn timber, and irrespective of end use whether it is a pulp, particle board, fuel wood or charcoal, saves costs and increases in the recovery from plantation management through harvesting to conversion (Barness and Gibson, 1986). There is no standard and quick method to assess stem straightness (Chamshama, 1979). Miller (1980) assessed trees for stem straightness visually. Four classes numbered from 1 (very good) to 4 (very poor) were allocated to the stems. The trees were again measured for straightness after being felled. The amount of sweep measured in the logs accorded well with visual classification made in order of measuring the stem straightness. Previous workers used visual assessment that is subjective rating of straightness of the standing trees (Brazier, 2000).

2.1.4 Stem roundness

Richard (1975) pointed out one of the possible difficulties in using dendrometer measurements to get volume estimates is their inability to detect, or compensate for the out of roundness of the stem. He defined roundness as the quotient of the difference (in length) between the longest diameter of the stem cross section (D_2) and the diameter at right angles (D_1) to it divided by the shorter diameter (D_s).

The expression D_2-D_1 was expressed in percentage of the shortest diameter D_s as: -

$$[(D_2-D_1)/ (D_s)] * 100$$

He found that roundness increases with the size, but is little affected by the slope of ground, amount of tree lean or density of the surrounding stand. Also out of roundness at the stump was greater than in upper stem positions.

2.2 Assessment of agents of tree defects

Two basic approaches may be adopted in the assessment of external characteristics and defects of stem. These are section concept and tree concept (FAO, 1981).

(a) Section concept

In this method the stem is divided into number of sections each of an absolute, relative or variable length. The quality of each section is assessed separately.

(i) Sections of absolute length

The length of each section in the stem remains constant according to chosen specification depending on local requirements. A standard log of 4m or 5m is usually used. One must be careful in allocating the defects in appropriate sections.

(ii) Sections of relative length

In this method the number of sections in the stem remains constant while the length of each varies in accordance with the length of the stem. With increasing number of sections quality assessment under this concept becomes more detailed and time consuming and also less reliable as the allocations of the defects to the appropriate sections becomes more difficulty.

(iii) Sections of variable length

The division of the stem is governed by the location of important defects, the purpose being to separate the logs or material deemed usable from defectives parts. The limits of each section would have to be determined by visual judgement. This procedure is accurate and practical for quality studies based on measurements of felled tress. It is time consuming, difficult and entails a great element of subjectivity.

(b) The tree concept

The tree (stem) is classified according to a series of selected quality or defect classes. The quality of only specified lower portion of the stem is used to classify the whole stem. The specified length of this chosen lower portion of the stem does not usually exceed six meters. In general the lower portion of the stem contains the great part of the total volume and is the part of the tree of the greatest value. Furthermore, certain types of bacterial infection and insect attack can reduce log quality substantially, and yet exhibit no external signs. The quality of the lower tree stem is also indicative of overall tree health (FAO, 2001). Therefore, both assessing impacts of silvicultural practices on tree quality and conducting forest inventories (and health) rely heavily on knowing lower stem soundness (Kellomaki, 1980). The proceeding sections discuss the different agents of tree defects.

2.2.1 Silvicultural practices

According to Larson (1979), good silvilcultural practices striving for optimum wood yield and uniformity of wood structure will normally produce optimum wood quality. Clearly, we need to develop varieties of trees capable of responding to intensive management, and establish management practices capable of utilizing the full potential of the improved varieties. Abnormal growth conditions introduced by silvilcultural operations, such as excessive initial spacing, heavy application of fertilizers, severe pruning or poor thinning regime, will increase variability of wood structure within the tree and so affect wood quality (Hägglund, 2001; Mitchell *et al*., 2006).

2.2.1.1 Seed quality and seed supply

Good parent trees are important because the seedling will be similar to the trees from which the seed is collected, if parent trees are protected from cross pollination with male tree which produces of unknown traits. Big, straight and vigorously growing trees will normally give straight and vigorously growing seedlings (Karki *et al*., 2002). The characteristics to look for in parent trees will depend on the purpose of the plantation. However, straight trees are important for wood or timber construction (FAO, 2001).

2.2.1.2 Unregistered seed sources

This type refers to collection from individual, good phenotypes or final crop trees of excellent phenotypes. Where a stand has been properly thinned (according to the thinning schedules) during its life, final crop trees are genetically superior to the origin crop (Evans, 1992; Mitchell, 2004). Seed collection is done between thinning and clear felling. The situation in the forest plantations in Tanzania is that thinnings do not follow the schedules (Chamshama and Philip, 1980, Ahlback 1988, Okama and Chamshama, 1988, Munishi and Chamshama, 1994). As a result, stands are overstocked with many trees of poor phenotype.

2.2.1.3 Registered seed stands

A seed stand is a plus stand that is generally upgraded and opened by removal of poor phenotypes and then cultured for production of plentiful seed of improved quality (Cavelier and Tobler, 2004). These seed stands are supposed to be used as temporary sources of seed and should be phased out as better genetic seed become available from seed orchards (Zobel and Talbert, 1984).

2.2.1.4 Seed orchards

A seed orchard is a plantation of genetically superior trees, isolated to reduce contaminated pollination from genetically inferior trees. Seed orchards are intensively managed to produce frequent, abundant and easily harvested seed (Banks, 1979; Zeide and Zakrzewski, 2001). Most seeds for forest plantation establishment are obtained from unregistered sources or poor quality seed orchards/stands. This has resulted into trees of poor quality in most second rotation plantations. In Tanzania Tanzania Tree Seed Agency (TTSA) is an organ for production of tree seed. TTSA is currently working to establish seed sources of various categories depending on species. It is equally important to ensure that quality seeds are available on demand and with affordable price (FBD, 2000).

2.2.1.5 Taungya system

It is a silvicultural practices whereby from planting, young trees grow together with agricultural crops until the tree canopy closes. The system has been quite wide spread in the high potential agricultural areas of Tanzania and Kenya since early 1900s, and still very popular (Oduol, 1989). Valdes et al., (2004) found that it is useful for forest plantation establishment especially in site preparation, weeding and access pruning. When properly practiced, the system allows sustained, optimum production of food along with forestry species from the same land and thus meets most of the social and economic needs of the *shamba* farmer. According to King (1986) its origin can be traced back to the1850s in Burma, where it was used as means of replanting teak plantations on badly degraded land. But nowadays various forms of practice can be found in different parts of the tropics (Pienaar and Shiver, 2003). The system continued fairly successfully due to availability of sufficient cultivable land; presence of a willing land – hungry farming population; availability of surplus produce; and security – protection against wild animals (Allan *et al.*, 2001).

The taungya system will continue to play a major role in forest plantation establishment in Tanzania tackling food and fuelwood shortages. According to Nair (1984) it has several drawbacks, the notable among them are:

- About 40% of the reported forest fires originated in these forest *shamba*, mostly at the time of clearing.
- The possible damage to crops by wild animals such as elephants, buffaloes, monkeys etc., discourages some participants, particularly in remote areas;
- The system requires high levels of supervision, otherwise the laid – down regulations would not be followed, thereby affecting tree establishment adversely. Experiences show that farmers tend to over prune or kill some trees in order to delay canopy closure (SUATF, 2007).
- The cultivation of glade (grasslands) in forest areas has reduced grazing land for both livestock and wild animals.
- In some areas the number of participants far exceeds the available land, thus leading to illegal clearing and conflicts.

Currently due to the problem of land and the continuous increase in population around the forest, squatters are favoured to stay and cultivate in young stands less than 5 years while early silvicultural practices such as weeding, access pruning are performed by them (SUATF, 2004). Close supervision should be given to squatters in order minimize over pruning and the tendency of squatters to stay and cultivate in these areas for a long time.

2.2.1.6 Pruning

The role of pruning is to control the production of knot and to influence the type of wood formed. Foresters cannot eliminate knots and also achieve optimal growth but they can control type, size and frequency of knots by pruning (Allan and Higgs, 2001; Malimbwi 1984). Green pruning will give rise to light ‘live’ knots while natural pruning tends to give loose ‘dead’ knot. Pruning results in reduction in growth particularly at the base of the tree (Farrar, 1961; Larson, 1979), thus creating a more cylindrical trunk. However, lower branches can be removed without much effect on the stem form and growth (Jacobs, 1981). Working with *P. patula* in Uganda, Plumptre (1979) reported narrow rings and more denser wood after pruning and from this, he recommended early pruning for coniferous plantations in tropics to restrict the knotty core to as small as possible. Karani (1978), working on *P. patula* from Uganda stated that density and strength of the base log can be improved through pruning to half height or frequency less severe pruning. It is true that knots have a strong influence on wood quality. Knots have a pronounced influence on wood utilization, affecting not only saw logs and veneer bolts but also pulp production (Pinkard,and Beadle, 2005).

2.2.1.7 Thinning

Thinning is a felling made in a stand at any time between establishments and the initiation of a regeneration cutting or clear felling in which trees removed the same species as the trees are favoured. Thinning is done for several reasons; the major ones are (Evans, 1992):

- To reduce the number of trees in a stand so that the remaining ones have more space for crown and root development encourages stem diameter increment and so reach usable size sooner.
- For stand hygiene both to remove dead, dying, diseased, and any others trees which may be a source of infection for, or cause damage to, the remaining health ones and reduce between tree competition to avoid stress level which may encourage pest and disease attack.
- To remove tree of poor form so that all future increment is concentrated only on the best trees and to favour the most vigorous trees with good form which are likely to make up final crop.
- To provide an intermediate financial return from sale of thinnings.

In Tanzania a preliminary analysis of the *P. patula* thinning experiments carried out in 1970 revealed that *P. patula* diameter increment was uninfluenced by growing space before 6 or 7 years of age and so thinning before that age might end up to loss in total volume production (Forest Division, 1970). In response to Micsski`s work, an amendment of technical order 17 for *P. patula* was made. The amendment involved omission of an early first thinning and increasing the final stocking from 250 stems per hectare to 370 stems per hectare. The first and current thinning schedules (Technical orders No 17 and 24) are shown in table 1and 2 respectively (Forest Division, 1970).

Table 1: Thinning schedule for *Pinus patula* in Tanzania

Operation	Stem per Hectare	Site class I (Years)	Site class II (Years)	Site class III (Years)
Planting	1680			
1st thinning	1100	5.5	6	7
2st thinning	740	9.5	10	11
3st thinning	490	13.5	14	15
4st thinning	370	17.5	18	19
5st thinning	250	21.5	22	23
Felling		25.0	30	35

Source: Forest Division (1962).

Table 2: Thinning schedule for *Pinus Patula* in Tanzania

Operation	Stem per Hectare	Site class I (Years)	Site class II (Years)	Site class III (Years)
Planting	1680			
1st thinning	1100	9.5	10	11
2st thinning	740	13.5	14	15
3st thinning	490	17.5	18	19
4st thinning	370	21.5	22	23
Felling		25.0	30	35

Source: Forest Division (1970).

2.2.1.8 Current directives of spacing, pruning and thinning at Meru/ Usa forest Plantation

(i) Spacing

Spacing has been varying from one forest to another and even within the same forest project (2.4 x 2.4 m to 3.0 x 3.0 m) but for most of the projects a spacing of 2.44 x 2.44 m is used. Currently at Meru/Usa forest plantation 3.0 x 3.0 m spacing for sawlog regime was adopted for pines. This spacing regime has been found to be cost effective in Zimbabwe and South Africa (Chamshama and Nshubemuki, 1998).

(ii) Pruning

Low pruning (1.5 – 2.0 m above ground) is carried out to provide free access into the forest plantation and reduce risk of fire. High pruning is carried out to produce knot free timber that should ideally fetch a higher price than timber full of knots. Higher prices from knot-free timber are sufficient to cover the compounded pruning costs, but currently is not the case in Tanzania (Chamshama and Nshubemuki, 1998). Table 8 show the pruning schedule for *P. patula* in Tanzania.

Table 3: Pruning schedule for *Pinus patula*

Pruning operation	Site class I			Site class II			Site class III		
	Age	H	H_p	Age	H	H_p	Age	H	H_p
1st	4	5.5	2.7	4.5	4.9	2.4	5.5	4.0	2.0^+
2nd	6	9.8	5.8	6.5	7.3	4.6	7.5	6.1	3.7^*
3rd	8	13.7	8.2	8.5	10.4	6.1	9.5	7.9	4.9^*

Where + = Whole crop, * = Selective, H = Mean height, H_p = Pruning height.

Source: Forest and Beekeeping Division (2003).

(iii) Thinning

Thinning schedule for *P. Patula* shown in Table 2 was practiced 33 years ago. This thinning regime was found to be not cost effective. A study conducted by Chamshama and Nshubemuki (1998) on thinning schedule for *P. patula* to examine costs for thinning and to shorten the rotation age. The following recommendations were made regarding funds as the main constraint:

- For existing stands, thinning should be done at the age of 11 years to 1111 stems per hectare,
- Adopting a spacing of 3.0 x 3.0 m (1111 stems per hectare), without thinning and rotation age of 24 years,
- Adopting a spacing of 3.0 x 3.0 m (1111 stems per hectare), and one thinning at age of 15 years,
- Selective low and systematic thinnings have very similar volume out turns.

Also the Forest and Beekeeping Division was advised to study the findings and revise technical order 24 of 1970 as soon as possible. The new thinning schedule for *Pinus patula* was developed (Table 4).

Table 4: Thinning schedule for *Pinus patula* in Tanzania

Operation	Stem per Hectare	Site class I (Years)	Site class II (Years)	Site class III (Years)
Planting	1111			
1st thinning	650	9.5	10	11
2st thinning	400	13.5	14	15
Felling		15	20	25

Source: Forest and Beekeeping Division (2003).

2.2.2 Tree pests and diseases

Diseases of trees are infectious and thus can cause epidemics unless controlled. Control relies on accurate diagnosis, knowledge of life cycles and information on potential loss to value of forest affected (Crous, 2005). The best defense against diseases is a well managed and healthy community of trees living in equilibrium with one another and suited to the environmental factors of the site.

Forest plantation pests pose the greatest threat to *P. patula* plantations. *P. patula* has relatively succulent needles and is frequently preferred by polyphagous insects to other pines such as *P. radiata* and *P. elliottii* (Lindelow and Bjorkman, 2001). The insect fauna of *P. patula* plantations is more varied and more numerous than that of other pine species in Malawi and East Africa. Sucking insects (Hemiptera) can cause some local damage resulting in die-back of infested leaders and other shoots, loss of photosynthetic area by browsing and premature shedding of needles (Rolando and Little, 2005). The proceeding sections discuss different plantation pests and diseases which affect tree growth.

2.2.2.1 *Pineus boerneri* (Adelgidae): Pine woolly aphid

This is an exotic pest and native in America. It was accidentally introduced to Kenya and Tanzania in the late 1960s. About 41 species of pines which have been introduced in Eastern and Southern Africa and nearly 30 species are recorded as furnishing food for the pine woolly aphid (Madoffe, 1989). *Pinus patula* and *P. kesiya* appear more susceptible to attack than other pines grown in East Africa as shown in Table 5. Nymphs and adult suck plant juice from needles, shoots or stems of pine and cause shoot deformity and loss of height growth. Excess plant juice excreted by pine woolly aphids as honey dew is favourable medium for growth of black sooty moulds on foliage, shoots and stems (Diekmann *et al*., 2007).

Table 5: Susceptibility of host plant to feeding injury by *Pineus boerneri* at two locations

Host plant species	Zimbabwe	Tanzania
	Susceptibility rate	
Pinus kesiya	H	H
P. caribaea var bahamensis	M	-
P. caribaea var caribaea	T	T
P. arizonica	T	-
P. Patula	M	M
P. oocarpa	T	M
P. elliottii	M	S

H = highly susceptible; M = moderately susceptible; S = slightly susceptible and
T = tolerant.
Source: Madoffe (1989) and Odera (1991).

2.2.2.2 *Eulachnus rileyi* (Lachnidae): Pine needle aphid

This needle infesting aphid of Holarctic origin was for the first time discovered in Zambia, in the late 1970`s but the species has subsequently spread to many parts of southern Africa where pines are grown. Like the pine wooly aphid, this species also attacks most of the common growing pines in this region although *P. patula* to be particularly susceptible. Combined attack of *P. boerneri* and *E. rileyi* especially towards the end of dry season could have much more serious consequences (Katere, 1984).

Heavy infestations of pine needle aphid cause needles to turn yellow and drop prematurely, resulting in growth reduction. It can be detected due to presence of foliage or stems covered with white, wax masses, deformed shoots and black sooty mould (Brokaw and Thompson, 2002).

2.2.2.3 Defoliation of *Pinus patula*

Losini (2004) found that there was a defoliation of *P. patula* by a loop caterpillar *Xanthisthisa tarspina* at Olmotonyi block in Meru/Usa forest plantation. The compartments 1, 2, 7 and 23 were affected by these defoliators. The compartments in the affected block are located in areas with low rainfall and shallow soils. This area is marginal for *P. patula*. The growth of *P. patula* in Olmotonyi was unreliable with rainfall less than 1000 mm, especially on upper slopes. Also the species is very intolerant in area with high temperature (FBD, 2000). According to Losini (2004) numerous larvae were present on the forest floor and small numbers were hanging from foliage and branches. Many corpses showed sign of viral infection. By the end of the rains in 2005, the insect population had fallen dramatically and the trees had gained considerable crown cover (Haule, C. Personal communication, 2007).

X. tarsispina warren was associated with the Buzura outbreak in Malawi and Uganda, and in the case of the Malawi outbreak in 1963 it caused more severe damage over a wider area than in Uganda. The Malawi population crashed with very high mortality of larvae and pupae within a few days probably as a result of a polyhedrolysis disease. *X. tarsispina* has also been recorded as causing slight damage in Kenya and other parts of Tanzania (Raigosa, 1990).

2.2.2.4 Diseases affecting *P. patula* plantations

A research conducted at Meru/Usa forest plantation the results have shown that roots of species were infected with *Armillaria mellea* (Bakari, 2004). Reports of *A. mellea* to attack *P. patula* plantations earlier have been traced from Tanzania and Kenya (Brown, 1970). The symptoms include the death of the tree with formation of characteristic thick mycelial sheets under the bark of the roots and the base of the stem. Black bootlace – like rhizomorphs are also often found, either under the bark, on the outside of roots or spreading from soil. The disease may be spread by these or by root contact between health and diseased trees. As a result, deaths occur in patches, with the most recent ones on the outside. The fungus sometimes forms toadstool – like fruit bodies with a honey – coloured cap, white gills and a ring on the stripe. The basidiospores formed by these are airborne but do not appear to be important in spreading the disease (Wilkes, 1980).

A. mellea is wide spread fungus which often exists as a harmless associate of the roots of forest trees; however, it will invade the host if it is weakened or cut down. The disease, therefore, is associated with plantations established on exploited forest sites where fungus is harboured in stumps residues (Pawsey, 1980). In South Africa stumps *Parinari mobola* frequently form infection centre, from which the disease is spread to *P. patula*. Damage from *A .mellea* is seldom severe, except on wet sites with high infestations of the fungus and under adverse conditions of growth for the host (Leathers, 1991).

2.2.3 Environmental catastrophes

2.2.3.1 Drought

Pinus patula has reputation for being drought sensitive, but the evidence on the actual degree of sensitivity relative to other species is conflicting. Ochieng (1982) stressed that *P. patula* is so sensitive to rainfall that any extended period of drought usually results in a few deaths. Dyson (1979) made a survey of the effect of the drought in Kenya in1960/61 resulting from failure of the short rains in the latter end of the 1960 and the delay to the start of the long rains. Of 31 plantations in the highlands in which deaths due to drought were recorded 52% were *P. patula*.

Poynton (1984) stressed the importance of soil depth and its effect on the drought resistance of *P. patula*. Providing there is an adequate supply of moisture in the soil *P. patula* can survive periods of several months without rain. It seems likely that *P. patula* has a good ability to put down roots, which can tap moisture reserves at depth over wide area. In this case *P. patula* should not be planted in climate of extremely aridity and of low humidity. In areas of relative high humidity, especially in areas prone to mist, the species can survive a dry season for several months provided there is sufficient soil depth to allow a build up of soil moisture.

2.2.3.2 Wind damage

Pinus patula is susceptible to wind damage. This damage occurs as a stem breakage and loss of tops rather than as uprooting of the whole tree (as contrast wind damage in *P. radiata*, which tends to have a relatively small uprooting of the whole tree). This tendency for the stem to break exacerbated by previous mechanical damage. Knuffel (2001) has pointed out that after loss of its leader, which may caused by hail, buck or monkey damage, or even by the weight of birds perching on it. *P. patula* reacts by producing whorl of heavy branches, one of which takes over as the leader. However, the remaining larger lateral at the point of damage partially “strangle” the stem and this point becomes a zone weakness at wind break occurs in later years (Kirschbaum, 2000).

Le Roux (1988) noted that at Sabie in East Transvaal 90 percent of wind damage occur in *P. patula* plantations and only 10 percent in *P. caribaea*. Most of this damage occurred as wind break in 20 to 25 years old plantations. Adlard (1994) confirmed Le Roux’ findings in his observation that wind break were frequent in *P. patula* in plantations over 20 years of age on Aberdare Mountains near Nyeri in Kenya.

2.2.3.3 Frost and snow

Golfari (1983) notes that in Mexico *P. patula* can withstand up to 10 ^{0}C of frost. Provided that the tree has hardened off, frost will do little harm, but on sites where frost can green succulent shoots damage can occur with 4 to 5 ^{0}C of frost. Prutector (1980) has described how the adverse effects of a hot sun on hoar frosted seedlings in the nursery can be ameliorated by brushing the hoar frost off. In general frost damage is more likely to occur in nurseries rather than in plantations and intelligent siting of nurseries to avoid frost hollows can prevent damage. However, Paddeny (1986) attributed the splitting of the bark in *P. patula* leaders to differential shrinkage age resulting from cold nights following hot days in highlands of Kenya; though Fry and Chalk (1994) attributed similar in *P. radiata* to hail damage. *P. patula* is not often planted in areas of heavy snow fall and its horizontal to upward growing branches are not adapted to shedding snow. Reports from South Africa indicate that snow fall without an accompanying wind can result in breakage (Poynton, 1984).

2.2.3.4 Fire

Pinus patula seedling and saplings have a thick bark and have a reputation for being very sensitive to fire damage. Fire precautions tend to vary with the risk of combustion (Nigh and Love, 2004). In Angola at Cuima, a site with a severe 3 to 4 month dry season, fifteen metre fire-breaks are constructed round any 20 hectare block of planting (Knuffel, 2001). In South Africa there used to be a policy of planting fire breaks with growing species such as *Eucalyptus grandis*; the policy of sweeping up leaves in the break, possible at a time of cheap labour, was followed ground fire would also be kept out of the plantations (Ochieng, 1982).

Current thinking has moved away from the static approach to a dynamic one of the highly mobile fire crews on 24 hours stand by in the fire season, baked up by efficient fire look out network and good communications using short wave radio and a well designed system of roads. Fire breaks which always combined with a road are 20 to 30 meters wide and enclose an area of 200 or more hectares (Paddeny, 1986).

2.2.4 Tree damage by humans

The establishment of Meru/Usa forest plantation displaced people who resettled on boundaries these plantations. These people now graze their livestock in the plantations and cause damage to trees in process. Trees also are damaged by wild animals (Maganga and Wright 1991), wind (Munishi and Chamshama, 1994) and human beings (Maganga, 1996). A study on human damage to trees was conducted in 1991 to assess the extent and types of damage, to identify some factors that influence human damage to trees. Results showed that extent of tree damage by human in stands ranged from 34% to 100% (Maganga, 1989).

The types of damage detected were debarking, debranching, slashing, cutting and their combinations. Debarking of pine trees of age 0-5 is done purposely in the compartment being under taungya system in order to kill trees. Damage to trees by humans is mainly due to three reasons: need for poles, firewood, encroachment into the forest plantation, and grazing domestic animals in the plantation (Maganga and Ng`ona, 1996). Tree damage affect quality, stocking and yield of the tree stand in the compartment.

2.2.5 Site classes

According to Malimbwi (1997) site is collective environmental factors such as rock soil, climate and vegetation that characterize an area on the ground. Foresters are interested in site productivity for land use allocation and developing plans, choice of species for planting and forecasting the growth of a managed forest especially plantations (Isango, 1994). Goelz and Burk (1996) consider site index as an intrinsic property of the site and that the observed height at the base age is an estimate of the true site index. A more meaningful site index requires that the degree of dominant trees remains constant over time (Magnissen and Penner, 1996). Significant variation in the degree of dominance may bring inconsistencies in the use of site index curves.

2.2.5.1 How site affects tree quality and productivity

Site characteristics that affect tree quality and productivity include soil depth, texture, moisture, and fertility, along with topography (Kalaghe and Mansy, 1989). On the whole, deep soils are better for tree growth than shallow soils because they potentially have a greater nutrient supply and water-holding capacity. Topography affects tree growth largely because of its influence on soil depth and moisture availability. Because gravity pulls soil particles and water downhill, soil depth, nutrient supply, and water supply usually are greater on bottomlands, lower slopes and benches than on steep slope ridge tops (Knudson *et al*., 1970).

Site preparation is carried out with objectives of securing survival, quality and rapid early growth of trees. This improves soil moisture relations and reduces weed competition hence increases water infiltration and storage (Mhando *et al*., 1993). Site preparation such as complete cultivation (ploughing and harrowing) improves the survival, early growth and quality of planted trees. This technique is suitable in terrain conditions of less than 10% slope as this would improve productivity of the second and subsequent rotations (Macfarlane *et al*., 2001). Mechanical site preparation should not be carried out when the soil water content is at field capacity as this may result in significant soil compaction, associated with increased bulk density and decreased macro pore space (MacRoberts, 2003). These changes result in reduced infiltration capacity, internal movement of soil water, aeration and increased mechanical resistance of soil to root growth (Raulier, *et al*., 2003). Hence site productivity in reduced. Appropriate pitting is necessary as the reduced soil strength of large pits enables early and fast root regeneration. This ensures rapid creation of contacts with soil moisture and nutrients (Sharma, 2002; Nigh and Love, 2004).

A site with limited nutrients affects survival, growth and quality of tree growth. Nutrient deficiencies especially in latosols like nitrogen, phosphorus and boron are serious problem to tree survival, growth and quality (Maliondo and Chamshama, 1998). Fertilization at planting is carried out on nutrient deficient sites to improve early survival, growth and quality of trees through provision of readily available nutrients which accelerates tree recovery thus survival and growth after field planting (Magnussen, 2003). Forest fertilization is gaining prominence with the extension of plantations into more marginal sites and the need to enhance tree growth and maintain productivity of second and subsequent rotations (Garcia, 2002).

2.2.5.2 Dominant height development

Dominant height is defined as the average height of the 100 fattest trees per hectare.

Development height over age is usually used in site classification since it is affected by silvicultural treatments. Spurs and Barness (1980) found that for a given species at a given age dominant height is closely related to the capacity of a given site to produce wood of that species. The basic assumption underlying the use of height/age relationship for site indexing is that a stand of a given species at given age and height always yield approximately the same volume under the same silvicultural treatments and site conditions.

2.2.5.3 Site and measure of site quality

Forest site quality or site productivity is defined as the sum total of all the factors affecting the capacity to produce forests or other vegetation. The factors include climatic factors, soil (edaphic) factors and biological factors (Spurs and Barness, 1980). Forest site quality determination in terms of physical outputs like volume of round wood, enables the forest manager to perform economic evaluation. Hence forest site quality determination facilitates decision – making on investments like afforestation, reaforestation regeneration and silvicultural operations like pruning as well as disinvestments like harvesting (Aust and Blinn, 2004). The estimation of the forest quality is needed for all tracts of land which differ in productivity, that is land units or land classes.

Ideally forest site productivity of a piece of land could be determined based on observation made on climatic and edaphic factors. Gessel (1967) suggested that forest site productivity could be expressed in terms of yield by treating yield as function of climate, soil, properties, topography or landform, age, biology (including animals and plants) and geology. Since observed tree growth is a reflection of its physiological responses to biological and biological conditions, embodying both influences, yield is required in Gessels yield expression. This would have been readily accommodated if the physiological reactions of the tree species to various environmental factors were known (Hauser *et al.*, 2001). With such knowledge it would be possible to forecast the tree species behaviour including its yield production under various combinations of the environmental factors. Although Kramer's approach is plausible, no model has been developed in this line because the real world is complex (Haywood *et al*., 2003).

Site productivity is based on measurements made on stand variables or site and stand variables, and then the values obtained are used in the model to express site productivity.

The method applied in determining forest site quality are categorized as 'direct' and 'indirect' depending on the variables embodied in the model being used in such exercise (FAO, 2003). A method is said to 'direct' when an applicable model correlates site productivity to some forest stand variables which are normally easily and cheaply measured. The indirect method entails evaluating site productivity by using site (physiographic) properties, vegetation (phytocenologic) or a combination (biophysiographic). Most of the models express the relationships between site index and site properties through functions which have been established by regression analysis. The common environmental factors which have been used in the model are climates, soil and topography. Irrespective of the ultimate approach used in evaluating site quality, the initial determination requires using a direct method by making some measurements of some attributes of tree growth from which direct methods can be developed. Therefore indirect methods are complementary rather than being substitutes for direct methods.

2.2.5.4 Approaches to site quality expressions

(i) Environmental factors

Soils, climate, fauna and flora affect tree growth, but their complexity makes it difficulty to apply them effectively in the measure of site quality (Eisenbies *et al*., 2004). Soil has been used as site classification. Roe (1935) published general relationship between site index and soil type for various cover types of lakes states in USA.

(ii) Indicators of plants

The use of plant species and communities as indicators or phytometers of site quality was mooted as early as 1892 (Lacey and Ryan, 2000). The approach entails classifying the understorey vegetation into types followed by investigation or the relationship between each type and site indices of wood species. When the phytometers site index correlation is validated; the vegetation types are used in determining the site indices of plantable land units. The assumption embodied in this approach is that the differences in composition and growth of understorey vegetation are associated with the natural drainage moisture fertility status and soil types (Gent *et al*, 2000). The use of existing understorey vegetation has been criticised on the ground that the effect of fire, drought, grazing, land preparation treatment during stand establishment and other disturbances on such vegetation make the approach invalid. This led to development of the 'habitat type' approach which is based on the potential climax vegetation (Mgeni, 1986).

(iii) Volume production

Hanzalik (1941) suggested the use of height times basal area divided by number of trees per hectare for even aged fully stocked stands. The main advantages of this method are that volume is the primary interest in forest management. But the main drawbacks is that volume can very much be influenced by silvicultural treatment of the stand and initial density.

(iv) Tree height

The basic assumptions underlying the use of height/age relationship for site indexing is that a stand of a given species age and height will always yield the same volume under the same silvicultural treatments (FAO, 2001). This is not always true due to some factors already mentioned above. For the site classification it is assumed that dominant height is affected by site factors only (Hauser *et al*., 2003).

2.3 Assessment of stand stocking

2.3.1 Stocking

In a forest plantation trees are planted for some purposes. However, though forest plantations are normally planted so that all possible area has trees growing on them, the site may not be fully occupied (Moulton and Hernandez, 2003). Apparently this is so at planting when trees are small, but also very wide initial spacing lead to much less than the fullest use of the site ever being made (Kooistra, 2002).

There is no minimum stocking, but in round figures, stocking at planting of less than 600/ha for fast growing species eucalypts and less than 900/ha for pines would be inadequate for proper plantation (Evans, 1992). Where the number of trees at planting is well below the above figures a plantation is only partially stocked, or if below 300/ha poorly stocked. The situation in many forest projects in Tanzania is that thinning operations do not follow the schedules as a result, stands are either overstocked and/or thinning is delayed unduly. Adopting a wide spacing would mean a later and merchantable thinning. Munishi and Chamshama (1994) found that overstocking was a major factor in increasing the risk of wind damage of *P. patula* at Kiwira Forest project.

2.3.2 Planting spacing in forest plantation

Planting spacing plays an important role in tree growth, influences costs of various operations and the quality and quantity of wood produced. Spacing affects tree growth by influencing competition for nutrients, moisture and light between trees and weeds (Iddi *et al.*,1996; Oreilly *et al*., 2002). The initial spacing may wind throws, taper, malformation, branch size and angle, costs of various operations such as planting, beating up and weeding, timing of thinning, selection of final crop, and rotation age (Evans, 1982; Forest Division, 1982).

2.3.3 Effect of spacing on stand development

2.3.3.1 Effect on tree survival

Malimbwi *et al.* (1992) assessed *P. patula* spacing experiment located at Rongai, northern Tanzania and found that survival percent increased with spacing. Before canopy closure, survival is normally independent of spacing. Canopy closure which sets in early in closer spacing contributes to a higher and longer period of competition, resulting in greater number of deaths.

2.3.3.2 Effect on branch diameter

The size and frequency of knots are important factors that influence the desirability of wood for lumber (Mohammed, *et al*., 2005). The size of knots is controlled by branch size while frequency is controlled by their number. Larger knots reduce the strength of lumber. Malimbwi *et al*. (1992b) found that the branch diameter of *P. patula* increased significantly with spacing. The increase in branch diameter may affect timber quality and strength due to knots. Evans (1992) observed that *P. patula* has persistent branches and pruning must be done if clear timber is desired.

2.3.3.3 Effect on height growth

Mishra and Gupta (1993) reported that in most cases, in experiments with pine species, the mean height of the stands increases with increasing spacing. Malimbwi *et al*. (1992b) showed that height growth for *P. patula* increased significantly with spacing.

2.3.3.4 Effect on diameter growth

Ola Adams (1990) reported that wide spacing results in greater diameter growth. In evaluation of effect of spacing on diameter growth of *P. patula*, Malimbwi *et al*. (1992a, b) found that mean breast height diameter increased significantly with increasing spacing. Wide spacing increase mean tree diameter which may or may not be advantageous depending on the markets.

2.3.3.5 Effect on basal area production

According to Ola Adams (1990), Mishra and Gupta (1990), greater total basal area production results from closer spacings. For *P. patula* spacing an experiment conducted at Rongai, Malimbwi *et al*. (1992a) found a significant increase basal area production with increasing spacing.

2.3.3.6 Effect on volume production

Total yield and woody quality determine the total income from a stand. Tomlinson *et al*. (2002) show that greater volume production results from closer spacings. Wider spacings reduce total volume production especially in short rotations since for longer period a site is not fully occupied (Evans, 1982; Pardos *et al*., 2004).

2.3.4 Diameters distribution

Unimodal is characteristics of the even aged stands. In unimodal distributions a distinction is made between left skewness and right skewness also kurtosis has to be defined. The unimodal diameter distribution is mainly fitted by the beta function. Beta function is simple and any form of diameter distribution can be fitted (Ponder, 2002). Stem diameter and volume- diameter distributions are very much affected by thinning intensity. There is a general agreement that with increasing thinning intensity, there is an increasing shift of the dimension and volume from small and medium diameter classes into the higher diameter classes or right skewness (Radoglou and Rafttoyannis, 2003).

2.4 Assessment of stand yield

2.4.1 Quantitative assessment

Quantitative assessment of the forest plantation has mainly two objectives:

(i) To provide forecasts of timber production in the form of thinning and final felling at national, regional and local levels and to keep these forecasts updated.

(ii) To provide forest managers with stand maps and crop descriptions.

These parameters are important as input in making management plans (Clinch, 1980). To be able to obtain such information inventory has to be done. Common parameters used to describe blocks of even aged crops of a single species are area, age, number of stems per hectare, mean diameter, mean basal area per hectare, volume per hectare, mean annual increment (MAI), form factor and current annual increment (CAI) (Philip, 1983). This parameter does not describe the stand alone but in combination. Example, the number of stems per hectare is a useful description of the crop, but does not define stocking density. The stocking density can be explained well when age, height and diameter distribution are also judged. Compartment characteristics like volume per hectares are defined as mean values obtainable by sample plots placed on the compartment (Evans, 1992).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study area

3.1.1 Location

Meru/usa forest project is located at around 3°15`S and 36°38`E in Arusha region, Arumeru district, Northern Tanzania. The whole plantation project lies on the lower slopes of Mount Meru from the East where Usa block is located, with a little break, and the southwest to West where the main forest lies (Shayo, 2002). The project which is located 15 km from Arusha city has relatively good forest roads, which are accessible throughout the year. Arusha city is the nearest administrative and business centre for the region. It is also a market centre for forest produce from Meru/Usa forest project accounting for about 80% of total purchase (Mkumbo, 2001).

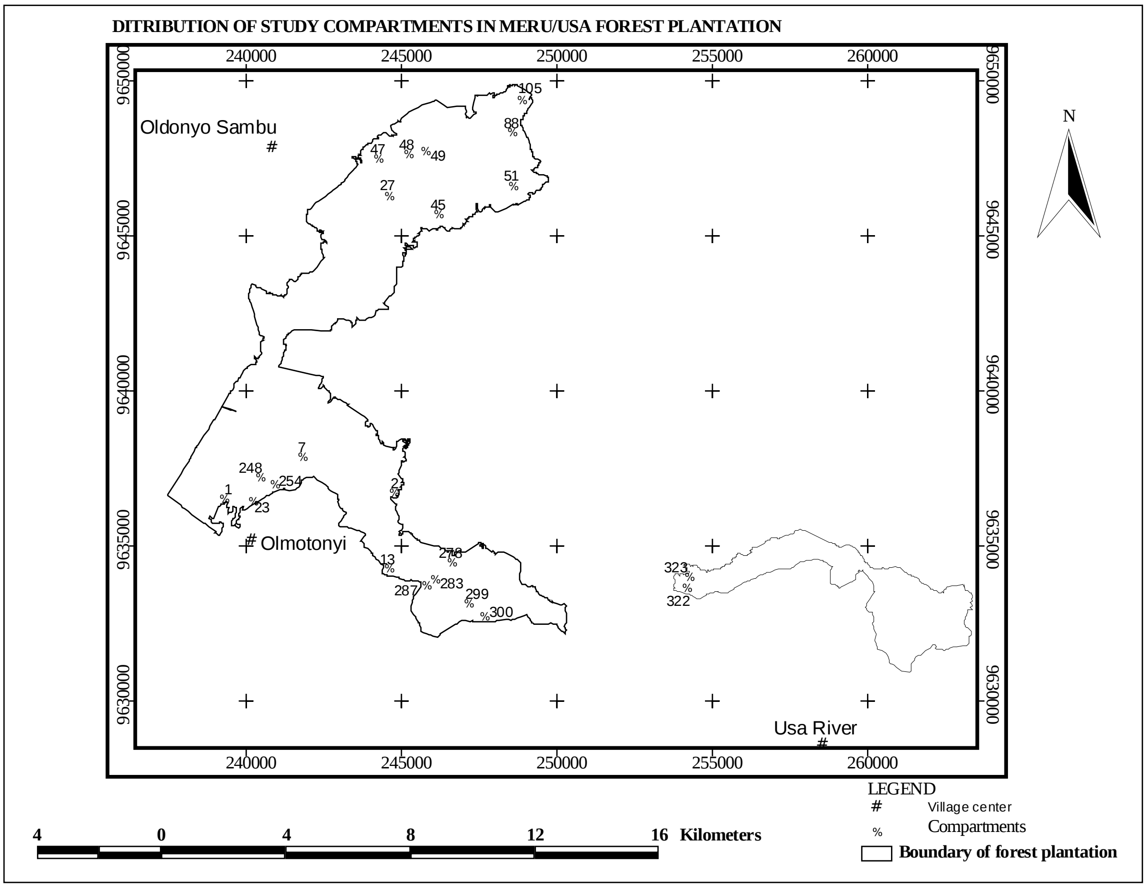

Figure 1: The Meru/Usa Forest Project plantation area showing the sampled affected and non-affected compartments by root disease and insect defoliators

3.1.2 Topography

The altitude of the forest plantation ranges from 1 400 to 2 600 m.a.s.l at Nadung`oro in Meru block. However majority of the forest plantations lie within ranges of 1 600 to 2 300 m.a.s.l. (FBD, 2003).

3.1.3 Geology and soils

The rocks are volcanic, overlain by soil originating from volcanic ash (Mduma, 2001). The soils are generally deep, black or brown, freely draining silts, which become very slippery when wet and easily eroded. They have a very low bearing strength and hence poor traction. During the dry season the surface layers become very powdery and dusty especially after being loosened by feet, animal hoofs and wheels. But they are fertile and thus have a high value for agricultural use (Tharcisse, 1998).

3.1.4 Climate

The climate is very seasonal but also varies between the eastern and western sides of the mountain. The area is marked with five months dry season from June to October followed by long rains and short rains. Short rains season occurs between November and December while long rains start in mid March and end by June. The annual average rainfall is 750 mm per year while temperature ranges between 15^0C and 28^0C (Chambo, 2004).

3.2 Sampling design, plot shape and size

Stratification by age classes followed by systematic sampling design was employed. The circular shape of each plot was adopted with an area of 0.04 ha both affected and none affected compartments. A total of 198 plots were sampled based on accessibility, budget and time available. This is equivalent to a sampling intensity of 2% calculated as: (198*0.04)/394.88*100 = 2%. Allocations of plots were proportional to the size of the areas of the two *P. patula* compartments.

The compartment maps of the affected and none affected compartments were traced from the plantation map by using transparent paper. Figure 1 is a map of Meru/Usa forest plantation area showing the affected and no-n affected compartments from which plots were located and measured. The decision was made on the number of transects to be established. After reconnaissance survey, number of transect to be laid were decided and drawn on the compartment map at equal intervals. The number of sampling units with equal intervals was plotted on the compartment map. The compass and field map were used to locate sample plots in relation to direction and location.

3.3 Tools and equipment

The field work was involved in measurements and observations. To accomplish this, the following tools and equipment were used; plantation map, a meter tape for measuring distance, caliper for measuring diameter of trees, suunto hypsometer for measuring height and a compass to direct the position of sample plots.

3.4 Primary data

3.4.1 Field work – data collection

The study was conducted in two *P. patula*, the affected by root disease and insect defoliators and none affected that was used as a control. The study also focused on management practices history of the two stands by collection of secondary data from available data sources.

Table 6 shows the distribution of plots per compartment in Meru/Usa forest plantation.

Table 6: Distribution of plots per compartments in Meru/Usa forest plantation

Block	Compartment Number	Size (Ha)	Planting year	Age (years)	Number of plots
Usa	322*	15.6	1997	10	8
	323*	14.8	1998	9	7
	300	8.9	2000	7	4
	299	8.7	2001	6	4
Olmotonyi					
	1**	10.8	2000	7	5
	2**	18.38	2001	6	9
	7**	12.3	1998	9	6
	23**	15.8	1998	9	8
	248*	19.9	1997	10	10
	254*	12.8	1997	10	6
	287	5.7	1997	10	3
	13	12	1999	8	6
	283	30	2000	7	15
	278	37	1997	10	19
Oldonyosambu					
	48*	10.3	1998	9	5
	47*	11.0	1997	10	6
	49*	33.6	1998	9	17
	105*	24.6	1999	8	12
	88	19.1	1999	8	10
	51	22.6	2000	7	12
	27	27.6	1999	8	14
	45	23.4	2000	7	12

Some notes to Table 6.

- Affected with root disease *
- Affected with insect (defoliators) and root disease **
- All plantations in the compartments are not thinned.
- Sampling intensity = 2%, plot size = 0.04ha.
- Age class of plantations in the compartments: 6 – 10 years.
- All plantations in the compartments are second rotation.

3.4.1.1 Inventory data

In each sample plot measurements were carried out as follows:

3.4.1.2 Data for quantitative assessment

(i) Diameters at breast height (DBH) for all trees were measured using caliper and recorded at 2 cm diameter classes and tallied according to prepared field record forms.

(ii) Three trees (small, medium and lager trees) were selected and their heights measured.

(iii) Four dominant trees were measured for total heights and diameter at breast height.

3.4.1.3 Data for qualitative assessment

In each established sample plot, 3 trees were randomly selected and measured for height and assessment for straightness, roundness and diseased trees were conducted.

(i) Straightness

For every selected tree a score of 1, 2, and 3 were allocated depending on the degree of straightness, as it has been seen by the assessor. The assessor stood about six meters from the base of standing tree to have a clear view of the whole stem. The stem was graded as follows: 1. Straight 2. Slightly 3. Crooked.

Forking tree within the height of 4m from the ground was grouped as crooked tree.

(ii) Roundness

Roundness for each tree was assessed by taking two measurements of diameter at breast height at different positions. The first measurement was minimum diameter (D_1) and the second was maximum diameter (D_2).

(iii) Diseased trees

In a sample plot each tree was examined for any indication of insect attack, signs and symptoms of disease. The number of diseased trees were counted and recorded.

3.5 Secondary data

3.5.1 The management practices history data

Data were collected from the management office by using existing documents and records at least five years back. Other data were collected from published and unpublished materials. Existing technical orders for spacing, pruning and thinning were consulted.

3.6 Data processing and analysis

Both qualitative and quantitative data analyses were done using the Microsoft excel and Statistical Package for Social Science (SPSS) programmes. The Microsoft excel was used to analyze quantitative data while SPSS was used to analyze qualitative data.

3.7 Site class

The dominant heights at various ages for dominant trees in the affected and non-affected compartments were determined. The site classes of each affected and non-affected compartments were determined by using site index curves which developed from polymorphic site index model.

$$H_{dom} = 1.32 * Site * [1 - \exp(-0.13 * age)]^{1.83}$$

3.8 Qualitative data analysis

(a) Straightness

All the data were coded in the computer for non – parametric analysis. The analysis mainly was cross tabulation of compartment against quality.

(b) Roundness

The coding of the quality was according to the percentage difference between the largest diameter and the smallest diameter at breast height.

[(Diameter difference)/ (Average diameter)] * 100 = Percentage difference

The grading of the difference was as follows: example 0 – 3% = 1, 4 – 7% = 2, > 7% = 3. The grading was based on the logs that are to be sorted for poles, plywood, veneer and saw logs.

(c) Combined qualities straightness and roundness

The two qualities were combined so as to determine the percentage of trees that have the good combination of two qualities. The combined score was taken as the sum of straightness class plus grade for roundness. For example the tree of quality 1 in straightness and quality 1 in roundness with total score of 2 was considered to be the best. The scores were put in the range as follows: 2 – 3 good, 4 – 5 medium, 6+ bad. Cross tabulation of the quality against compartment was done.

(d) Diseased trees

For each sample plot the diseased trees were identified. The number of diseased trees were counted and divided by the plot area. The result was the number of diseased trees per hectare. The arithmetic mean of diseased trees per hectare for all plots in a particular compartment was taken as mean number of diseased trees per hectare for that compartment.

3.9 Quantitative data analysis

Quantitative data analysis was based on all sampled plots.

(a) Number of stems per hectare (N)

For each plot the number of stems were counted and divided by the plot area to give the number of stems per hectare. The arithmetic mean of stems per hectare for all plots in a particular compartment was taken as mean number of stems per hectare for that compartment.

(b) Standing volume per hectare (V)

Volume for each sample tree was calculated per plot as:

$v_{ij} = ghf$

$V_i = \Sigma\, v_{ij} / a_i$

$V = \Sigma\, V_i / n$

Where:

v_{ij} = Volume of the j^{th} tree in the i^{th} plot.

V_i = Volume per hectare, m^3/ha in the i^{th} plot of size a_i, ha.

V = Average volume per hectare of the stand m^3/ha

n = Number of sampling units

f = Form factor of the j^{th} tree which is normally (0.45)

g = Basal area of the j^{th} tree in the i^{th} plot.

(c) Diameter distribution

The distributions of diameter classes were determined for each compartment by generating histogram in relation to the diameter class. Then a search for mathematical model to describe the diameter distribution was done by computing the value of kurtosis and skewness. These are measures of dispersion of a frequency distribution curve.

(d) Basal area per hectare (G)

Basal area per hectare (G) was calculated by proportion to plot area as: $G = \Sigma gi/a*n$ where: gi = cross sectional area of i^{th} tree in a plot, a = plot area, n = number of plots sampled.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Management history of two *P. patula* populations.

4.1.1 Silviculture of *P. patula*

4.1.1.1 Nursery

Meru/Usa forest project has central nursery size of one hectare and its annual production capacity of 800 000 – 1000 000 seedlings. The tree species currently grown mainly are *P. patula, G. robusta, Eucalyptus maidenii and E. saligna* others includes *Acacia melanoxylon, Casuriana* sp, *Olea africana*, *O. capensi* and *Juniperus procera.* The seeds used at the nursery were purchased from Tanzania Tree Seed Agency (TTSA) and some are collected from selected tree stands. According to the nursery calendar, seed sowing starts in July/August in order to time for the rain season in April. The *P. patula* seeds were soaked in cold water for 24 hours to hasten germination which takes about 21 days. The seeds were sown in a seedbed using broadcasting method, and then seedlings pricked out and planted in prepared pots which were filled with soil mixture. It takes 9 to 10 months to raise *P. patula* seedlings to the required size (30 to 45 cm).The soil mixture ratio used is 5:2:2:1 which means:

- 5 parts of top forest soil
- 2 parts of pine litter
- 1 part of sand
- 2 parts cow manure

In the soil mixture 125 grams of NPK fertilizer is added per unit volume of the mixture.

4.1.1.2 Planting

The land for planting was prepared through taungya farmers when preparing site for agricultural crops. Planting operations were done by labourers under supervision of forest field officers. It is done during rainy season at spacing 2.5 m by 2.5 m giving 1600 initial stems per hectare (Mmassy, 2002). The seedlings were loaded horizontally in a tractor/lorry and transported to the field. This loading is not recommended since some seedling are heated and damaged especially if transported at long distance (Chambo, 2004). The seedlings after reaching the field were unloaded and placed to the prepared site ready for planting. The pit size ranges from 1 – 2 feet. Survival in the field normally is more than 90% if planting techniques, tending operations, supervision of taungya system are done correctly and grazing is controlled. Also the seedlings planted should have undergone hardening off while beating up is done when survival is less than 90% (Tharcisse, 1998).

4.1.1.3 Weeding

This operation was done through taungya system, whereby farmers tend the trees while attending their agricultural crops. This operation requires high supervision since some taungya farmers kill trees in order to favour their crops, hence affect stocking of the forest. The system continues untill the canopy closure which prohibits growth of agricultural crops. In *P. patula* plantation the canopy closes within 3 to 4 years (Magayane, 2001).

4.1.1.4 Pruning

Pruning was done by taungya farmers under supervision of field officers. The tools used for pruning are swords and machetes which are not recommended for pruning. In the study it was observed that only access pruning was conducted, which means no high pruning was done. This operation like weeding requires high supervision because some taungya farmers over prune to favour their crops, thus affecting tree growth.

4.1.2 Site class distribution in Meru/Usa Forest Plantation

Results of site class, dominant height and age analysis are shown in Table 7.

Table 7: Distribution of Site class, dominant height and age per compartment in the affected and no – affected by root disease and insect defoliators in Meru/Usa forest plantation

Affected compartments				Non – affected compartments			
Compartments	Age	Site class	Dominant heights (M)	Compartments	age	site class	Dominant heights (M)
322	10	IV	16.20	300	7	II	14.8
323	9	III	17.30	299	6	II	13.20
1	7	IV	12.01	287	10	III	18.50
2	6	II	14.83	13	8	II	16.75
7	9	IV	14.90	283	7	II	15.73
23	9	III	18.56	278	10	III	16.78
248	10	II	19.00	88	8	II	17.1
254	10	IV	16.33	51	7	II	15.75
48	9	IV	14.50	27	8	III	15.89
47	10	II	20.33	45	7	III	14.87
49	9	III	16.42				
105	8	IV	12.33				

Three compartments in the affected compartments (323, 23, and 49) and four compartments in the non- affected compartments (287, 278, 27 and 45) were located at site class III as shown in Table 7. Three compartments in the affected compartments (47, 248 and 2) and six compartments in the non – affected compartments (300, 299, 13, 283, 88 and 51) were located in site class II as indicated in Table 7. Generally in this research it was revealed that sites II and III were suitable for the tree species. The problem was that management of the forest plantations in the compartments was not good. The village communities nearby practice illegal grazing, debarking, cutting of trees for house construction and firewood, by doing so they affect stocking of forest plantation. These factors affect survival, growth and quality of trees. Lastly six of the affected compartments (322, 1, 7, 48, 254, and 105) were located at site class IV as shown in Table 7. In this study it was revealed that the site was not suitable for tree species. The site may have been depleted with some nutrients which support performance of the tree species to match with the prescribed silvicultural schedules of tree species.

4.1.2 Factors affecting performance of Meru/Usa forest plantation

4.1.2.1 Illegal harvesting

Unauthorized felling of timber was experienced in some areas of the plantation, especially in Olmotonyi, Narok and Theme. Illegal harvesting affect stocking of the forest plantation since reduces the number of stems per hectare. The FBD (2000) reported that illegal harvesting is estimated to be equivalent to first thinning volume per hectare i.e. $50m^{3.}$ Frequency of cases apprehended and prosecuted per year is about 3 – 5.

4.1.2.2 Encroachment

Encroachment by animal herders and farmers due to land pressures was reported to be present in borderline areas. Encroachment affects stocking and yield of forest plantation.

According to FBD (2000) encroached areas in the forest plantation were estimated to cover an average of 10 hectare.

4.1.2.3 Other problems

Other problems which also hinder effective performance of Meru/Usa forest plantation include financial constraints, lack of silvicultural flexibility and low quality of raw material. Studies in some forest projects (Chamshama and Philip, 1980, Ahlback, 1988, Okama and Chamshama, 1988, Munishi and Chamshama, 1994) and personal observations in other forest projects show that thinning operations do not follow the prescribed schedules. The main reasons given for neglect of thinning being shortage of funds, lack of markets of unsawn thinnings and lack of processing plants (Chamshama, 1979; Ahlback, 1988). However currently it is not the case at Meru/Usa forest plantation because at present thinnings at Meru/Usa forest plantations are highly demanded due to shortage of wood products. The wood product users were limited with preferences and choice since is only thinnings were available at Meru/Usa forest plantation (Mushi, J.F. Personal communication, 2007).

4.2 Qualitative parameters of two *P. patula* populations

4.2.1 Straightness distribution

Results of straightness analysis are shown in the Table 8.

Table 8: Distribution of trees in the affected and non - affected by root disease and insect defoliators with classes of straightness in Meru/Usa forest plantation

Compartments	Classes of straightness		
	1 (%)	2 (%)	3 (%)
Affected	30.6 ± 4.8	44.8 ± 4.9	24.6 ± 3.7
Non - affected	25.4 ± 2.6	50.8 ± 5.7	23.8 ± 4.2

Note: 1 = straight, 2 = slightly, 3 = crooked

The weighted means of straightness for the affected compartments are 30.6 ± 4.8%, 44.8 ± 4.9% and 24.6 ± 3.7% in class 1, 2 and 3; while for non – affected compartments are 25.4 ± 2.6%, 50.8 ± 5.7% and 23.8 ± 4.2% in class 1, 2 and 3 as shown in Table 8 respectively. The percentage of straightness distribution per compartment for affected and non – affected compartments are more detailed in Appendix I.

Possible reasons for poor straightness can be due to poor site in which compartments were located, improper implementation of silvicultural practices, presence destructive agencies (wild animals and humans). Destructive agencies like animals for instance monkeys also contributed to poor straightness, monkeys break branches as they jump from one tree to another. Also they break the terminal leaders of the tree which cause the tree to develop multiple leaders. Humans damaged trees in the process of farming (taungya farmers), grazing by using swords, hoes and machetes. Also failure of the management to do proper cultural activities like weeding and sanitary slashing can result into crooked trees. Weeds can smoother and eventually kill trees by their cumulative weight, shading and growth habit – twining and twisting. Selective thinning would remove most of the crooked, leaning and badly formed trees. The field observations show that most of the compartments had not received high pruning.

4.2.2 Roundness distribution

Results of roundness analysis are shown in Table 9.

Table 9: Distribution of trees in the affected and non - affected by root disease and insect defoliators with classes of roundness in Meru/Usa forest plantation

Compartments	Classes of roundness		
	1 (%)	2 (%)	3 (%)
Affected	41.7 ± 5.1%	36.4 ± 6.1	21.9 ± 4.5
Non - affected	56.9 ± 7.1	27.6 ± 7.3	15.5 ± 4.1

Note: 1 = round, 2 = slightly, 3 = defected

The weighted means of roundness for the affected compartments are 41.7 ± 5.1%, 36.4 ± 6.1% and 21.9 ± 4.5% in class 1, 2 and 3; while for the non – affected are 56.9 ± 7.1%, 27.6 ± 7.3% and 15.5 ± 4.1% in class 1, 2 and 3 as pointed out in Table 9 respectively. In this study it was revealed that improper implementation of silvicultural practices and presence destructive agencies (wild animals and humans) affect tree roundness distribution in Meru/Usa forest plantation. The percentage of roundness distribution per compartment for affected and non – affected compartments are more detailed in Appendix II.

In examining the historical background of these compartments, it was found that all of them were planted using seeds from Tanzania Tree Seed Agency (TTSA). Roundness of the stem is a quality which is mostly genetically controlled but also depends on the environment. Williamson (2002) found out that of roundness depends on the orientation of slopes. He further noted that trees which were out of roundness were also leaning. This finding is in concurrence with those found in this study that the compartments which had relatively higher number of leaning tree had also higher percentage of trees with poor stem roundness. Wild and grazing animals are among the destructive agencies in stem roundness. Most wild animals scratch the bark up to the breast height level. Grazing animals like goats have tendency to debark trees hence create deformation.

4.2.3 Combined roundness and straightness

Results of combined roundness and straightness analysis are shown in the Table 10.

Table 10: Distribution of trees in the affected and non - affected by root disease and insect defoliators with combined grades roundness and straightness in Meru/Usa forest plantation

Compartments	combined grades of roundness and straightness		
	Good (%)	Medium (%)	Bad (%)
Affected	51.9 ± 5.0	32.6 ± 5.9	15.5 ± 4.9
Non - affected	60.9 ± 6.9	21.7 ± 6.4	17.4 ± 3.2
Overall weighted mean	56.4	27.2	16.4

The weighted means of combined roundness and straightness for the affected compartments are 51.9 ± 5.0%, 32.6 ± 5.9% and 15.5 ± 4.9% in good, medium and bad grades; while for non - affected are 60.9 ± 6.9%, 21.7 ± 6.4% and 17.4 ± 3.2% in good, medium and bad grades as pointed out in Table 10 respectively. The percentage of combined roundness and straightness grades distributions per compartment for affected and non – affected compartments are more detailed in Appendix III.

The qualities combined are among the most important ones that have to be observed as they are bases for the quality of a tree. Other things being equal a tree which is straight and has good roundness is a tree with high quality. Results show that overall weighted mean in compartments 56.4% of trees are good, 27.2% are medium and 16.4% are bad as shown in Table 10. The fact is that the forest plantation is young and will still be subjected to many thinnings, hence the quality of trees will be improved. Generally the stem quality in terms of combined straightness and roundness can be considered to be satisfactory as shown in Table 10. Qualities as assessed can be very much improved if proper sivilcultural techniques and cultural activities are followed. Most of the trees which have been found to have poor qualities were either in poor sites or were in the compartments which have not been properly maintained. So, quality of stands can be improved by establishing them in the good site and using proper tending techniques.

2.4 Diseased trees

Results of the average number of stems per hectare analysis are shown in Table 11.

Table 11: Average number of stems per hectare in the affected by root disease and insect defoliators compartments in Meru/Usa forest plantation

Compartment	Size (Ha)	Stems per hectare
322	15.6	263
323	14.8	186
1	10.8	240
2	18.38	158
7	12.3	96
23	15.8	94
248	19.9	133
254	12.8	129
48	10.3	215
47	11.0	113
49	33.6	49
105	24.6	42
Mean		143
Standard error of the mean		4.0

The overall mean of stems per hectare of diseased trees was 143 ± 4 per compartment as shown in Table 11. All forest plantations in the compartments are second rotation. The trees are affected with root disease *Armillaria mellea* (Bakari 2004). The site may have been depleted with some nutrients which support performance of the tree species to match with the prescribed silvicultural schedules of tree species. This situation caused the trees to be affected with root disease (Pawsey, 1980). The compartments 322, 1and 48 were more affected compared to the rest as shown in Table 11. Trees in these compartments may have been planted in poorest sites. In this study it was revealed that root rot disease affected stocking distribution in the Meru/Usa forest plantation. The disease kills trees and hence affects stocking in Mreu/Usa forest plantation. The root rot disease (*Armillaria mellea*) affects survival, growth and quality of trees. During the field work visual observations of the affected area were unhealthy.

4.3 Stand parameters of two *P. patula* populations

Stocking, basal area and volume results of inventory analysis are shown in the Table 12.

Table 12: Stand parameters in the affected and non – affected compartments by root disease and insect defoliators in Meru/Usa forest plantation

Compartments	Stand Parameters		
	Stems per hectare	Basal Area (M^2/ha)	Volume (M^3/ha)
Affected	569 ±137	17 ± 4	129 ± 35
Non - affected	709 ± 184	23 ± 2	153 ± 37

4.3.1 Stocking distribution

The mean stocking is 569 ± 137 stems per hectare for affected compartments while 709 ± 184 stems per hectare is found in the non – affected compartments (Table 12). The stocking distribution per compartment for affected and non affected compartments are more detailed in Appendix V. The distribution of stocking per hectare by diameter classes for two types of compartments in Meru/Usa forest plantation is shown Figure 2. The overall stocking generally shows a slightly left skewed shape of diameter breast height distribution which is not expected for forest plantation with active tree growth. In this study the reason for this is not known. Stocking of two types of compartments were not good when compared to the initial planting; most likely due to poor survival of tree, human damage, illegal harvesting and grazing, which are apparent Meru/Usa forest plantations.

The diameter classes 5 - 7.4, 8 – 10.4, 17 – 19.4 and 26 – 28.4 have high number of stems per hectare in the affected compartments than in the non – affected compartments (Figure 2). In this research it was observed that tree growth in the affected compartments may have better survival and less susceptible to root disease as compared to non – affected compartments. The diameter classes 23 – 25.4 have equal number of stems per hectare (Figure 2). Possibly the main reason in these two types of compartments, may be that trees were grown in the same site quality. Also may be progeny and provenance sources were the same.

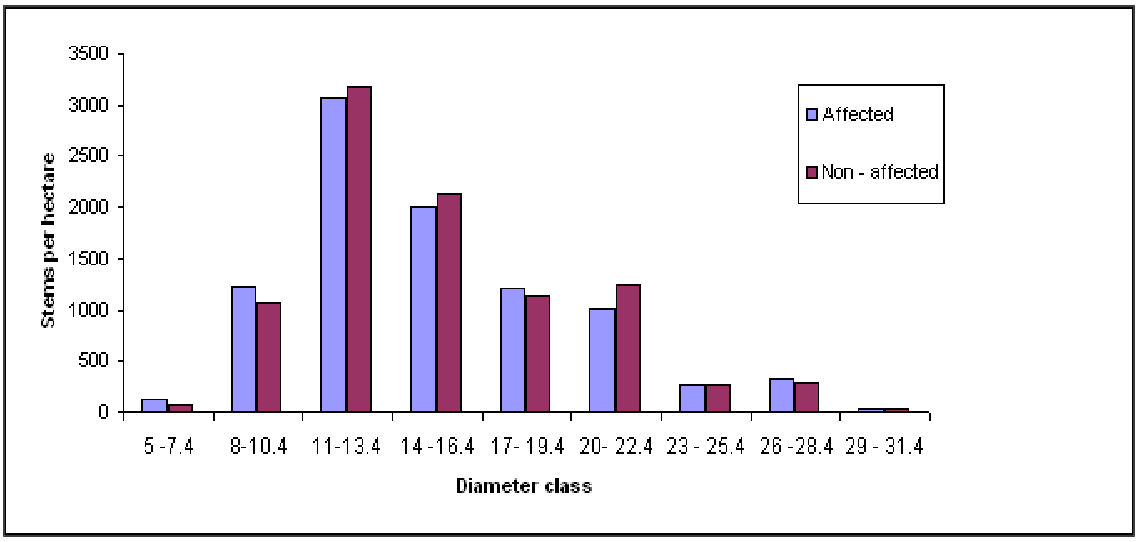

Figure 2: Stocking distribution in the compartments at Meru/Usa forest plantation

The difference in stocking between affected and non – affected compartments may be due to improper implementation of silvicultural practices, effect of drought, root diseases, defoliators and tree damage by animals. Visual observation during field work revealed the presence of monkeys, cows, goats, sheep, donkeys and diseased trees in the affected stocking in the compartments in various ways.

Chambo (2004) reported an average stocking of 945 ± 371 stems per hectare for unthinned compartments with age class 6-10 years in the Meru/Usa forest plantation. Mmassy (2002) found an average stocking of 878 ± 423 stems per hectare for unthinned compartments with the same age class in the Meru/Usa forest plantation. Also In yield table trees with age 6 – 10 years reported of an average stocking of 1306 – 1195 stem/ha in Meru/Usa plantations (Tharcisse, 1998). In this study, stocking was found to be less compared to other researchers as stated above. Improper implementation of silvicultural practices like taungya system, use of genetically inferior seeds may contribute to poor survival. According to Evans (1992), stocking of planting less than 900 stems per hectare at age class 6-10 years for pine would be inadequate for a proper forest plantation. In this study stocking was less than 900 stems per hectare in all compartments except compartments 283, 88, 27 and 45 as shown in Appendix V. It was also revealed that all forest plantations under the study were unthinned and have the same age class (6-10 years).

4.4 Yield parameters of two *P. patula* populations

4.4.1 Basal area distribution

The mean basal area in affected compartments was 17 ± 4 m^2/ha, while that of the non – affected compartments was 23 ± 2 m^2/ha (Table 12). The basal area distribution per compartment for affected and non – affected compartments are more detailed in Appendix V. Distribution of basal area according to diameter classes in the affected and non – affected compartments in Meru/Usa forest plantation (Figure 3). The diameter classes 8 – 10.4, 23 – 25.4 and 29 – 31.4 of basal area distribution were higher in the affected than in the non – affected compartments (Figure 3).

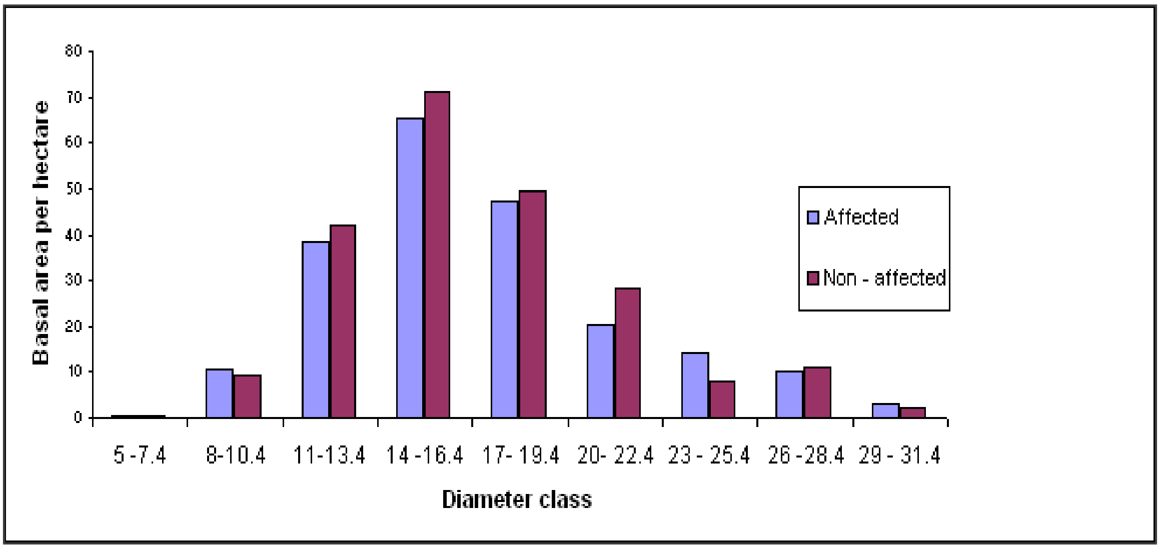

Figure 3: Basal area distribution in the compartments at Meru/Usa forest plantation

In forest plantation frequency distribution of basal area for different diameter classes is a very useful means of characterizing the structure of the forest stand (Philip 1983). There is clear evidence that the large number of trees in Meru/Usa forest plantations have diameter at breast height class 14 – 16.4 cm (Figure 3). This class represents the largest portion of basal area distribution when compared to other classes. It is likely that thinning of the small poor quality stems would bring the distribution to normal.

Magayane (2001) reported an average basal area of 25 ± 7 m^2/ha for unthinned compartments with age class 6 – 10 years in Meru/Usa forest plantation. Mmassy (2002) reported an average basal area of 29 ± 12 m^2/ha for unthinned compartments with the same age class in the Meru/Usa forest plantation. Also in yield table trees with age 6 – 10 years reported an average basal area of 18 – 23 m^2/ha in Meru/Usa plantations (Tharcisse, 1998). In this study it was found that basal area was less than those reported by other researchers stated above. The differences of in the two types of compartments may be due to effect of improper implementation of silvicultural practices, effect of drought, root disease, defoliators and illegal cutting of trees in the forest plantation. All these factors affect the growth of tree diameter hence contribute to basal area distribution. Malimbwi (1997) found that in young plantations, basal area normally ranges from 10- 20 m^2/ha rising to 60 m^2/ha. Results of this study fall within the range for both types of compartments, but the differences between the two types of compartments may be due to the effect of improper implementation of silvicultural practices, presence of destructive agencies (wild animals and humans), root disease (caused by *Armillaria mellea*), drought, grazing and defoliators (*Xanthisthisa tarspina*) which affect survival and tree growth. All these factors affect site yield and productivity in Meru/Usa forest plantation.

4.4.2 Volume distribution

In this study it was found that the mean volume in the affected compartments was 129 ± 35m^3/ha while in non – affected compartments was 153 ± 37m^3/ha (Table 12). The volume distribution per compartment for affected and non – affected compartments is more detailed in Appendix V. Distribution of volume according to diameter classes in the affected and non – affected of Meru/Usa forest plantation is shown in Figure 4. The diameter class 20 – 22.4 cm of the volume distribution in the affected was higher than in the non – affected compartments (Figure 4).

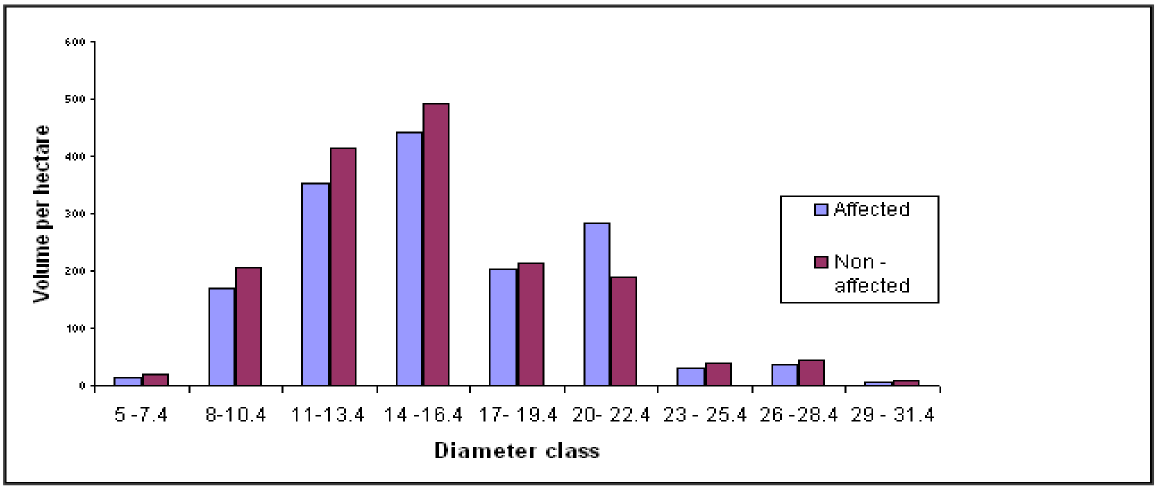

Figure 4: Volume distribution in the compartments at Meru/Usa forest plantation

Possibly the non affected trees in the affected compartments are located at better site and hence taller trees since the opposite trend is indicated for basal area (Figure 2).

Mduma (2001) reported an average volume was 160±48 m^3/ha for unthinned compartments at age class of 6-10 years in the Meru/Usa forest plantation. A study by Mmassy (2002) in the same forest plantations found an average volume was 173±39 m^3/ha for unthinned compartments with age class 6-10 years. In this study, it was found that volume was less compared to others researchers stated above. As already observed, is probably due to the effect of improper implementation of silvicultural practices, illegal harvesting, root disease and defoliators. Also this study revealed that the site yield and productivity have been decreased in Meru/Usa forest plantation.

Mkumbo (2001) reported that most of the compartments in Meru/Usa forest plantations were poorly stocked and the average volume was estimated at 200 – 300m^3/ha for matures trees. Also In yield table trees with age 6 – 10 years reported of an average volume of 175.0 – 220.3 m^3/ha in Meru/Usa plantations (Tharcisse, 1998). In this study it was revealed that the volumes for affected and non – affected compartment were less compared to that stated above. The causes may be due to the fact that the trees in the compartments being young and unthinned. Also in this study it was revealed that the growing stock in Meru/Usa forest plantations was poorly stocked when compared with initial stocking.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study showed that Meru/Usa forest plantation has suitable trees that may fetch good price at the markets if silvicultural practices are implemented accordingly. Also the Meru/Usa forest plantation compartments in which the study was executed are young of age class of 6-10 years and that they can be subjected to many proper silvicultural practices to improve wood quality.

It was observed that land preparation, weeding and access pruning are executed under supervision of field workers through taungya system in Meru/Usa forest plantation. Further, it was revealed that some taungya farmers kill trees to favour their agricultural crops. The supervision is inadequate due to insufficient the number of field workers.

Most of the compartments are under stocked compared with the initial planting, high pruning is not conducted and other silvicultural practices like pruning schedules are not done correctly.

Forest plantation structure shows a slightly left skewed shape of diameter at breast height distribution (DBH) which is not expected for forest plantation with active tree growth. Stand parameters like stocking, basal area and volume distributions in Meru/Usa forest plantation were affected with improper silvicultural practices, tree damage by humans, illegal harvesting, grazing, root disease and defoliators.

Tree straightness and roundness in Meru/Usa forest plantation is affected with improper silvicultural practices, presence of destructive agencies like wild animals, grazing animals and tree damage by humans. Tree roundness is mostly genetically controlled but also depends on the influence of the environment.

5.2 Recommendations

- Proper improvement of forest management especially silvilcultural practices and cultural operations like proper high pruning, taungya system, sanitary cleaning (slashing) should be practiced correctly. Crooked trees should be removed to improve the quality of stand. Appropriate selection of progeny; provenance, site and preventive measure against destructive agencies should be practiced to ensure producing good quality trees.

- Research should be conducted in the Compartments which have been affected with diseases to find stern measures on how to control them. Meanwhile preventive measure like removing all diseased trees that show signs of disease should be done to avoid spreading of the disease.
- Forest extension to local communities around the forest plantation should be given more emphasis in order to create their awareness of forest plantations. Also the local communities should be encouraged to adopt and practice agroforestry.

- People practising taungya system should be re- educated on proper pruning and weeding techniques and supervision should be intensified. Proper pruning should be practiced by using pruning saws. Also forest guards who are responsible for patrolling, supervision of taungya system and pruning in Meru/Usa forest plantation should be given better monetary incentives.

- Law of enforcement should be used whenever necessary.

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APPENDICES

Appendix 1: Distribution of trees per compartments in Meru/Usa Forest plantation with classes of straightness

(a) Distribution of trees in the affected compartments with classes of straightness

Compartment	Classes of straightness 1 %	2 %	3 %	Number of trees observed
322	29.2	45.8	25	24
323	28.6	42.9	28.6	21
1	26.7	33.3	40	15
2	22.2	44.4	33.3	27
7	11.1	61.1	27.8	18
23	37.5	45.8	16.7	24
248	36.7	50	13.3	30
254	33.3	38.9	27.8	18
48	13.3	66.7	20	15
47	33.3	44.4	22.2	18
49	38.9	36.1	25	36
105	35.3	41.2	23.5	51
Weighted mean by number of observations	30.6	44.8	24.6	
Standard deviation (S)	9.17	9.63	7.15	
Standard error of the mean (SE)	4.8	4.9	3.7	

Note: 1 = straight, 2 = slightly, 3 = crooked (b). Distribution of trees in the non- affected compartments with. classes of straightness

Compartment	classes of straightness 1 %	2 %	3 %	Number of trees observed
300	20	40	20	12
299	25	41.2	33.3	12
287	22.2	66.7	11.1	9
13	33.3	38.9	27.8	18
283	28.9	40	31.1	45
278	22.8	50.9	26.3	57
88	30	56.7	13.3	30
51	19.4	61.1	19.4	36
27	26.2	52.4	21.4	42
45	22.2	55.6	22.2	36
Weighted mean by number of observations	25.2	50.8	23.8	
Standard deviation (S)	4.56	9.91	7.19	
Standard error of the mean (SE)	2.6	5.7	4.2	

Note: 1 = straight, 2 = slightly, 3 = crooked

Appendix 2: Distribution of trees per compartment in Meru/Usa forest plantation with classes of roundness

(a). Distribution of trees in the affected compartments with classes of roundness.

Compartment	classes of roundness			Number of trees observed
	1 %	2 %	3 %	
322	37.5	50	12.5	24
323	33.3	42.9	23.8	21
1	33.3	26.7	40	15
2	37.1	33.3	29.6	27
7	66.7	11.1	22.2	18
23	54.2	20.8	25	24
248	43.3	43.3	13.3	30
254	38.8	27.8	33.3	18
48	33.3	46.7	20	15
47	44.4	44.4	11.1	18
49	38.9	41.1	19.4	36
105	41.2	37.3	21.6	51
Weighted mean by number of observations	41.7	36.3	21.9	
Standard deviation (S)	9.81	11.75	8.59	
Standard error of the mean (SE)	5.1	6.1	4.5	

Note: 1 = round, 2 = slightly, 3 = defected

(b) Distribution of trees in the non - affected compartments classes of roundness.

Compartment	Classes of roundness 1 %	2 %	3 %	Number of trees observed
300	75	8.3	13.3	12
299	50	25	25	12
287	77.8	11.1	11.1	9
13	44.4	33.3	22.2	18
283	57.8	15.6	26.7	45
278	66.7	14.1	15.8	57
88	60	33.3	6.7	30
51	50	41.7	8.3	36
27	57.1	33.4	9.5	42
45	41.7	41.7	16.7	36
Weighted mean by number of observations	56.9	27.3	15.4	
Standard deviation (S)	12.20	12.65	7.08	
Standard error of the mean (SE)	7.1	7.3	4.1	

Note: 1 = round, 2 = slightly, 3 = defected

Appendix 3: Distribution of trees per compartment in Meru/Usa forest plantation with grades combined roundness and straightness.

(a). Distribution of trees in the affected compartments with Grades combined roundness and straightness.

Compartment	Combined grades			Number of trees observed
	Good %	Medium %	Bad %	
322	41.7	50	8.3	24
323	42.9	47.6	9.5	21
1	40	20	40	15
2	48.1	29.6	22.2	27
7	61.1	22.2	16.7	18
23	62.5	25	12.5	24
248	66.7	26.7	6.7	30
254	55.6	16.7	27.8	18
48	40	46.7	13.3	15
47	61.1	27.8	11.1	18
49	52.8	30.6	16.7	36
105	47.1	39.2	13.7	51
Weighted mean by number of observations	51.9	32.7	15.5	
Standard deviation (S)	9.63	11.33	9.48	
Standard error of the mean (SE)	5.0	5.9	4.9	

(b). Distribution of trees in the non - affected compartments with Grades combined roundness and straightness .

Compartment	Combined grades			Number of trees observed
	Good %	Medium %	Bad %	
300	75	6.7	13.3	12
299	41.7	33.3	25	12
287	77.8	11.1	11.1	19
13	55.6	22.2	22.2	18
283	60	13.3	26.7	45
278	66.7	17.5	15.8	57
88	56.7	26.7	16.7	40
51	55.6	33.3	11.1	36
27	75	8.3	16.7	22
45	50	36.1	13.9	36
Weighted mean by number of observations	60.9	21.7	17.2	
Standard deviation (S)	11.90	11.05	5.57	
Standard error of the mean (SE)	6.9	6.4	3.2	

Appendix 4: Diameter breast height class (Dbh) with relation to Stocking, basal Area and volume distributions in the compartments in Meru/Usa forest plantation

	Affected compartment			Non - affected compartment		
Dbh class (cm)	Stems/ha	Basal area (M^2/ha)	Volume M^3/ha	Stems/ha	Basal area (M^2/ha)	Volume M^3/ha
5 -7.4	121	0.38	12.81	81	0.3	20.23
8-10.4	1225	10.58	169.22	1070	9.32	204.89
11-13.4	3076	38.62	352.81	3180	42.04	414.44
14 -16.4	2001	65.45	442.26	2120	71.16	492.84
17- 19.4	1204	47.09	203.44	1143	49.32	215.23
20- 22.4	1013	20.26	282.12	1236	28.13	190.17
23 - 25.4	263	14.26	30.43	273	8.02	40.25
26 -28.4	332	10.1	36.52	295	11.14	45.41
29 - 31.4	45	3.02	5.07	32	2.18	7.5

Appendix 5: Stand parameters per compartment the Meru/Usa forest plantation compartments

(a). Stand parameters per compartment in the non - affected compartments.

Compartment	Volume (M^3/ha)	Basal area (M^2/ha)	Stems per hectare
300	21.66	23.43	456
299	152.4	18.65	412
287	236.69	28.86	408
13	149.08	19.63	1038
283	141.82	19.53	517
278	195.51	25.66	520
88	171.6	23.63	1033
51	178.92	25.6	669
27	166.59	22.99	1043
45	109.24	16.81	1000
Mean	152.35	22.48	709.6
Standard deviation (S)	57.072	3.75	283.89
Standard error of the mean (SE)	36.50	2.2	183.5

(b) Standard parameters per compartment in the affected compartments

Compartment	Volume (M^3/ha)	Basal area (M^2/ha)	Stems per hectare
322	161.99	17.63	478
323	164.74	20	593
1	49.84	8.78	165
2	93.35	14.48	439
7	60.42	10.13	804
23	108.07	14.08	791
248	170.96	22.12	543
254	136.72	19.35	667
48	159.2	21.13	590
47	208.3	23.91	233
49	187.86	23.62	778
105	51.19	10.36	744
Mean	129.39	17.13	569
Standard deviation	54.91	5.42	211
Standard error of the mean (SE)	34.5	3.8	137.4

Appendix 6: Site class, height and diameter breast height of dominant, intermediate and small trees per compartment in Meru/Usa forest plantation.

(a) Site class, height and diameter breast height of dominant, intermediate and small trees in the affected compartments in Meru/Usa forest plantation**.**

Compartments	Site class	Dominant		Intermediate		Smallest	
		Height (M)	Dbh (Cm)	Height (M)	Dbh (Cm	Height (M)	Dbh (Cm)
322	IV	16.20	27.46	14.37	19.13	12.07	11.07
323	III	17.30	25.42	16.45	18.42	12.85	11.85
1	IV	12.60	16.34	10.90	10.42	7.50	5.40
2	II	14.83	21.43	13.03	15.86	12.01	11.76
7	IV	14.90	20.31	12.58	15.86	11.16	13.03
23	III	18.56	20.13	14.87	15.53	12.68	10.50
248	II	19.00	26.12	16.50	17.69	13.75	11.74
254	IV	16.33	21.56	15.00	15.10	11.58	8.85
48	IV	14.70	23.40	13.07	16.80	11.80	12.40
47	II	20.33	26.00	17.83	18.00	14.83	11.66
49	II	16.42	25.91	13.58	17.52	12.11	11.76
105	IV	12.33	20.00	9.79	13.58	7.83	8.00

(b) Site class, height and diameter breast heights of dominant, intermediate and small trees in the non - affected compartments in Meru/Usa forest plantation.

Compartments	Site class	Dominant		Intermediate		Smallest	
		Height (M)	Dbh (Cm)	Height (M)	Dbh (Cm	Height (M)	Dbh (Cm)
300	II	14.8	26.95	13.87	18.97	13.00	11.20
299	II	13.20	21.87	12.75	16.37	12.02	10.80
287	III	18.50	25.70	16.66	19.33	12.66	13.63
13	II	16.75	23.33	14.75	16.38	10.58	10.51
283	II	15.73	21.24	14.16	15.88	12.51	10.49
278	III	16.78	25.44	16.10	18.65	13.13	11.80
88	II	17.1	23.94	15.65	16.62	14.00	10.31
51	II	15.75	23.85	14.41	16.17	13.00	8.79
27	III	15.89	23.52	14.60	16.86	13.25	11.15
45	III	14.87	21.20	13.54	14.45	11.95	8.89

(c) The table showing Site index and age in relation to dominant height.

Site index

Age	**15**	**18**	**21**	**24**	**27**	**30**
4	3.80	4.55	5.31	6.07	6.83	7.59
8	8.91	10.69	12.48	14.30	16.05	17.83
12	12.86	15.43	18.00	20.60	23.15	25.72
16	15.51	18.61	21.71	24.80	27.92	31.02
20	17.19	20.63	24.07	27.50	30.95	34.38
24	18.23	21.87	25.50	29.2	32.81	36.46
28	18.86	22.63	26.40	30.20	33.95	37.72

Appendix 7: Data for affected and non - affected compartments showing the values of skew ness, kurtosis and stocking at various ages in Meru/Usa forest plantation.

(a) Data for affected compartment showing the values of skewness, kurtosis and stocking at various ages in Meru/Usa forest plantation.

Compartment	Stems per (Ha)	Planting year	Maximum Dbh (cm)	Mode (cm)	Minimum Dbh (cm)	Coefficient Skewness	Coefficient Kurtosis
322	681	1997	27.7	16.3	10.9	0.5193	-0.0842
323	721	1998	25.6	19.6	11.4	0.0508	-0.1952
1	830	2000	16.6	11.5	5.2	-0.2865	0.1337
2	713	2001	21.4	15.4	10.7	0.2643	-0.1417
7	450	1998	21.4	15.4	10.7	0.2643	-0.1417
23	700	1998	20.1	15.7	9.5	-0.283	-0.379
248	937	1997	26.7	18.1	10.9	0.3653	0.1124
254	1054	1997	21.3	14.7	8.3	-0.0192	-0.2802
48	900	1998	24.2	15.8	11.8	0.2815	-0.4793
47	871	1997	26	17.8	11.7	0.1555	0.1102
49	875	1998	26.6	18.1	11.1	0.14	-0.0773
105	567	1999	20.3	15.4	8	-0.4138	0.1532
Mean	775		23.2	16.1	10	0.0865	-0.1058

(b) Data for non-affected compartments showing the values of skewness, kurtosis and stocking at

various age in Meru/Usa forest plantation.

Compartment	Stems per ha	Planting year	Maximum Dbh (cm)	Mode (cm)	Min Dbh (cm)	Coefficient Skewness	Coefficient Kurtosis

300	856	2000	26.9	15.9	11.1	0.2467	-0.3207
299	956	2001	21.9	13.7	10.9	0.2863	-0.469
287	950	1997	27.8	16.7	13.6	0.4426	-0.2607
13	925	1999	24.2	16	10.38	0.3612	-0.2012
283	973	2000	21.3	15.7	10.7	0.1289	-0.2216
278	957	1997	25.4	18.1	11.7	0.132	-0.0359
88	1028	1999	23.9	15.3	10.2	0.0799	-0.0837
51	1027	2000	24.3	17.6	9.7	-0.1909	0.0155
27	1042	1999	23.5	15.2	10.7	0.2523	-0.4774
45	1000	2000	21.2	15	7.9	0.0472	-0.0449
Mean	971		24	15.9	10.7	0.1786	-0.2099

Appendix 8: Field record forms for data collection

FIELD RECORD FORM I

LOCATION………………………………………………………………………………....

COMPARTIMENT NUMBER……………… AGE……………… AREA……………

PLOT NUMBER………………………………… PLOT SIZE ……………………….

DBH CLASS	NUMBER OF TREES	DBH CLASS	NUMBER OF TREES
5			
7			
9			
11			
13			
15			
17			
19			
21			
23			
25			
27			
29			
31			
33			
35			

THREE TREES	HEIGHT (M)
1 (small)	
2 (medium)	
3 (Large)	

FOUR TREES	DIAMETER (DBH) (CM)	TOTAL HEIGHT (M)
1		
2		
3		
4		

SAMPLE TREES	DBH (CM)	TOTAL HEIGHT (M)	MAXIMUM DIMETER (CM)	MINIMUM DIAMETER (CM)	STRAIGHTNESS 1, 2, 3	DECAY 1, 0
1						
2						
3						

Note: 1 Straight, 2 Slightly, 3 Crooked,

FIELD RECORD FORM IV

HISTORICAL DATA FOR EACH COMPARTMENT

MERU PROJECT

COMPARTMENT NUMBER ………………………BLOCK……………………….

YEAR PLANTED ……………………………………………………………………

SEED SOURCE ……………………………………………………………………

PLANTING STOCK ………………………………………………………………

ESTABLISHMENT METHOD

(a) Land clearing using taungya system ……….

(b) Land clearing by hand ………

(c) Mechanical land clearing ……….

(ii) Planting spacing …………………………………………………

(iii) Beating up (a) First beating up…………………………

(b) Second beating up……………………….

TENDING

Operation	Year	Remarks
(i) Weeding		
(ii) Pruning		
(iii) Thinning		

DAMAGE CAUSED TO PLANTATION DUE TO:
(a) Grazing ………………………………………………………………………………
(b) Game………………………………………………………………………………
(c) Insect and pests ………………………………………………………………………
(d) Occurrence of disease…………………………………………………………………