



The United Republic of Tanzania
Ministry of Natural Resources and Tourism

FOREST PLANTATION AND WOODLOT TECHNICAL GUIDELINES



Forestry and Beekeeping Division

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FOREWORD

Among the essential requirements for a vibrant and competitive commercial forestry sector is that nursery operators and tree growers of all scales – public and private – use the best possible planting materials and apply best practices to maximise the productivity and quality of plantations and woodlots. As wood markets in Tanzania continue to develop, demanding quality wood products, it will be those tree growers who apply best practices that will be well placed to benefit most.

These *Forest Plantation and Woodlot Technical Guidelines* were prepared to provide information on best silvicultural practices for the three main commercial plantation tree species grown in Tanzania – Pine, Eucalyptus and Teak. The intended audience includes large and small tree planters, extension agents and whoever is engaged in preparing training materials on commercial forestry. As such, the guidelines are intended to be used as a technical base for preparing other extension, teaching and management material.

This publication is meant to add value to previous papers published in Tanzania including the Technical Specification on Management of Forest Plantations in Tanzania, which was used as background document for the preparation of Technical Order No.1 of 2003, and the *Mwongozo wa Kupanda Miti Tanzania*, prepared by the Tanzania Tree Seed Agency. These new guidelines also incorporate tending techniques, pruning and thinning schedules as well as management practices used by the private sector plantation operators. The scope of the guidelines covers key technical considerations up until the stage of harvesting and marketing.

Forestry companies, public institutions, non-governmental organisations and development programmes are urged to maximise the use of these guidelines for the long-term benefit of the commercial forestry sector in Tanzania.

I would therefore urge the Forestry and Beekeeping Division to make sure that these guidelines are made available to all relevant stakeholders whenever needed.


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The Forestry and Beekeeping Division views these technical guidelines as the latest achievement in the quest for commercial forestry development in Tanzania. Adhering to these guidelines will ensure high productivity and quality of plantations hence contributing to solving the growing demand for wood raw materials in the country.

I would therefore encourage all stakeholder in commercial forestry plantations to make use of these guidelines for the betterment of the forestry sector in Tanzania.



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¹ The Forestry Development Trust was established by the Gatsby Charitable Foundation in 2013 through a Memorandum of Understanding with the Ministry of Natural Resources and Tourism, as an independent Tanzanian institution with a long term vision for development of the commercial forestry sector. In order to increase household income from timber resources in the short-term and increase asset valuations of timber resources in the medium term, the Trust aims to strengthen the ability and motivation of forest institutions (private and public) to provide services to growers that collectively improve wood volumes, quality and market access. Specifically, the Trust works to increase demand for, and supply of, an improved genetic resource base; increase demand for, and access to, improved input and output markets; and strengthen the enabling environment through sector insight and stakeholder coordination.

ABBREVIATIONS & ACRONYMS

°C	Degrees Centigrade
Cm	Centimetre
FAO	Food and Agriculture Organisation of the United Nations
FBD	Forestry and Beekeeping Division
FDT	Forestry Development Trust
FSC	Forestry Stewardship Council
GR	Green Resources Limited
Ha	Hectare
IAA	Indole acetic acid
IBA	Indole butyric acid
IPM	Integrated Pest Management
ISTA	International Seed Testing Association
ITTO	International Timber Trade Organization
K	Potassium
Kg	Kilogramme
KVTC	Kilombero Valley Teak Company
L	Litre
M	Meter
MNRT	Ministry of Natural Resources and Tourism
Mg	Milligram
N	Nitrogen
NAA	Naphthanyl acetic acid
P	Phosphorus
PFP	Private Forestry Programme
RCD	Root collar diameter
SAIF	South African Institute of Forestry
SPGS	Saw Log Plantation Grant Scheme
SPH	Stems per hectare
SUA	Sokoine University of Agriculture
TAFORI	Tanzania Forestry Research Institute
TFS	Tanzania Forest Services
TTSA	Tanzania Tree Seed Agency
TANWAT	Tanganyika Wattle Company
Yr	Yea

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1. INTRODUCTION

Historical context and role of plantation development

Plantation forestry in Tanzania (then Tanganyika) was preceded by nursery, species and provenance trials during the period 1891-1950. In the early 1950s, large scale forest plantations commenced in various parts of the country. At present, the total area of public sector plantations is 95,000 hectares (ha) while that of private industrial plantations is about 40,000 ha (Chamshama, 2011; MNRT, 2015a). The total area of private woodlots is estimated at 419,500 ha (MNRT, 2015b).

The justification for forest plantation and woodlot development in Tanzania and elsewhere include growth superiority (over 20 times utilizable timber) and product uniformity attributes over most natural forest tree species. Forest plantations also have higher stocking per hectare and the ability to provide affordable wood for industry and wood-based products for consumers (SPGS, 2009). This offsets pressure for wood production from natural forests and vulnerable forest ecosystems to allow them to be managed for conservation, protection and recreational purposes (FAO, 2006; Carle and Holmgren, 2008).

Importance of good silviculture and technical guidance

The success of any plantation or woodlot depends largely on the adoption of appropriate technical nursery and silvicultural practices, which consist of various treatments applied to maintain and enhance their utility for any purpose. These practices include: choice of species including seed source, method of regeneration, site preparation, initial spacing, planting, tending (i.e. weeding, pruning and thinning) and site management for the following rotation. Appropriate and timely silvicultural practices determine the pattern and quality of crop development thereby modifying both the quality and the quantity of end products (Smith et al., 1997). It is this effect on quality and quantity of the final wood products that makes silvicultural practices important in forest management. In addition, well managed forest plantations and woodlots can also contribute positively towards provision of environmental and social services and therefore to livelihood support (Carle et al., 2002).

The first technical guidelines for public conifer plantations were prepared in 1982 (Forest Division, 1982). In 2003, the Forestry and Beekeeping Division issued Technical Order No 1 on spacing, species-site matching, pruning and thinning of public sector forest plantations (FBD, 2003). In 2014, Tanzania Tree Seed Agency prepared nursery, establishment, management technical guidelines for plantations and woodlots (TTSA, 2014). Though these guidelines are more recent, they have not provided required detail on tending techniques and pruning and thinning schedules as well as management practices used by the private sector plantations.

Scope and target audience of guidelines

In light of the above, this document provides updated and consolidated silvicultural and forest health technical guidelines for public and private sector forest plantations and woodlots in Tanzania. The guidelines should be followed so that well-managed plantations and woodlots contribute to poverty alleviation, economic development and environmental stability.

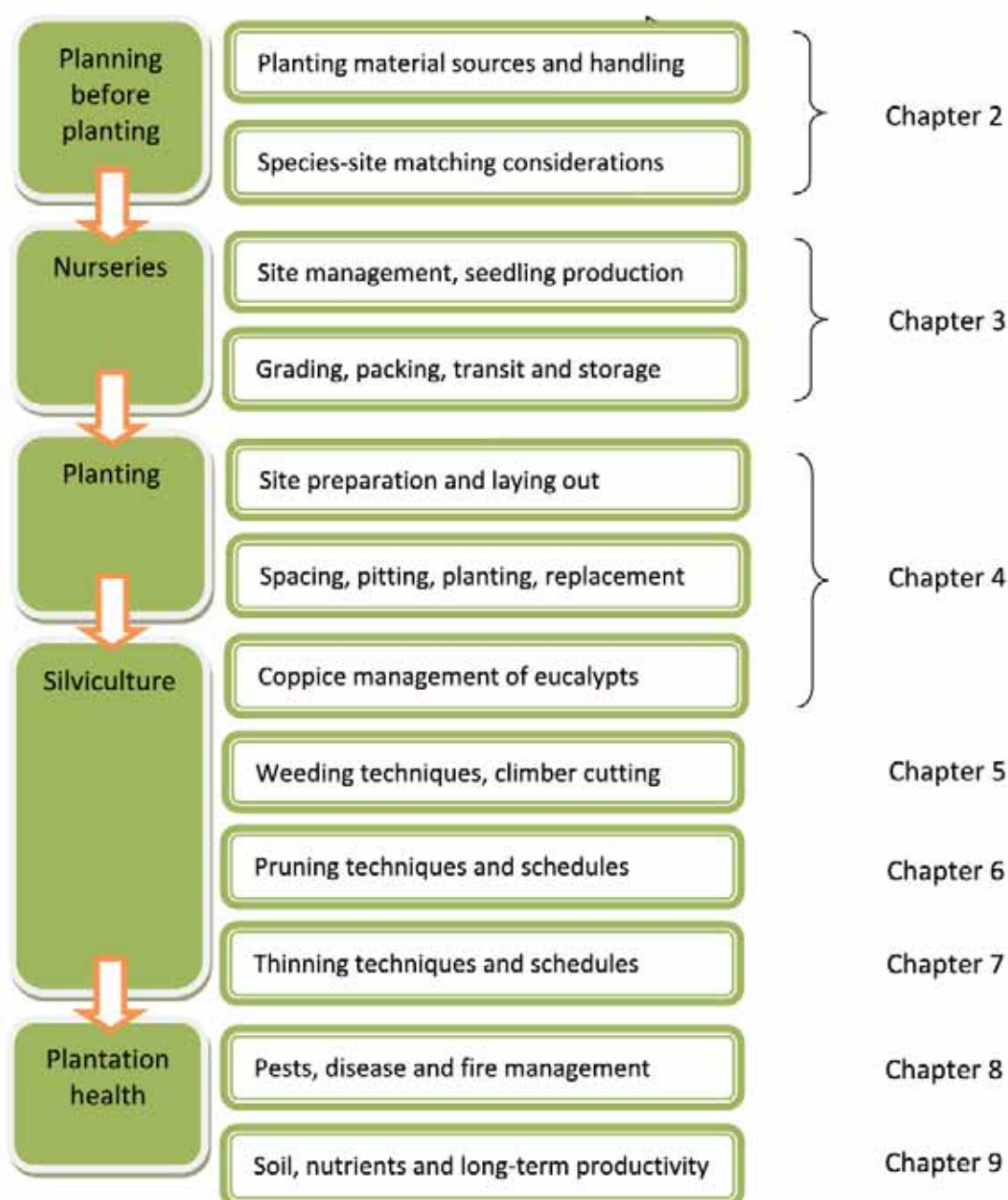
The intended audiences for the guidelines are plantation managers from the public and private sectors, forestry extension staff and all those involved in developing learning and teaching materials for tree growers. In this way, the guidelines are intended to be used as the technical

basis for developing other tailor-made material, such as teaching and extension material (e.g. videos, leaflets, posters, trainer guides) and area specific plantation management guidelines.

It should be noted that responsible management of planted forests should also consider institutional, policy, legal, economic, social and cultural aspects as well as road construction and timber harvesting aspects. However, these aspects are outside the scope of this document.

Reference guide

The diagram below provides easy reference to using the guidelines:



2. PLANTING MATERIAL AND MATCHING SPECIES TO SITE

2.1 Planting Material

2.1.1 Introduction

Plantations/woodlots must be established using genetically improved seed or vegetative propagules so as to produce fast growing trees of good form. However, there are only few seed orchards in the country and the seed supply does not meet the demand. Use of vegetative propagules is also limited. TTSA has only four seed orchards of *Pinus patula*, *Tectona grandis*, *Eucalyptus tereticornis* and *Grevillea robusta* currently producing seed (TTSA, 2010; Mtika, 2014). There is also a Tanzania Forestry Research Institute (TAFORI) seed orchard of *Cupressus lusitanica* as well as improved *Eucalyptus* clones. As a result, most plantations/woodlots continue to be established using seed of low genetic quality from older stands or TTSA unimproved seed source classes. Due to the use of seeds of low genetic quality, most public forest plantations as well as private woodlots constitute a significant proportion of trees of low productivity and quality (Chamshama and Nshubemuki, 2011) (**Figure 2.1**). On the other hand, the private sector plantations have in most cases been established from imported genetically improved seed and are generally of better quality (**Figure 2.2**).



Figure 2.1: Poor stand of *Pinus patula* from seed of low genetic quality



Figure 2.2: A good stand of *Pinus patula* from genetically improved seed at Kilolo, Iringa region

2.1.2 Vegetative Propagules

The main vegetative propagules used in forest plantations/woodlots are cuttings and single cell or organ used in tissue culture. For large scale production of cuttings, a hedge bank of the relevant species is established. Further details on vegetative propagation methods are in Chapter 3 (3.4.3).

2.1.3 Seed Sources

The following are the main sources of seed, which are all used in Tanzania (Zobel and Talbert, 1984; SPGS, 2009). Seed quality generally increases going down the list.

- (a) **Seed from unselected, natural populations:** This source is unimproved and is mainly used by small nurseries raising seedlings for personal woodlots or sale;
- (b) **Seed from individually good phenotypes:** Outstanding phenotypes from natural stands or plantations are marked and seed is collected from them. Seed from such trees will be well adapted to the areas in which they grow but will only yield limited volume improvement. There will also be some improvement of straightness and limb quality. A selection intensity of 12-25 trees per ha is recommended;
- (c) **Seed from good stands:** Collections are made from very best stands (plus stands) in the plantation. Gains are like collections from individual good phenotypes;
- (d) **Seed production areas (seed stands):** Seed stands have low genetic gain in volume and other quality characteristics and are thus supposed to be used as interim sources of seed and should be phased out as better genetic seed become available from other seed orchards. In seed production areas, poor phenotypes are rogued from the stand and the good trees are left to interbreed. Rogued trees should be removed from the stand to reduce potential dangers from pests as well as wildfires. Trees left must be vigorous, occupying the dominant and codominant position, straight, of desirable limbs and form, and free from insects and diseases. There is limited volume improvement. A seed stand should have at least 4 ha with 50 - 125 stems per ha (SPH) in order to be efficient. Seed stand management after thinning includes fertilization and spraying of pesticide to control insects. There should be an isolation zone (122-152 meters (m)) with low growing annual crops or a species that does not hybridize with the one in the seed stand;
- (e) **Seed from proven sources:** This involves going back to the source of a proven provenance after trials have proven that the species is suitable. Credible suppliers are needed to ensure that the sources are accurately matched; and
- (f) **Seed orchards:** These are areas managed to obtain greatest genetic gain. They may be vegetative i.e. formed from grafts, cuttings or tissue culture or seedlings. Individual tree selections of plus trees form an unrogued first generation seed orchard. These orchards are improved by roguing i.e. removal of the poor genotypes after progeny testing. Good general combiners from a number of orchards put together will form a greatly improved first generation seed orchard, while the best trees of the best families selected after progeny testing will form a second generation seed orchard. A seed orchard can have 25-40 clones/seedlings and an area of 2 ha or more depending on seed requirements. A pollen dilution zone of 122-152 m is required. Orchards must be located in the geographical range of the species, in accessible areas with flat or gentle slopes. Orchard care to increase seed yield includes fertilization, irrigation, sub-soiling, insect and disease control and fire protection.

2.1.4 Seed Collection/Procurement

Seed/fruits can be picked from the ground after shedding. This ensures collection of only mature seed. The area must be clean from bush and canvas or other sheeting material must be spread to catch the seed. Alternatively, seed/fruit can be collected by climbing manually and picked by hand, secateurs, knocking off with hooks, poles or rakes. For short trees, collection can be done from the ground or by shaking the branches.

Enough information must be collected concerning the stand from which the seed was collected and the date of collection to enable it to be located again. The description should also include the locality name; latitude and longitude; altitude, aspect, slope; climate; soil texture, pH, geology and colour; scientific/common name of the tree and other stand information about the source. The recipient can then trace back the seed if problems later develop, or if the stand is showing promise to merit further trial.

The amount of seed to be collected or procured from within or outside the country is computed based on the following information (SPGS, 2009):

- (a) Expected number of seed per kilogramme (kg) for the species;
- (b) The area to be planted (ha);
- (c) The number of SPH. With 2.5 x 2.5 m spacing, SPH equal 1600 obtained by dividing area of one ha i.e. 10,000 m² by 2.5 x 2.5; and
- (d) Beating up and transport losses (20%).

Thus, the number of kg required = (SPH x 1.2) x ha to be planted ÷ seeds per kg.

2.1.5 Seed Handling

Seed handling must be carefully carried out as poor handling will lower seed quality. Pods, cones, capsules and fleshy fruits should be handled carefully and placed in hessian sacks or boxes and taken to extraction plants as soon as possible to avoid heating and fermentation. Seed/fruit drying can be carried out in the shade or sun depending on the species. After drying, cones and capsules will release seed while threshing of pods is done using slender pole or using pestle and mortar. Pulpy fruits are squashed and macerated using feed grinders, concrete mixers or commercial macerators, then cleaned and dried. Seed of non-recalcitrant species like Pines and Cypress should be dried to 5±2% moisture content which is the internationally agreed standard. The seed of recalcitrant species like *Araucaria*, *Podocarpus*, *Syzgium* and *Trichilia* cannot be dried below 40% moisture content.

2.1.6 Seed Testing

Seed Suppliers must provide the following information about the seed: percent purity, germination percent, number of seed per unit weight, viability and for dormant seed, pre-treatments to break dormancy. Supplied seed must also be tested for germination to confirm the information given. In order that tests may be reproducible, it is important to adopt the seed sampling and testing procedures approved by the International Seed Testing Association (ISTA). The objective of germination test is to determine the maximum germination potential of a sample (and by inference the seed lot). Germination tests are carried out with "pure" seed samples in which randomly selected replicates are spread out evenly on a moist substrate in a nursery or controlled environment. Normally, a test consists of 400 seed, in replicates of 100, 50, or 25. Usually seed are spaced at a distance of not less than 1.5 – 5 times the diameter of the seed to be tested. This reduces fungal spread, should it occur.

An exception to the normal practice of testing a fixed number of seed is made with Eucalypts. It is difficult to separate whole seed from empty seed cases here and the test is made on a seed and chaff mixture. For Eucalypts and other very small seed, replicates of equal weight are used, usually 250 milligrams (mg).

The substrate for seed germination testing should be porous to allow aeration and moisture

retention, non – toxic, and free of fungi and other microorganisms, e.g. absorbent paper for very small seed, sand and vermiculite for large seed. The substratum should not be allowed to dry out but be moist at all times, but excessive moisture which forms a film around the seed must be avoided.

2.1.7 Seed Storage

Seed should be stored in sealed air tight containers such as metal, glass or plastic bottles or in sealed plastic bags of 400-500 gauge (10-13 μm). Seed of *Acacia* and *Eucalyptus* species can be stored for several years at room temperature without losing viability (SAIF, 1994). Seed of other species including most Pines and Cypress should be stored at low temperature (3-5°C). Seed of recalcitrant species like *Araucaria*, *Podocarpus*, *Syzygium* and *Trichilia* cannot be dried below 40% moisture content and should be stored at temperatures just above freezing for at least one year (SAIF, 1994, 2000).

2.1.8 Dormancy and Pre-Germination Treatments

When seed fail to germinate even when conditions are ideal until they undergo physical or physiological changes, they are said to be dormant. Information on dormancy and how to break it is to be provided by Seed Suppliers. Dormancy can be due to growth inhibiting chemicals (chemical dormancy), hard seed coat (seed coat dormancy), exposure to high temperature (induced/secondary dormancy) and incomplete maturation of the embryo (morphological dormancy).

Pre-germination treatments include (SAIF, 1994, 2000; Chamshama, 2014; Uronu et al., 2014):

- (a) **Cold stratification:** cold storage at 1-4°C will break induced/secondary dormancy;
- (b) **Hot water treatment:** seed are put in water (2 to 3 times the volume of seed) at 90°C and allowed to cool. This will break seed coat dormancy;
- (c) **Scarification:** nicking, chopping, drilling, and filing will break seed coat dormancy;
- (d) **After ripening:** seed are stored for 1-6 months to break morphological and embryo/chemical dormancy; and
- (e) **Chemical treatment:** soaking seed in indole acetic acid (IAA), gibberellic acid, hydrogen peroxide and potassium nitrate for prescribed periods of time will break embryo/chemical dormancy while concentrated sulphuric acid and hydrochloric acid will break seed coat dormancy.

2.1.9 Conclusion

Seed supply for forest plantations and woodlots is still largely obtained from sources other than seed orchards thus limiting the quality and productivity of these forests. On the other hand, use of vegetative propagules is limited. There are some efforts towards establishing seed orchards as well as increasing use of vegetative propagules. However, a major effort is needed to ensure local availability of genetically improved seed (seed orchard source) for the main forest plantation and woodlot species. As there is no need to “re-invent the wheel,” the best option would be to test seed from advanced generation seed orchards from neighbouring countries (with similar ecological conditions) in pilot plantations followed by large scale planting.

2.2 Matching Tree Species to Site

2.2.1 Introduction

Due to their evolutionary development, most tree species are generally site specific and careful consideration must be given to matching species to overall site characteristics (Zobel et al., 1987). This entails adequate knowledge of the climate, edaphic and topographic factors both in the natural habitat of the species (for an exotic) and in the proposed country of introduction. “Off-site” planting results in low productivity of various tree species as well as susceptibility to pests and diseases (Jackson, 1984; Zobel et al., 1987; FAO, 2001, 2002) (**Figure 2.3**). In addition to matching species to site, the plantation/woodlot owner must consider the possible markets for the intended end products.



Figure 2.3: Dried/dead improved *Eucalyptus grandis* due to a hard pan in Wasendo Range, West Kilimanjaro forest plantation

Extensive species/provenance trials (to at least half rotation length) spread over the areas to be planted should precede widespread commitment to even the most promising introduced species (FAO, 2002). In absence of such trials, performance in countries with similar ecological conditions may be used as a basis for selecting species/provenances for planting in pilot plantations.

Climate change might impact the agro-ecological zoning and needs to be observed in the medium and long term to possibly adjust recommendations on optimal growing ranges for the commercial species.

2.2.2 Tree Species and Site Matching in Tanzania

Table 2.1 shows tree species-site matching in Tanzania according to forestry zones (FBD, 2003). Species diversification is emphasized as it may serve as an insurance against pests, diseases and climatic fluctuations. Additionally, this may result in increased market security through species and product diversification. Forest Plantation Managers and Forestry Extension Officers should use this guide when recommending trees to be planted in forest plantation areas or by communities in various parts of the country respectively.

Table 2.1: Tree species-site matching according to forestry zones in Tanzania

Zone & Major Species	Alternative Exotic	Species Indigenous	Remarks
Lake Victoria <i>P. caribaea</i>	<i>Pinus tecunumanii</i> <i>P. kesiya</i> <i>Corymbia citriodora</i> <i>E. saligna</i> <i>Cedrela odorata</i> <i>Acrocarpus fraxinifolius</i> <i>Grevillea robusta</i>	<i>Antiaris toxicaria</i> <i>Maesopsis eminii</i> <i>Markhamia platycalyx</i> Syn. <i>M. lutea</i> <i>Milicia excelsa</i> <i>Hallea rubrostipulata</i> <i>Trichilia emetica</i> <i>Podocarpus usambarensis</i> <i>Khaya anthotheca</i>	Suitable for areas receiving more than 1600 mm mean annual rainfall
	<i>Albizia lebbbeck</i> , <i>P. kesiya</i> <i>Azadirachta indica</i> , <i>E. alba</i> <i>E. crebra</i> , <i>E. cloeziana</i> <i>E. melanophlora</i> <i>E. microtheca</i> , <i>E. camaldulensis</i> <i>Mellia azedarach</i>	<i>Faidherbia albida</i> <i>Acacia nilotica</i> <i>A. polyacantha</i> Miombo species (see Inland plateau)	Suitable for areas receiving less than 700 mm mean annual rainfall
Inland Plateau (None)	As for the Lake Victoria zone receiving less than 700 mm mean annual rainfall <i>E. camaldulensis</i> , <i>P. kesiya</i> <i>Casuarina equisetifolia</i> <i>Tectona grandis</i> (dry area provenance)	<i>Azalia quanzensis</i> <i>Dalbergia melanoxylon</i> <i>Julbernardia globiflora</i> <i>Pterocarpus angolensis</i> <i>Vitex keniensis</i>	Miombo covers 40% of the country. Thus future forestry development depends on this area
Highland Areas <i>P. patula</i> <i>Cupressus lusitanica</i> <i>E. grandis</i> <i>E. regnans</i> <i>E. saligna</i>	<i>Casuarina junghuniana</i> <i>Pinus elliottii</i> <i>P. kesiya</i> <i>P. taeda</i> <i>Cedrella odorata</i> <i>Cryptomeria japonica</i> <i>Cinamomum camphora</i> <i>Grevillea robusta</i> <i>P. radiata</i> (resistant strains) <i>E. botryoides</i> <i>Combrya citriodora</i> <i>E. globules</i> , <i>E. maculata</i> <i>E. maldenii</i> , <i>E. microcorys</i>	<i>Beilschmedia kweo</i> <i>Cordia africana</i> <i>Cephalosphaera usambarensis</i> <i>Fagaropsis angolensis</i> <i>Newtonia buechananii</i> <i>Olea capensis</i> , <i>P. usambarensis</i> <i>Vitex keniensis</i> <i>Ocotea usambarensis</i> <i>Olea capensis</i> <i>Juniperus procera</i> <i>Acacia sieberiana</i> var. <i>sieberiana</i> <i>A. seyal</i>	Rainfall over 1000 mm per year
Eastern Arc Mt. foothills <i>T. grandis</i>	<i>C. odorata</i> <i>Gmelina arborea</i> <i>G. robusta</i> <i>Terminalia superba</i> <i>T. ivorensis</i> <i>C. japonica</i>	<i>Brachylaena huillensis</i> <i>Entandrophragma stolzii</i> <i>K. anthotheca</i> , <i>Milicia excelsa</i> <i>Trichilia emetic</i> , <i>P. angolensis</i> <i>Sterculia appendiculata</i> <i>Dalbergia melanoxylon</i>	Rainfall over 1500 mm per year
Coast <i>P. caribaea</i> , <i>P. elliottii</i> <i>P. patula</i> ssp <i>tecunumanii</i>	<i>Dalbergia sissoo</i> <i>E. camaldulensis</i> <i>E. tereticornis</i> <i>C. equisetifolia</i>	<i>D. melanoxylon</i> <i>Rhizophora spp</i> <i>P. angolensis</i> <i>Sterculia appendiculata</i>	Other mangrove species also suitable Rainfall over 800 mm per year

Source: FBD (2003)

In plantation/woodlot establishment, the following mitigation measures must be observed as required by national laws, Food and Agriculture Organisation (FAO) planted forests voluntary guidelines and Forest Stewardship Council (FSC, 1996; URT, 2004; FAO, 2006; GR, 2008):

- (a) No cultivation should be carried out within 60 m from a water body;
- (b) Invasive alien species must be uprooted in the areas for planting and local communities should be informed of the problems of such species;
- (c) Rare, threatened and endangered species should be surveyed and if possible must be protected;
- (d) Sites of special interest should be identified, demarcated and mapped in collaboration with local communities. These include: marsh areas, burial sites, archaeological sites, spiritual sites and gullies; and
- (e) The maximum planting slope is 60%.

Further, it is important to identify the trees and their placing in the landscape and how they should be managed to produce the best environmental outcomes, i.e. minimising water use/increasing water use efficiency (Vanclay, 2008).

2.2.3 Conclusion

Species/provenances must be matched to the site for better production. Species diversification is key as it yields more diverse products and may have lower risk against pests, diseases and climatic fluctuations. Forest plantations/woodlot design should ensure biodiversity and soil and water conservation. It should take into account water use to produce the best environmental outcome.

3 TREE NURSERIES

3.1 Introduction

The nursery operations must be geared to produce good quality seedlings that will give high field survival and fast initial establishment. Timing of raising seedlings in the nursery is important so that seedlings are of the required age and size when planted out. Good quality seedlings produce root hairs quickly to access soil nutrients and moisture and thus cope with normal environmental stresses. On the other hand, low quality seedlings grow more slowly after field planting even when planted on a well prepared, good site. They also add to weeding and maintenance costs, and are more susceptible to diseases and insect pests. Thus seedlings that don't meet quality standards must be sorted out before packing. In the following sections, nursery techniques to produce good quality seedlings are discussed. These are general nursery techniques, not specific to any species. Nursery trials will indicate appropriate techniques for a given tree species.

3.2 Nursery Site Selection

Nursery site selection must be done with considerable care and caution. Many ecological and economic factors influence the success or failure of a nursery. A nursery site must be located with the realization that a perfect site does not exist and the choice of site will require compromise. A team approach for nursery site selection is probably best. A nursery is called flying if it is located on a planting site and is normally used for one season only, while a temporary nursery is used for a few years (< 5 years). A permanent nursery is established to supply seedlings to a large area in which afforestation will be carried out for many years and is the one discussed in detail in this chapter. Permanent nurseries have higher capital costs compared to the other two, but produce better quality seedlings.

Preferred nursery sites are those with favourable climatic and environmental conditions. Windy areas should be avoided to minimize windburn, desiccation effects and whipping of seedlings as well as disruption of irrigation sprays. Frost hollows and areas subject to cold air drainage should also be avoided. Maximum, minimum and average temperatures, the incidence and severity of hail and the occurrence of mist or drizzle which are conducive to disease outbreaks should also be considered (SAIF, 1994). Nurseries should be at least 40 m from a river and should not be placed in a wetland.

The nursery should be located close to major afforestation areas, to assure timely transportation of seedlings from the nursery to the field. Nurseries should also be within proximity to towns, power sources, telephone systems and major roads if possible.

For drainage control and mechanization, nursery beds should have gentle slopes (1-3° or 1 in 100) to allow rain to run off without eroding the soil. Flat sites are subject to flooding and should be avoided. In general, hilltops and valley bottoms are unsuitable. Locations on middle to lower slopes are preferable.

Soil in a nursery site intended for bare root seedling production should be deep (1-2 m), light medium loamy sand or sandy loam (15-20% silt) with permeable subsoil. Such a soil has a good air-water relationship, is easy to work, and does not crack on drying. Seedlings are easily lifted with minimum root damage. For containers, a supply of suitable soil must be near the nursery. Soil acidity or reaction (pH) is probably the single most important chemical property

of nursery soils. Optimum pH varies with the species, but for many, neutral or slightly acidic conditions are desired (Zobel et al., 1987).

The availability of sufficient clean water and of high quality (neutral pH as extremes result in damping off) all year round is essential. The water supply should be regularly monitored to determine whether it contains excess salts or pollutants. Water requirement will vary with growing medium and nursery type being used, but 10 litres (l) per m² nursery bed is a guide (SPGS, 2009).

Air pollution is a potential problem for nurseries located close to industrial areas. Pollutants such as sulphur dioxide or hydrogen fluoride must be monitored.

Nurseries require skilled and unskilled labour and must therefore be located close to cheap available labour sources.

Layout and Development of the Nursery

A nursery can be privately owned by a woodlot owner or business man selling seedlings to small growers or larger commercial ones with higher investment in infrastructure. About 1 ha (including space for office, sheds, storage areas, paths etc.) is needed for a nursery producing 1 million seedlings (SPGS, 2009). The nursery site must be cleared of trees, weeds, roots and stones and dug to 30 cm depth (GR, 2008).

For large, bare root stock mechanized nurseries, a rectangular arrangement (bed length 200 m +) minimizes time needed for equipment turn round. For container plant nurseries, a compact near square layout is desirable. There should be logical sequence of activities to ensure smooth flow, avoid bottlenecks and double handling (SAIF, 2000) (**Figure 3.1**). There should be no waste of ground.

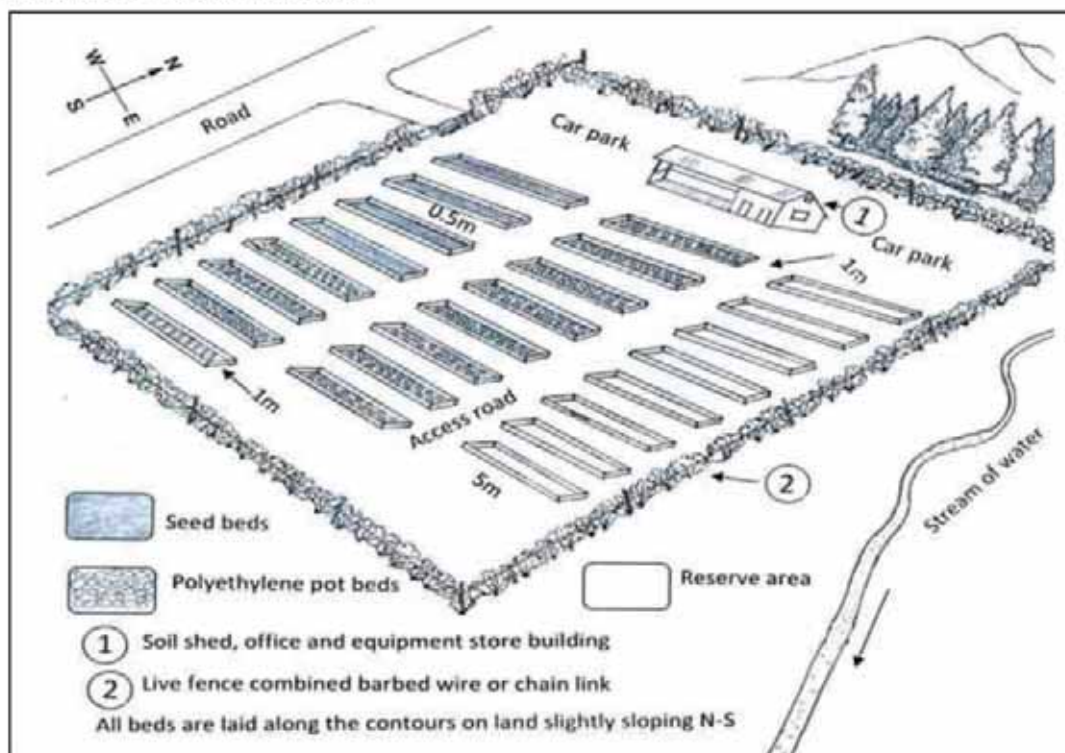


Figure 3.1: Example of a nursery layout

Natural drainage of the site should direct water away from media mixing and germination areas so that any diseases that develop in areas with older plants are carried away from newly germinated seedlings (Evans and Turnbull, 2004).

The nursery production areas are the ones set aside for actual growing of seedlings. This is on average 70 – 80% of the total area. For manual operations in the nursery:

- (a) Germination beds should be 1 m wide, 8 m long and 20 cm high, at the bottom a wire mesh is placed to control rodents followed by 5 cm of gravel, 10 cm of 50% sand and 50% forest soil and at the top 5 cm of sand (Uronu et al., 2014) (**Figure 3.2**); and
- (b) Transplant beds and Swaziland beds should be 1-1.2 m wide edged with cement bricks or timber. Optimum bed length should not exceed 20 m (SPGS, 2009). Swaziland beds are on an impervious layer.



Figure 3.2: Germination bed at Kawetire forest plantation

Blocks in a nursery should be separated by roads, paths and drainage ditches. Main access, paths and parking areas should be gravelled for all weather use. Where necessary, roads within the nursery should be gravelled for collecting seedlings. Nursery entrance and exit should be away from the growing section to avoid traffic moving through the production area (SAIF, 2000).

Buildings and other structures will be needed for various uses and should be as much as possible under one roof to reduce costs (Figure 3.4) (SAIF, 2000):

- (a) Water storage tanks;
- (b) Offices;
- (c) Store for small tools, sieves, pots, fertiliser, fungicides, seed etc.;
- (d) Vehicle and machine storage; and
- (e) Shelter for preparing potting mixtures, filling pots, seed extraction etc.

Irrigation system should be carefully designed. It should be placed near production areas to

reduce original and replacement piping costs. Irrigation can be manual, surface/underground pipes or overhead pipes leading to overhead rotary or oscillating sprays or static lines (**Figure 3.3**). Manual irrigation uses jerry cans or pipes (**Figure 3.4**). Surface pipes can be conveniently moved, removed or added but impede movement of vehicles. Underground pipes are more expensive to construct.



Figure 3.3: Watering of seedlings by sprinkler system at village nursery in Njombe



Figure 3.4: Manual watering of seedlings at village nursery at Kilolo, Iringa region

The nursery should be fenced using barbed wire/smaller sized mesh or live fence using thorny species like *Dovyalis caffra* to protect it from animals. Windbreaks should be planted on the windward side to reduce drying, eroding and abrasive effects of winds on growing seedlings. Every effort must be made to control weeds in and around the nursery as weeds may host insects and pathogens (SPGS, 2009).

3.3 Raising Tree Seedlings

There are two general methods of raising tree seedlings:

- (a) In containers (polytubes and trays with inserts) which are taken to the planting site and planting the seedlings with a ball of soil around the roots i.e. containerised system; and
- (b) In an open bed (Swaziland) from which seedling plants are lifted and planted with roots bare of soil i.e. bare root or naked rootsystem.

3.3.1 Production of Container Stock

Container Types and Sizes

Use of containers is especially necessary when planting in dry areas – seedlings start growing soon after field planting i.e. short period of shock after field planting. Choice of container depends on availability, cost and convenience. Container types include polythene tubes, seedling trays with inserts, metal tubes, veneer sleeves, reinforced paper, beer tins, bamboo pots, folded banana leaves etc. Polythene tubes and bags (pots) are however the main types of containers used in Tanzania and other East African countries. The size ranges 7 – 10 cm lay flat diameter and 9 – 15 cm long depending on species being raised (Evans and Turnbull, 2004; SPGS, 2009; Chamshama, 2014; TTSA, 2014). Seedling trays with inserts are to some extent used by some private companies. They may be polystyrene or plastic PVC of variable volume.

Polystyrene trays are porous and must be coated with an emulsion containing copper to prevent growth of roots that come into contact with the coating. Because of uniformity of the trays, operations such as filling and sowing can be fully mechanised. Each cavity has an opening at the base to permit aerial pruning of the roots and drainage. For both polythene tubes and seedling trays, generally, seedling size, field survival and growth tend to increase with container size but costs prohibit the use of too large containers.

Polythene tubes/bags have some disadvantages (Evans, 1992). First, time must be taken to remove or slit the container at planting otherwise root growth is distorted leading to instability of the tree.

Secondly, seedlings left too long result in root coiling. Normal root development is impaired resulting in instability problems. A lot of soil is also used which may be scarce and needs to be transported a long way. This method is also labour intensive.

Growing Medium or Potting Mixture

The soil for potting mixture is often imported from outside the nursery. The soil mixture should be light, cohesive, well aerated, water retentive and non-cracking on drying. It should contain adequate nutrients. A wide range of soil mixtures are being used in forest plantations and woodlots in Tanzania, some of which are shown in **Table 3.1**. The main components are top forest soil, pine mycorrhizal soil for Pine seedlings, cow manure and nitrogen, phosphorus and potassium (NPK) fertilizer. Other growing media which may be made locally or imported include peat moss, vermiculite, composted bark, coconut peat and perlite. A nursery at Them range, Meru forest plantation that just uses forest top soil states that seedlings are growing very well (**Figure 3.5**).



Figure 3.5: Mature *P. patula* seedlings raised using forest top soil at Them range, Meru Forest Plantation

Forest top soil should be collected during the dry season before nutrients leach out once rains start (SPGS, 2009). All components must be sieved before mixing. Potting mixture should be kept under shade as rain will leach some nutrients. It must be made up at least three months

in advance before use to ensure sufficient time for organic material to break down and nutrients to become fully available (GR, 2008).

Table 3.1: Examples of soil mixtures used in forest nurseries in Tanzania

Forest Plantation	Soil Mixture	Fertilizer
Meru forest plantation, Arusha	Pine 1. Forest soil 5 wheel barrows 2. Pine mycorrhizal soil 1 wheel barrow 3. Cow manure 2 wheel barrows	50 grams (g) NPK for the soil mixture
Meru forest plantation, Themti	Pine Forest top soil	-
Shume forest plantation, Lushoto	Pine 1. Forest soil 20 wheel barrows 2. Cow manure 4 wheel barrows	1 kg NPK for the mixture
Sao Hill forest plantation, Division I, Mufindi	Pine 1. Forest soil 5 parts 2. Clay 1 part 3. Pine mycorrhizal soil 1 part	8 g NPK per tin of mixture
TANWAT Ltd - Njombe	Pine 1. Black soil 4 wheel barrows 2. Pine mycorrhizal soil 1 wheelbarrow 3. Wattle spends 4 wheel barrows 4. Sand 1 wheel barrow	3 kg TSP
	Wattle 1. Black soil 5 wheel barrows 2. Wattle spends 4 wheelbarrows 3. Sand 1 wheelbarrow	3 kg TSP
	Eucalyptus 1. Black soil 5 wheel barrows 2. Wattle spends 4 wheel barrows 3. Sand 1 wheel barrow	3 kg TSP

The following are the main components of a potting mixture:

- Clay:** retains moisture and nutrients, makes pot – soil stick together;
- Sand/gravel:** improves soil structure for root penetration, drainage and aeration;
- Organic matter:** improves soil structure and retention of water and nutrients;
- Forest soil:** contains well decomposed organic matter and nutrients-also microflora and fauna necessary for circulating nutrients;
- Mycorrhizal soil:** to inoculate seedlings e.g. Pines; and
- NPK:** macronutrients as amendments.

A simple test for a good soil is to wet it and roll it between palms. A good soil should form a

roll but break if the roll is bent (SPGS, 2009).

The potting mixture may be sterilized by heating to 60°C for 30 minutes or fumigated using methyl bromide or formalin.

Container Filling, Sowing and Pricking Out

The soil is first sieved before filling and adding of fertilizers if necessary. Tubes are normally filled individually by hand. The potting mixture is first moistened and the soil is firmed while filling to make sure it keeps in the polythene tube. The rate of filling depends on container size and experience of the worker.

Direct sowing into containers

The Seed Supplier will provide recommendations on whether to sow directly into containers or use germination beds. Recommendations on pre-sowing treatments should be followed. Normally, direct seeding into pots is done for large seed. To give a reasonable chance of obtaining one seedling per container, more than one seed may be sown, as indicated in **Table 3.2**, depending on the germination percent (Gunn, 1998 in Evans and Turnbull, 2004). With less than 40% germination, seed should be sown in germination beds.

Table 3.2: Germination percent and number of seeds to be sown

Germination percent	Seeds sown per container
40-60	3
60-90	2
> 90	1

After germination, where more than one seedling occurs in a container, the surplus is pricked out into empty ones or new containers. Direct sowing allows undisturbed seedling growth and thus reduced stress. It also saves time, labour and money (SPGS, 2009).

Sowing into Germination Beds and Pricking Out

Small seed (e.g. Eucalypts) are mixed with 2 – 3 times their volume of fine dry sand for easy broadcasting (even and modest density reduces damping off incidence). Large seed are sown by dibbling with a stick. Large seed are line sown. Narrow depressions “drills” are made deep enough to allow the seed to be covered to twice its depth (GR, 2008). The spacing for Pine or Cypress seed should be 2 – 3 cm. Generally, seed are sown at a depth equal to its shortest dimension. Small seed are covered with a light dusting of fine sand free of weed seed.

Pricking out from a germination bed is either into pots/tubes or transplant beds. The practice is labour intensive and tedious. It requires good supervision and training. Poor pricking out may be associated with damping off. The age at which seedlings are pricked varies with species: Eucalypts should be transplanted when the first two pairs of leaves begin to develop; pine when cotyledons have opened out.

Lifting is carefully done with a pointed stick. The stick is also used to make holes deep enough to not bend the tap root resulting in J roots. Seedlings should be handled by their leaves. The seedlings are firmed by gently pressing the sides of the hole together. Transplants should be well watered and shaded for some days until they are settled in the new site.

The germination bed method is desirable under the following circumstances:

- (a) When very small seed is involved;
- (b) Expensive seed; and
- (c) Seed of low germination capacity (less than 40%).

3.3.2 Bare Root Seedling Production

The term bare root refers to plants grown in beds and lifted and transported to the planting site with roots not in soil or other medium. Two main ways of raising bare root seedlings are the use of boxes or Swaziland beds. For both types, overstocking must be avoided and a density range of 150-200 seedlings per square meter is recommended (Zobel et al., 1987). The main benefit of bare root seedlings is that they are cheaper to produce. On the other hand, they have low field survival where lower than expected rainfall has fallen.

Boxes

A typical open topped wooden box measuring 38 cm square and 12 cm deep with the bottom slatted with 1 cm gaps between slats to allow free drainage is used. Young seedlings are transplanted 5 x 5 cm (49 per box in 7 x 7 rows). Fortnightly intercutting between the rows is done with a sharp knife, each week in alternate direction; in addition to periodic lifting of the box or undercutting to prevent the roots through the slats resulting in the development of a dense fibrous root system. At planting out time, the boxes are taken to the planting site and each individual plant is removed and planted.

Swaziland Beds

Swaziland beds vary in size but are normally raised 10 cm above ground. The beds are made using the soil on site or an imported soil mixture. The bed is enclosed by cement blocks, bricks or wood and rests on a flat surface of compacted earth.

Seedling spacing in Swaziland beds is the same as in boxes. The beds are undercut once a week by drawing a length of steel wire (gauge 16, 18, 20 or 22 piano wire) along beneath it. The concrete blocks or wood serve to hold the wire at the right level. The wire may be tensioned in a tubular steel frame. The wire should be dragged by two men in alternate direction each week to prevent long roots being dragged horizontally without being cut.

At planting, seedlings may be put in carrying boxes with soil undisturbed or the soil is shaken off and roots puddled in clay thus avoiding transporting large amounts of soil. Seedlings raised by Swaziland beds should ideally be planted the same day due to susceptibility to desiccation during lifting, transportation and just after planting. Root exposure for up to 30 minutes can damage fine roots. To prevent the damage, dipping in clay slurry is recommended. Other ways of preventing root desiccation include soaking roots in bundles of dry grass, putting bundles in cloth bags with wet sphagnum moss, using wet sacks and keeping the plants cool in the shade. Seedlings raised in boxes or Swaziland beds may be prepared for planting as striplings or stumps.

3.3.3 Vegetative Propagation Methods

Vegetative propagation is a way of raising planting stock not involving seed. It results in genetic copy of the parent and includes cuttings, layering, budding, grafting, micro-propagation and tissue culture. Vegetative preproduction is used to:

- (a) Hasten introduction of genetically superior parents through multiplication of species whose seed are difficult to obtain or produce seed that are difficult to germinate; and
- (b) To conserve gene pools of rare or threatened species by building a clone bank of desirable genotypes.

Cuttings: Stemwood cuttings taken from small branches or twigs are commonly used. Cuttings are normally 10 – 30 cm long and 0.3 – 2.0 cm diameter. One or two leaves are usually left near the tip. Cuttings are common with *Populus* sp., *Gmelina arborea* and Eucalypts.

For production of cuttings in large numbers, a hedge bank of the relevant species is established (10-20 clones). Maturation of hedges which results in a decline in rooting is handled by cycling the parent hedge every few years (3-5 years) (SAIF, 2000).

The cutting is carefully inserted into a sterile medium (coarse sand, peat or vermiculite) and to promote root growth, plant hormones e.g. IAA, indole butyric acid (IBA) and naphthyl acetic acid (NAA) in concentration 10-30 parts per million (ppm) are used. Misting to prevent water stress, high temperature (25-30°C) and potting medium with good drainage and aeration are necessary. Generally, higher carbohydrate concentration in the cutting material, stem cuttings from young plants (juvenility is maintained by hedging), collection during the grand period of vegetative growth/nutrient demand/uptake and maintaining turgidity of cuttings (leaves removal/sealing cut surfaces) result in higher rooting of cuttings (Hartmann and Kester, 1989).

Tissue Culture (Single Cell or Organ): This is an asexual reproduction method resulting in rapid reproduction of genetically identical, disease – free progeny from a superior phenotype.

Tissue culture technique consists of:

- (a) Seed sterilization (e.g. Mercuric chloride for 10 minutes) followed by germination. When shoot tips develop, they are cut off and cultured. A single cell may also be used;
- (b) Alternatively, shoot tips (meristem tips) are cut (1.0 – 1.5cm) from a selected tree and sterilized and then cultured;
- (c) A sterile agar medium in test tubes is used for culturing. It consists of Agar, Murashige and Skoog macro/micro salts, sucrose (3%), various levels of IAA, IBA, NAA and cytokinins e.g. Benzlamino purine and kinetin;
- (d) Incubation is at a specified photoperiod and temperature e.g. 12 hour photoperiod, 2000 – 3000 lux and 25 ± 35°C;
- (e) After plantlet formation to >3cm height (i.e. after shoot and root development), transplanting into peat/vermiculite mixture in pots is done. Pots are then put in humidity chambers (100% R.H);
- (f) During transplanting, blunt forceps are used to remove plants from test tubes. Watering should be frequent. Temperature range 25 – 35°C; and
- (g) Field planting after transplants have reached an optimum size is done. Appropriate cultural techniques should be applied in the nursery.

3.4 Nursery Cultural Techniques

3.4.1 Watering

Water is a physiological requirement for seedlings in the nursery to grow normally. Watering is necessary especially after sowing or pricking out (transplanting). Watering can be done by: fine rose gardeners watering can, knapsack pressure spray, oscillating spray with fine nozzle, rotary sprayers, open trench or flooding over bed, overhead sprinkler (perforated pipe, nozzle line (jets) or rotary).

Under or overwatering should be avoided (overwatering leads to nutrient leaching and/or disease building). Frequent watering is needed in seed compared to transplant beds. Watering is reduced as seedlings get larger.

Hardening off or gradual reduction of watering toward field planting condition seedlings to withstand temporary water deficits during transit, storage and planting out after seedlings have attained optimum height is advised. Field survival and growth is improved because hardening off results in increased root/shoot ratio leading to better ability to withstand shock as well as ability to develop many new roots after planting out (Abod and Sandi, 1983). However, excessive hardening-off should be avoided as overly stressed trees will not be able to react quickly when planted out (SPGS, 2009).

3.4.2 Shading and Shelter

Germinating seed and young seedlings due to tenderness must be protected against direct sun or downpours of rain by a sloping roof of grass, banana leaves, polythene, grass mulch, wood, split bamboo, veneer offcuts, shade cloths, reed mats, shade nets (nylon), chicken wire mesh, or natural shade from trees in the nursery. Height of shade should be 1 m on the higher side and 0.75 m on the lower side (SPGS, 2009). Shading reduces water loss in the growing substrate by limiting evaporation and water loss through the leaves by limiting transpiration (SPGS, 2009).

The need for shading differs with species. Other species like Teak do not need any shading and grow satisfactorily from the time of germination in an open bed. Where shading is used, the intensity of shade (shading percent) is reduced gradually as seedlings grow until a stage is reached whereby full light is provided.

Tender seedlings may also need shelter from wind (damages seedlings, accelerates desiccation, erodes dry soil around the root collar, upsets irrigation spray), large hailstorms (break and crash seedlings), frost and heavy rain (causes physical damage, erodes soil around seedlings) and may lead to local water logging (Evans, 1992).

Seedlings may be mulched to conserve soil moisture and thus cut down amount of watering. Mulching materials include chopped grass, wood shavings and coffee husks (GR, 2008).

3.4.3 Root Pruning/Wrenching

Root pruning or wrenching (regular severance of seedling roots after adequate height has been attained) is carried out in the nursery with the objective of hardening seedlings to withstand shock during lifting and planting; and to ensure high field survival and growth. Two or three weekly root pruning is appropriate for most species. Instead of cutting the roots, pots can be moved sideways every few weeks (SPGS, 2009). Sufficient irrigation is needed after

root pruning as it reduces the ability of the root system to supply sufficient moisture (SPGS, 2009). Root pruning minimises the planting shock period and enables a fast establishment of contact with soil moisture and nutrient reserves, thus improving survival potential (Rook, 1969, 1971; Chamshama and Hall, 1987a). Field planting is done only after seedlings have recovered from the root pruning stress.

3.4.4 Fertilizer Application

Production of healthy seedlings ensures good survival and growth in the field and reduced susceptibility to diseases and pests. Adequate supply of plant nutrients is therefore essential. In most cases, the potting and transplant beds mixtures provide adequate nutrients, but in some situations, additional fertilisers (applied uniformly) are provided at various stages while seedlings are in the nursery due to leaching losses and uptake by seedlings. The questions of what fertiliser and how much to apply are decided by local experimentation for the species and soil concerned. In most cases however, NPK fertilizer is used.

It is important that the right amount of fertiliser is applied uniformly. Improper fertilisation leads to poor nutrition with symptoms like (Evans, 1992): chlorosis (pale colour of leaves), poor needle/leaf retention, stunted/deformed growth, purplish tints to foliage, needle tip burn etc.

3.4.5 Inoculation

Many tree species require a particular soil mycorrhizal, rhizobium (*Rhizobium* or *Bradyrhizobium*) strains or frankia association for successful growth in the nursery and good field survival and growth. Pines are among the many species groups requiring mycorrhizae as an aid in the uptake of nutrients from the soil, while N fixing trees require bacteria rhizobium and Casuarina require fungus frankia (Alexander, 1977). Provision of inoculum is by adding soil from an infected established stand to the potting mixture or transplant bed or spore inoculation of seed in the nursery.

3.4.6 Weed, Pest and Disease Control

Competition from weeds for light, nutrients and moisture results in depressed seedling growth. Therefore, weed control is a prerequisite.

The following are the main weed control methods:

- (a) Uprooting by hand – this is safe and simple;
- (b) Hand cultivation/mechanized cultivation in beds (serves to break the crust and permits adequate aeration and improves water absorption);
- (c) Herbicides - pre sowing (e.g. glyphosate, paraquat);
- (d) Pre - emergence (e.g. propazine);
- (e) Post- emergence (e.g. diphernamid);
- (f) Fumigants (e.g. methyl bromide); and
- (g) Sterilants (e.g. formalin).

Chemicals (herbicides) used to kill grass/herbs will also kill broadleaved species and are thus restricted to conifers. The use of chemicals is cheaper than most other methods but requires greater care, supervision and environmental considerations.

Nursery protection against destructive agents is mandatory. Seedlings must be protected against rodents, insect and fungal diseases. Protection against rodents e.g. rats, rabbits and mice is achieved by clean weeding, fine wire netting or poison traps. Birds eat seed or peck shoots. The presence of people in the nursery is a deterrent. Before any treatment, there must be a proper diagnosis which consists of identifying the problem, diagnosing the true cause and determining the impact on nursery production (SAIF, 2000).

Insect pests in nurseries include: caterpillars, white grubs, leaf cutting ants, termites, cutworms, snails and borers. Control is by soil sterilization and by using insecticides e.g. furadan and dusban. Application rate is as specified by the manufacturer.

Damping off is a common fungal disease in nurseries. It is a fungal disease commonly caused by e.g. *Phytophthora*, *Fusarium*, *Pythium*, *Cylindrocladium* and *Rhizoctonia* sp. In damping off, seedlings begin to rot from the stem tissue just above the root collar resulting in seedling toppling over. Another common fungal disease is mould – a foliage disease favoured by cooler and moister conditions and overcrowding. The causal species are *Botrytis* and *Penicillium*. Powdery mildews produce white powdery growths on the surface of leaves and are caused by *Oidium* sp.

Three patterns of damping off are:

- (a) Pre-emergence – fungal attack after seed germination but before emergence;
- (b) Post-emergence – fungal attack after seedlings start to grow; and
- (c) Collar rot or root rot that occurs after 5 – 6 weeks of growth when secondary thickening has begun.

Damping off is encouraged by excessive watering, too much shade, poor ventilation, dense stands of seedlings, excessive organic matter, high N and alkaline conditions (pH >6).

Control measures include:

- (a) Nursery cleanliness – site, equipment and procedures;
- (b) Application of wettable powders e.g. thiram, captan, ridomil, etc.;
- (c) Soil sterilization (methly bromide gas, formalin, steam);
- (d) Strict phytosanitary procedures during seed importation; and
- (e) Use of appropriate cultural techniques e.g. avoiding excessive watering or shade.

Mould and other foliage diseases can be controlled by chemicals e.g. copper sulphate, copper oxychloride or benlate. Chemical application should be in the afternoon and there should not be any watering after spraying (SPGS, 2009). Infected seedlings should be removed, burned and all tools disinfected (SPGS, 2009). The workers handling chemicals must strictly adhere to application and safety instructions.

3.5 Grading, Lifting, Packing, Transport and Storage

3.5.1 Grading

Size at planting out varies depending on species. Uronu et al. (2014) recommend a seedling height of 25-30 cm. Other measures of seedling quality sometimes also used are: root collar diameter (RCD) of 3-4 mm, root mass (over 3 ml) and root/shoot ratio (1:2). RCD is related to the size of the root system and is thus considered a better indicator of seedling survival than height and shoot size (Evans and Turnbull, 2004). Poor quality seedlings must be thrown away, even earlier before time of field planting, as if left may be a source of infection and a waste of labour (SPGS, 2009).

3.5.2 Lifting, Packing, Transportation and Storage

Types of seedlings

Before lifting, seedlings may be processed into other forms as follows:

- (a) **Striplings:** These are seedlings (2-3 m) that have been stripped of foliage and branches except for a few apical leaves and usually root pruned before planting out. When they are over 2 m tall they are sometimes called saplings. Striplings are used in areas prone to animal damage, where stem borers are a problem and in underplantings where weed competition is severe. Striplings have been made for *Cedrella odorata*, *C. mexicana* and *Khaya anthotheca*.
- (b) **Stumps:** A stump is a kind of cutting from a seedling of 1-2 m height. Average stump size is 20-25 cm long, of which 80% is root and 20% is shoot stripped of leaves. Root collar thickness ranges from 1-2.5 cm. Species that can be planted as stumps include: *Azadirachta indica*, *Dalbergia melanoxylon*, *Senna siamea*, *Milicia excelsa*, *Gmelina arborea*, *Tectona grandis* and *Pterocarpus angolensis*. The great advantage of stumps is the ease of transport, storage and cultivation.
- (c) **Balled stock:** These are seedlings where the root system is enclosed in a ball of soil. Seedlings may be raised in balls or put in balls near planting out. The soil with about 50% silt and clay is worked out with water until it can be moulded in the hand without exuding moisture. Two hemispheres of soil are formed and the seedling roots are gently pressed between to form a ball in which the seedling stays until lifting.

Lifting, Packing, Transport and Storage

If a well hardened seedling is not handled carefully during lifting, packing, transporting and storage it will lose its usefulness. These operations must be well timed and executed due to the intensity of the sun, low relative humidity and winds that blow during planting. Abuse to seedlings during transit from the nursery to the field will result in reduced survival and growth.

Lifting must be done in the early morning or evening when soil and air temperatures are low and the turgor within the plant is high. Seedlings must be watered before they are loaded. To avoid desiccation, roots of bare root seedlings are dipped in clay slurry before packing. Bare root seedlings require a shorter period between lifting and planting.

Handling should be minimized to avoid mechanical damage to the seedlings. Packages should be firm to prevent compression during transport. Plastic bags are not advisable as seedlings are easily damaged or broken during transport and their exposure to sun will result in "cooking" the seedlings.

Boxes or trays must be spaced apart to allow free air circulation, as tight packing will also result in heating. Seedlings should be transported in an enclosed vehicle to protect seedlings from direct sunlight and drying winds. The vehicle or trailer should be fitted with racks to avoid physical damage to seedlings and trays. Seedlings should be heeled in, stored in shaded places and watered regularly until planting. Seedlings must be planted within a short period after transportation to the field.

3.6 Control and Nursery Records

Each nursery should keep a detailed and careful record of:

- (a) Labels in seed beds, transplant beds, boxes and pots of species, batch number, date sown, quantity sown, date of germination, date of transplanting and number transplanted;
- (b) Financial records: budget estimates, salaries, other costs, capital expenditure and overheads;
- (c) Stock (stock taking for some items must be on a daily basis);
- (d) Labour records for each operation on a daily basis; and
- (e) Records should also be kept of: climatic data, irrigation schedules, protection measures, seeds received and costs, seedling sales, soil condition in the nursery and fertilizer addition, seedling nutrient content, pests and diseases outbreak.

3.7 Conclusion

Nurseries must be geared to produce high quality seedlings and at the lowest possible cost. The on-going climate change will make tropical climate more variable and extreme events more severe. There is a need to emphasize seedling drought hardening techniques in the nursery so as to ensure high early field survival and growth.

4. PLANTATION/WOODLOT ESTABLISHMENT

4.1 Introduction

Plantation/woodlot establishment is the formation of a healthy tree crop by planting or direct seeding. However, use of direct seeding is not common in Tanzania. The overall objective of plantation/ woodlot establishment is good survival and rapid early growth. This is achieved by correct choice of species (i.e. matching species to site), adequate ground preparation to aid rooting and nutrient availability, control of competing vegetation, proper pitting, proper spacing and addition of fertiliser if necessary. Overall, it remains essential that species and sites are properly matched and that the resulting forest must be economically viable, socially acceptable and ecologically sustainable (Evans and Turnbull, 2004).

The purpose of plantation (end use) is considered at establishment as choice of species and spacing to be used will depend on end use. The purpose of plantation can be industrial (fuelwood, wood pulp, sawn timber, plywood, electric or telecommunication poles) or domestic (firewood and building poles).

4.2 Site Preparation Techniques

Depending on the method of site preparation, the immediate goals include (Evans and Turnbull, 2004):

- (a) Reducing competition from unwanted species;
- (b) Removal of physical obstructions to tree growth e.g. hard pans;
- (c) Cultivation to improve soil structure, to aid root development and to ensure the trees obtain sufficient oxygen, soil moisture and nutrients;
- (d) Modification of natural drainage: improve drainage on wet sites or retain moisture on dry sites; and
- (e) Construction of contour ditches, walls, or other engineering works to reduce soil erosion.

The aim is for minimal action in the cheapest way: ground preparation is often the costliest silvicultural operation. The degree of ground preparation depends on the purpose of planting (i.e. minimum site disturbance if purpose is to protect soil), species to be planted (e.g. Eucalypts require completely cultivated and weed-free site, while many Pines and tropical Acacias tolerate grass competition), vegetative cover (diverse clearance practices in sites with vegetation ranging from grass to dense forest), and site and soil condition (ensure adequate cultivation of soil at lowest cost i.e. minimum cultivation) (Evans and Turnbull, 2004).

Studies on the effects of different site preparation techniques on early survival and growth have been carried out. Studies show that rigorous site preparation such as complete cultivation (ploughing and harrowing) results in improved survival and early growth of planted seedlings compared to strip or no cultivation (**Table 4.1**) (Chamshama and Hall, 1987b; Kalaghe and Mansy, 1989; Mhando et al., 1993).

Table 4.1: Effect of site preparation techniques on 6-year performance of *Pinus patula* at Sao Hill, Tanzania (Kalaghe and Mansy, 1989).

Treatment	Survival %	Height m	DBH cm	BA m ² ha ⁻¹	Volume m ³ ha ⁻¹
1. Complete ploughing & harrowing to 25 cm depth	92	10.2	13.8	20.3	121
2. Complete ploughing + subsoiling to 20 cm depth	92	10.0	13.5	19.2	106
3. Strip ploughing to 15 cm depth	95	8.1	11.5	13.5	63
4. Control pitting 30 cm deep	76	6.5	9.7	7.6	30

4.2.1 Manual Site Preparation Techniques

Manual clearance, Spot Preparation and Minimum Cultivation

Afforestation is usually in areas where grasslands dominate. Manual slashing of grass, smaller shrubs and trees is carried out. Fewer bigger trees should be felled by power saws and axes. Trash is piled, dried and burned (controlled, cool burn) while wood may be sawn or converted into charcoal. When clearing is done properly, it has the positive effect of reducing the cost of subsequent operations (SPGS, 2009). Manual clearance may be followed by spot preparation or minimum cultivation.

In spot preparation only the actual planting spot is cultivated. The soil is loosened in a circle with a diameter of about 0.5 m. Around this cultivation pit, an area of about 1.0 m radius is cleaned of all grass and weeds. After planting, periodic cleaning around the trees is necessary. Minimum cultivation entails the cultivation of only a small spot where the tree is to be planted. The method is the cheapest of all but results in the highest rate of mortality and the slowest rate of growth. The method is normally only used on sites that are very erosion prone (SAIF, 1994).

In hilly areas contour trenching and terracing and/or tie ridging may be manually done - these catch runoff, prevent erosion and encourage infiltration.

Burning

Fire as a silvicultural tool has long been used in different parts of the world, either alone or in combination with chopping and/or herbicide spray. Burning is relatively inexpensive and when controlled is very efficient in clearing vegetation and reducing debris on site, thus improving access. To be successful, the burn must be cool, and this is ensured by vegetation matter being dry and well compacted, a calm weather (late evening or at night) or when rains have just started. There must be precautions to keep the fire under control. The resulting ash is rich in base nutrients (which may be lost by leaching or surface movement) and vermin are killed. Hot burns (>300°C) result in volatilisation of N and sulphur, loss in organic matter, degradation in soil structure, reduction in macro pores, erosion by wind and raindrops and decreased infiltration rates due to fire induced water repellence (SAIF, 1994). It also contributes to air pollution.

4.2.2 Mechanical Site Preparation Techniques

Ploughing

Ploughing and other mechanical site preparation techniques should not be carried out on steep slopes to avoid erosion. Ploughing removes competing vegetation and modifies the soil to improve infiltration. Ploughing is essential for species sensitive to competition e.g. most Eucalypts. Before ploughing, the site must be cleared and stumps uprooted. Uprooted trees and shrubs are pushed to the boundaries and ploughing of the site is done using farm tractors.

Ploughing is relatively cheap. Its disadvantages include high capital cost, problems with equipment maintenance and spares, supply of fuel and oil, the need for training and supervision, employment of few, soil erosion acceleration during extraction of woody material, and damage to soil from compaction (increased bulk density and reduced macro pore space, reduced infiltration capacity, reduced internal movement of water and nutrients, reduced aeration and root growth).

Disking (complete preparation)

This is complete cultivation of site by ploughing and harrowing to a depth of 20-25 cm as is normally done for agricultural crops. This method can usually only be used on a fairly flat area (6° slope) (SAIF, 1994). Wheeled tractors with 5 - 6 disc ploughs are used for ploughing followed by disking with a heavy-duty harrow with cut-way discs.

Although the cost is high, it incorporates organic matter into the soil and has the advantage of better survival, rapid early growth of young trees and reducing the growth of weeds (SAIF, 1994).

Bedding

This results when a single gang harrow is used to roll the soil into two sides of a strip to form a ridge. Male (1981) listed six reasons why bedding is beneficial. These are improvement of soil moisture, aeration, soil structure, infiltration rate, soil depth, the roots ability to penetrate soil and mineralization of nutrients. However, weeds remain in the space between beds and will compete with seedlings.

Ripping

This refers to cultivation to a depth of 45 - 100 cm along planting lines using a standard rock ripper or ripping rig. Between the strips the soil is uncultivated resulting in areas where weeds could grow vigorously. The treatment is thus less effective in controlling unwanted vegetation. Ripping is done on slopes angle less than 22° and should be done during the dry season to ensure maximum shutter of the soil.

Subsoiling is used for loosening deep layers of compacted soil. It reduces bulk density, thereby improving aeration and water infiltration, greater root proliferation and stand stability.

4.2.3 Use of Chemicals

Chemical site preparation involves use of herbicides e.g. Glyphosate to control competing vegetation before planting of tree seedlings. Chemical site preparation is considered a low cost

tool with the main advantage of causing minimal site disturbance to soil and land surface. Herbicides have potential hazards to those applying them and to the environment. They must be stored and used with great care. Applicants must adhere to manufacturers safety precautions, use protective clothing and apply correct doses. Herbicides may drift over to non-target areas, which may then cause injury to desirable flora, fish, insects, wildlife and man. The danger of drift may be reduced by use of drift retardants and high volume droplet application per unit area.

Chemical site preparation is used in some private forest plantations in Tanzania. At Kilombero Valley Teak Company (KVTC), after vegetation clearing and burning, pre-planting herbicide (Glyphosate 3 l/ha) application is done (Bekker et al., 2004). At Green Resources plantations in Mufindi, Glyphosate 3 l/ha is applied to grass followed by screefing before pitting and planting (Mussami, 2010).

4.3 Planting and Coppice Management

4.3.1 Time of Planting

Time of planting is critical in order to maximise initial survival and growth. In many areas of the tropics, planting time is difficult to predict due to great variations in rainfall both in space and time.

As a rule of thumb, planting should start when soil moisture has accumulated to 25 - 35 mm (i.e. rainfall minus evapotranspiration and runoff) or a soil moisture depth of 15 - 30 cm or 100 mm of steady rain fallen (Zobel et al., 1987; Evans, 1992; GR, 2008). Planting must be done during cool/cloudy weather, carefully with proper supervision and should be completed as soon as possible so that plants can establish deep root systems before the onset of dry weather.

4.3.2 Laying Out Planting Positions

Row alignment should fit with the intended extraction system and should be at right angles to the main extraction roads and tracks. Roads and tracks mostly follow the contour, while rows run up and down slopes. Where rows follow contour they should end at a road.

Laying out planting positions starts with establishing a baseline (50 to 100 m) along the edge of the area to be planted. The cable or rope is marked at intervals with the desired spacing. A compass is used to make alignment (or the 3, 4, 5 rule). Two cross-lines at 90° (marked with correct spacing) at each end of the baseline are marked. The baseline is moved up between the two cross lines, stopping at each mark and marking the pits on the ground (SPGS, 2009) (**Figure 4.1**). Where holes are not dug immediately, a hoe can be used to mark the planting position or a stick/peg about 2 m high can be used. At the end of the cross-lines, the procedure is repeated in the area next to the marked one. On steep slopes, the cross lines need to be held level and not on the ground (SPGS, 2009). For second and later rotations planting position is readily located in relation to the old stumps.

The diagram illustrates the method of measuring distance by stepping. It shows a person stepping along a line, with a 'Base line' and 'Cross line AE' marked. The distance is measured in steps, with a '3m mark on rope' and a '3m' distance indicated. The diagram also shows a 'Cross line CE' and a '3m' distance.

Spacing can be square or rectangular. Spacing depends on several factors: species, purpose for which it is grown, availability of moisture at critical periods of the year, tolerance of the species to weed competition and economics. Overall, if the quantity of wood only is important e.g. for firewood or pulp, then closer spacing is desirable. When large trees are desired to improve conversion recovery for sawn timber and veneer then wider spacing is desired.

Due to limited moisture availability levels in semi-arid areas, wider spacing (4 x 4 m or 5 x 5 m) is advocated so that moisture is made available to fewer trees for better survival.

Table 4.2: Initial spacing used in public and private sector forest plantations/woodlots in Tanzania

Name of forest project/plantatio	Species	End product	Rotation age	Spacing
Public sector forest plantations (FBD, 2003)	<i>Pinus patula</i> , <i>P. tecunumanii</i> , <i>P. elliottii</i> , <i>P. caribaea</i> , <i>Cupressus lusitanica</i>	Saw logs Pulpwood	25 - 30 years 10 years	3.0 x 3.0 m 2.0 x 2.0 m
	<i>Tectona grandis</i> and <i>Grevillea robusta</i>	Saw logs	30 - 40 years	2.5 x 2.5 m
	<i>Eucalyptus</i> spp	Saw logs Pulpwood	25 - 30 years 10 - 15 years	3.0 x 3.0 m 2.0 x 2.0 m
	<i>Acacia melanoxylon</i> and <i>Olea capensis</i>	Saw logs Pulpwood	25 - 30 years 10 - 15 years	2.5 x 2.5 m 2.0 x 2.0 m
Private Woodlots, Makete (Malimbwi et al., 2010)	<i>Pinus patula</i> , <i>C. lusitanica</i> , <i>Eucalyptus</i> spp.	Saw logs	25 - 30 years	2.5 x 2.5 m 3.5 x 3.5 m
Green Resources, Mufindi (Mussami, 2010)	<i>Pinus patula</i> , <i>P. elliottii</i>	Saw logs, pulp wood, energy,	Saw logs 25 years	3.0 x 3.0 m
	<i>Eucalyptus camaldulensis</i> , <i>E. saligna</i> , <i>E. grandis</i>	Saw logs, pulp wood, energy, poles	Saw logs 25 years	2.5 x 2.5 m
Kilombero Valley Teak Company (Bekker et al., 2004)	<i>Tectona grandis</i>	Saw logs	20 - 25 years	2 x 2 m (1993-1999) 3 x 3 m (2000+)
TANWAT (TANWAT, 2004)	<i>Acacia mearnsii</i>	Bark	10 years	2.7 x 1.8 m
	<i>Eucalyptus grandis</i> , <i>E. cloeziana</i> , <i>E. maidenii</i> , <i>E. citriodora</i>	Telegraphic poles Transmission poles	8 - 10 years 10 - 12 years	2.7 x 3.0 m
	<i>Eucalyptus smithii</i>	Firewood	6-7 years	2.7 x 3.0 m
	<i>Pinus patula</i> , <i>P. elliottii</i> , <i>P. radiata</i>	Saw logs	20-23 years	3.0 x 3.0 m

4.3.4 Pitting and Planting

Planting is a critical part of establishment and planters must be properly trained to use good planting practices. Poor planting techniques can result in poor survival and growth. For pitting and planting, the following general rules apply. Pits should be large: 20 - 30 cm deep x 20 - 30 cm diameter (SAIF, 2000; GR, 2008; SPGS, 2009; TANWAT, n.d.). In dry areas, larger sizes are advocated (40 cm depth and diameter). Pitting is best done when the ground is a bit moist from early rains (SPGS, 2009).

In planting, roots are inserted into the pit up to the root collar. Careful inserting of roots will avoid breaking, bending or crushing them. Polythene containers must be removed. The soil is gently firmed around the roots to eliminate air pockets and bring the earth into intimate contact with the roots. On dry sites, the planting position should maximize water retention e.g. by use of micro-catchments.

4.3.5 Fertilisation at Planting

On nutrient deficient sites, addition of inorganic fertiliser is necessary to improve survival and growth. Application is in a ring 10 cm from the tree up to two weeks after planting. The type and

rate of fertilizer to apply will depend on fertilizer trial results. At TANWAT, borate and phosphate fertilizers are applied at planting at rates of 80 and 180 kg/ha respectively (TANWAT, 2004). At New Forests, 30 g NPK enriched with Boron is added per seedling. Fertilizer response is enhanced by good site preparation, which minimizes weed competition for the fertilizer. Use of fertilizer can reduce the amount of weeding due to early canopy closure, increase in stand uniformity, tree form and survival (Zobel et al., 1987).

Other than the use of inorganic fertilizers, experience from Australia, New Zealand and Hawaii (Will and Manley, 1983; Waring and Snowdon, 1984; Debell et al., 1989; Binkley et al., 1992) suggests that soil fertility can also be increased by annual and perennial N fixing legumes planted as companion crops (mixed species) or during fallow periods.

4.3.6 Replacement of Casualties - (Beating Up, Re-filling, Blanking, In-filling)

Some mortality is usually expected after planting. This may be due to (Zobel et al., 1987; Evans, 1992):

- (a) Loss of fine roots while lifting seedlings;
- (b) Poor planting skill – (planting depth and poor root to soil contact);
- (c) Poor quality planting stock;
- (d) Improper handling of plants - desiccation during transport and storage;
- (e) Bad post planting weather (lack of moisture, low humidity, winds);
- (f) Damage by animals (browsing, trampling, breaking, gnawing bark), insects (mainly termites) and pathogens;
- (g) Weed competition; and
- (h) Transport damage.

Plantations/woodlots should be inspected 3-4 weeks after planting to assess numbers and distribution of casualties. Seedlings should be planted away from where fertilizer was put. With high mortality of > 20% (at 1250 SPH) or 10% for lower stocking and 5% for 625 SPH failures have to be replaced. Replacement has to be done as soon as possible so that the newly planted seedlings catch up with the rest. Delay in replacement results in a stand with great variation in tree sizes. For very low survivals the area must be replanted.

Abnormally slow growth may be noticed due to numerous causes e.g. poor species/provenance choice, acute nutrient deficiency, poor soil physical conditions due to compaction or erosion, lack of mycorrhizal associations or nitrogen fixing bacteria, inadequate weeding, excessive browsing or prolonged overhead shade, use of slow growing indigenous species instead of vigorous exotics (Evans and Turnbull, 2004). Depending on the cause, appropriate action should be taken immediately.

4.3.7 Coppice Management of Eucalypts

Although some Pines e.g. *P. oocarpa* stump sprouts, sprouting is mainly a feature of hardwoods like Eucalypts. It is commonly used as a method of regeneration. Use of coppices is simple because planting costs are eliminated, but it costs to reduce the sprouts to the desired number (Zobel et al., 1987).

For Eucalypts, coppice reduction should start when the dominant height is 2 - 4 m, 2 - 3 shoots should be left and at a dominant height of 7 - 8 m, 1 - 2 shoots per stool should be left (SAIF, 1994; TANWAT, n.d).

One disadvantage of coppice is that the sprouts are identical to the trees originally planted and if genetically improved stock is available, the savings in planting costs must be weighed against the amount of genetic improvement (Zobel et al., 1987).

4.4 Conclusion

Proper site preparation, healthy planting stock, timely planting and proper planting are key to successful plantation establishment. Recommended spacing based on expected end use should be used. Mixed species plantation involving N-fixing tree species should be tested especially in woodlots.

5. PLANTATION/WOODLOT MAINTENANCE

5.1 Introduction

Plantation/woodlot maintenance (tending operation) is done to ensure that the plantation/woodlot is adequately established and protected up to the production stage. This involves ground weed control, cleaning and release operations. The two operations (i.e. weeding and cleaning/release) reduce or eliminate the competition for light, soil moisture and nutrients from undesirable species - which have grown around seedlings or young trees. When the operations are not conducted properly both survival and early growth are impaired. Further, dense ground vegetation increases fire hazard and can shelter harmful animals as rats that may eat seedlings while other wild animals and cattle may trample seedlings.

5.2 Weeding

Weeding can be manual, mechanical or by use of chemicals as explained in the following sections.

5.2.1 Manual Weeding

Manual weeding can be done by slashing and/or hoeing. Bush knives, slashers and hoes are used to cut away competing vegetation and undertake some soil cultivation as cutting alone gives temporary results and vigorous re-growth occurs thereafter. If slashing alone is used as a weed control method, it must be done as low as possible and must be preceded by spot weeding to reduce chances of slashing tops of the trees off or placing a stick between the tree and the weeds (SPGS, 2009).

There are three different kinds of hoeing (SPGS, 2009): (i) spot covering an area of 1 m diameter, (ii) line where the tree line is hoed (1 m width or 0.5 m on each side of the tree line) and the inter-row is left, and (iii) full cover hoeing where the entire area is hoed (**Figure 5.1**). In general, the greater the area weeded, the less the competition to the tree and the better the tree survives and grows. Thus, spot weeding is less effective than strip weeding, with clean weeding being the best of all (**Table 5.1**). Steep, erodible slopes should not be clean weeded. Instead, slashing may be done. Within 20 cm from the tree, weeds should be hand pulled to minimize damage to surface roots (SPGS, 2009).



Figure 5.1: Spot, strip and complete weeding

Taungya system where farmers are allowed to intercrop annual crops with tree seedlings enables weeding of trees when food crops are weeded (**Figure 5.2**). Crops like maize will

shade seedlings and delay early growth. Taungya seeks to satisfy both social needs (land for growing food crops) and the establishment of a plantation. However, poor supervision of Taungya farmers may lead to over pruning and tree root damage (TFHF, 2014). To minimize these negative impacts, Taungya should only be allowed for one cropping season.



Figure 5.2: Taungya system with carrots at Shume forest plantation, Lushoto, Tanga region

Table 5.1: Effects of weeding on survival and growth of 3.2 year old *Eucalyptus camaldulensis* seedlings at Igwata, Mwanza, Tanzania (Sabas and Kalaghe, 1986)

Treatment	Survival %	DBH cm	Height m
Spot weeding and slashing	56.1	3.8	3.6
Slashing alone	11.5	2.6	2.1
Spot weeding alone	37.5	3.5	3.6
Strip weeding	86.2	4.6	4.7
Clean weeding	91.4	5.2	5.4

Mulching post-harvest plantation residues is effective in weed control as it excludes light and provides a physical barrier to the emergence of weeds and improves soil moisture conservation (SAIF, 2000).

5.2.2 Mechanical Weeding

In mechanical weeding, use is made of disc harrow or rotovator. Mechanical weeding is by harrowing, rotovating or shallow ploughing. The rows must be 2.5 m apart for the tractor to move while pulling the machine. All stumps and post-harvest plantation residue must be removed before mechanical weeding and the slope should allow tractor use ($< 10^\circ$ slope). Care is needed to ensure that roots in the inter row area are not damaged while undertaking mechanical weeding. Also soil disturbance may stimulate seed germination and there may be soil compaction (SAIF, 2000). Weeds in tree rows tend to be missed.

5.2.3 Chemical Weeding

Weed control by herbicides often gives better and longer lasting effects than other methods as plants are killed. This is one reason why herbicide weed control tends to improve tree survival and growth rather than hand weeding, which may simply cut the weed plant.

For effective herbicides use, consultation with herbicide suppliers is necessary on the following aspects: choosing the right herbicide and dosage to control the weed species encountered, training operators to minimise any health hazard and to apply the dosage rate safely, applying under favourable weather conditions to limit drifting, volatilisation or washing by rain, and timing for optimum kill of weeds. Training should include good storage of chemicals and proper disposal of used chemical containers (SPGS, 2009).

Application of herbicide is from knapsack (back pack) sprayers, ultra-low volume applicators (1 worker, 1 ha per day and 20 l at a time), tractor with booms or from the air. Limited information is available on use of chemical weeding in Tanzania. At TANWAT, chemicals are used to control wattle re-growth and tussock grass (*Eragrostis* sp.) using glyphosate 150 ml per 10 l of water (200 l of mixture per ha) (TANWAT, 2004).

The advantages of chemical weed control are: one application provides long lasting control, weeds are usually killed so completely removing their competitive effect, dead weeds are left in-situ acting as mulch and so reducing erosion risk, higher productivities are achieved than in manual weeding— it is cheaper where labour rates are high.

The main disadvantages of chemical weed control include: hazard to health, damage to crops, adverse ecological effects including contamination of water ways, cost of equipment and chemicals and need for training and supervision.

5.3 Climber and other Cuttings

After ground weed control, cleaning and release operations should follow. This involves removal or killing of perennial plants, unwanted trees, climbers, stump regrowth and singling (forked or multiple stems) if used for veneer or saw logs. This work may be needed for several years. Re-spacing may also be undertaken during the first two years in the following situations: (i) too close initial spacing, (ii) natural regeneration is competing with replanted second rotation trees, (iii) as a very early thinning, and (iv) to thin out after direct seeding. Climber and other cuttings may be done manually or by use of chemicals.

5.4 Conclusion

Post planting care is necessary to get a healthy and well-stocked stand. This must be well timed and properly done so that newly planted seedlings do not compete for moisture, nutrients and light with weeds.

6. PRUNING

6.1 Introduction

Artificial pruning is the severance of live or dead branches of trees. Some species are natural pruners (i.e. dead branches soon fall off) e.g. *Terminalia superba*, *Terminalia ivorensis*, *Cordia alliodora* and most Eucalypts. Dead branches are attacked by saprophytic fungi or insects and weakened. They fall on their own weight or by force of wind, rain or whipping by subordinate trees. For other species, dead branches remain on a stem for many years, and pruning must be done if knot free timber is desired. Species with persistent branches include *Cupressus lusitanica* and *Pinus patula*.

There are two main objectives of artificial pruning:

- (a) **Low or access pruning** is done to all trees in a stand to (i) provide free access into the plantation, (ii) reduce fire risk, (iii) facilitate the felling and extraction of thinnings, and (iv) produce knot free timber at the base of the tree. Low pruning is achieved by pruning the whole crop to about 3 m. Low pruning is the only pruning that may be done to pulp plantations. It is often incorporated in pruning schedules as the first pruning; and
- (b) **High pruning** is done to increase the net value of the stand. It should be done after thinning so that resources are not wasted to prune trees that are about to be thinned. This is achieved through the production of knot free timber, which ideally should fetch a higher price than timber full of knots, sufficient to cover the compounded pruning costs. Dead branches are also removed during high pruning to get rid of loose knots, which degrade timber.

Knot free timber is highly desirable in (i) veneer: to ease peeling for plywood and match making, (ii) structural timber needing uniform strength, good machining, finishing and seasoning qualities, and (iii) transmission poles.

There are situations where knot free timber is unnecessary e.g. (i) plantations grown for firewood, pulp and particle board, (iii) low grade saw timber for shuttering and packing cases, and (iv) protection plantations such as shelter belts, erosion control and sand dune stabilization.

6.2 How to Prune

Pruning and consequent production of knot free timber involves:

- (a) **Removal of branches:** Branches should be cut flush with the trunk using a sharp curved pruning saw (**Figure 6.1**) using ladders if necessary or long handled pruners. Sharp pruning saws ensure a clean cut and prevent tearing the tree's bark (**Figure 6.2**). Bush knives (pangas) should never be used as they never do a clean cut and may damage the tree bark. Workers should wear safety hard hats and goggles for protection of head and eyes against dust respectively. Where branch removal tears the bark of the main trunk, it is safer to prune in two stages: first cut the branch about 50 cm from the bole and then, as a second operation, cut off the remaining stump (**Figure 6.2**). **Figure 6.3** shows poor pruning operations. Avoid pruning when growth is taking place (wet season) as bark is loose and easily slips from the wood leaving serious wounds. The risk of fungal infection is high (germination of spores due to moist conditions). Splinters of wood or broken stubs should not be left as they interfere with callus formation;

- (b) **Healing of pruning scars:** Scar occlusion involves growth of callous tissue (a mass of thin walled cells usually developed as a result of wounding or infection) from peripheral cambium. Rate of occlusion differs with species, tree health, scar size, vigour and how flush it is to the trunk and sometimes time of the year or season of cutting. Rapid occlusion may be associated with pruning near the start of the growing season. Some species exude a sealant of resin or gum to protect the pruning scar from fungal and insect attack during growth of the callous tissue; and
- (c) **Laying down knot free wood:** Knot free timber is laid down in the years following pruning. The earlier pruning is done and the longer the rotation, the higher the proportion of knot free timber and the smaller the size of knotty core (*Figure 6.4*).

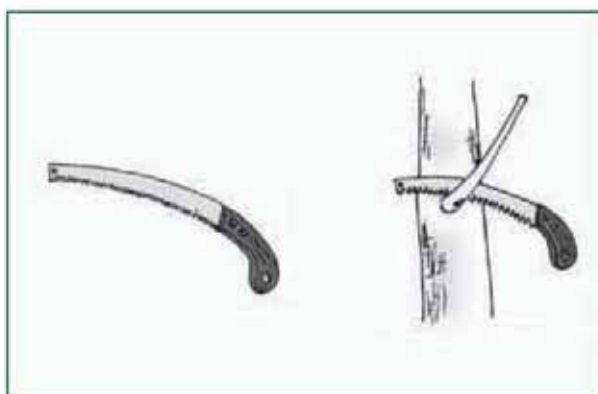


Figure 6.1: A pruning saw

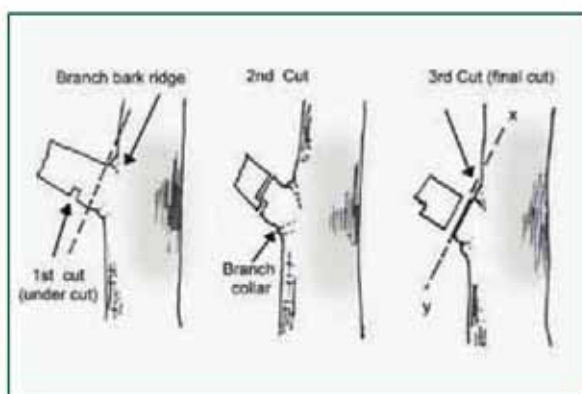


Figure 6.2: Proper pruning operation



Figure 6.3 Poor pruning operation (branches not cut flush with stem) and with damaged bark

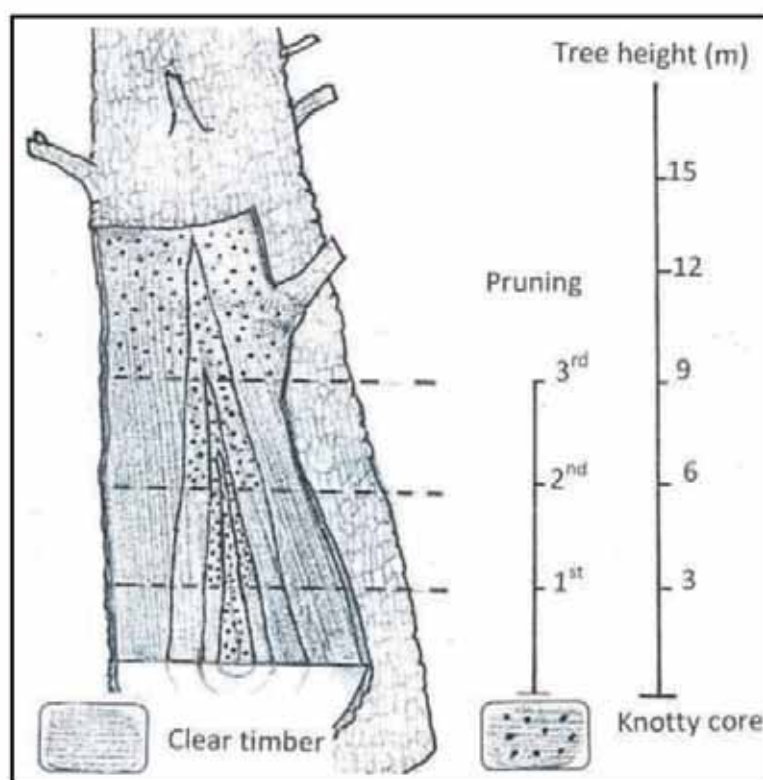


Figure 6.4: Laying down knot – free timber

6.3 Pruning Schedule

Pruning schedules indicate the timing of pruning as well as pruning height. They vary with species, sites and growth rates (SPGS, 2009). On average, 40-50% of the living crown is removed in three to five times (Zobel et al., 1987). Further, where possible, pruning should coincide with thinning so that the pruned trees respond to thinning and thus compensate for possible loss in increment due to pruning (Zobel et al., 1987). The pruning schedule for *Pinus patula* and *Cupressus lusitanica* in public sector plantations is shown in **Table 6.1**. Pruning schedule for some private sector companies are shown in **Table 6.2** and **Table 6.3**. The public and private sector pruning schedules are within the levels considered appropriate for the various species and compare favourably with those in other East African countries (Chamshama, 2011).

Pruning must start before the branches die, otherwise dead knots will form. Consequently, plantations must be monitored to see when canopy closure has occurred so that pruning is undertaken (SPGS, 2009). Pruning schedules must be followed as pruning too high reduces diameter and height increment, while pruning too low leaves branches that can cause knots.

Table 6.1: Pruning schedule for *Pinus patula* and *Cupressus lusitanica* in public sector plantations (FBD, 2003)

2003/

Pruning type	Site class I			Site class II			Site class III			
	Age, yrs	Ht, m mean	Ht, m pruning	Age, yrs	Ht, m mean	Ht, m pruning	Age, yrs	Ht, m mean	Ht, m pruning	
<i>P. patula</i>										
1st	3.0	5.5	2.7	3.5	4.9	2.4	-	-	-	W.C
2nd	5.0	9.8	5.8	5.5	7.3	4.6	7.0	6.1	3.7	S
3rd	7.0	13.7	8.2	7.5	10.4	6.1	9.0	7.9	4.9	S
<i>C. lusitanica</i>										
1st	1.0	2.4	1.2	2.0	2.4	1.2	-	-	-	W.C
2nd	3.0	6.7	3.4	4.0	5.5	2.7	5.0	4.0	2.0	S
3rd	5.0	10.1	6.7	6.0	7.3	4.9	7.0	5.2	3.4	S
4th	7.0	12.8	8.5	8.0	9.1	6.1	9.0	6.4	4.3	S

Notes: WC = Whole crop pruned; S = selective pruning; Ht = Height

Table 6.2: Pruning schedule for Pines in Green Resources (GR, 2008)

Age (years)	Mean dominant height (m)	Pruning height (m)	Number of trees pruned
4	4.5	2.0	All
6-7	8.0	4.2	800
8-10	11.0	6.2	450

Table 6.3: Pruning schedule for Pines at TANWAT (TANWAT, 2004)

Mean dominant height (m)	Age (years)	Pruning height (m)	Diameter limit (cm)
4.0	3-4	2.0	Half height
7.5	5-6	3.0-4.0	9.0
10.5	7-8	5.0-6.0	10.0
13.5	9-10	7.0+	11.0

6.4 Conclusion

Craib (1939) has shown that the clear timber must be at least 10 cm thick to be economically justifiable. To obtain this for pruning as high as 7 m, the mean breast height diameter over bark would need to be at least 45 cm for most Pines (Marsh, 1978). Rotation length must be adjusted to allow for such growth (Zobel et al., 1987). Pruning will be less feasible on poor sites that require longer rotations to attain the desired dimensions. Pruning trials should be established for new species currently being used in plantations.

If the demand and price of high quality timber rises in the tropics, this will make pruning an attractive silvicultural operation, given the advantage of fast growth rates.

7. THINNING

7.1 Introduction

Artificial thinning is the removal of a proportion of individual living trees from a stand before clear felling (SAIF, 2000). It is generally understood to take place after the onset of competition. The major objectives of thinning are to (Evans, 1992; SAIF, 2000): (i) reduce the number of trees in a stand so that the best remaining ones have more space for crown and root development to encourage stem diameter increment and so reach a usable size sooner, (ii) for stand hygiene both to remove dead, dying, diseased and any other trees, which may be a source of infection for, or cause damage to the remaining healthy ones and to reduce between tree competition to avoid stress levels which may encourage pest and disease attack, (iii) remove trees of poor form (crooked, forked, basal sweep, roughly branched, etc.) so that all future increment is concentrated only on the best trees, (iv) to favour the most vigorous trees with good form which are likely to make up the final crop, and (v) provide an intermediate financial return from sale of wood from thinning especially second thinning onwards. More trees are initially established than the required final crop so that there are sufficient trees from which the final crop can be selected and to enhance early canopy closure to suppress weed growth and utilise the site better (SAIF, 2000).

7.2 How to Thin

Marking for thinning must be done carefully by competent persons. Individual tree selection is recommended and is done as follows (SPGS, 2009):

- (a) Decide on plot size. A size of 10 x 10 trees is workable. The 4 border trees can be marked with a colour tape;
- (b) For a spacing of 3 x 3 m, the plot for 10 x 10 trees will have an area of 27 x 27 m or 729 m²;
- (c) As a ha has 10,000 m², this gives $10,000 \div 729$ plots i.e. 14;
- (d) If in the thinning 700 stems per ha were to be left, the number of stems to be left per 10 x 10 tree plot will be 50;
- (e) One crew member should identify trees to remove and the other to mark them with spray paint and not panga. In case of delays in thinning, trees marked with a panga will open to infection or in case of errors in marking, such trees cannot be retained; and
- (f) Starting at one point of the compartment, the crew should systematically work their way through the compartment.

Overall, a 10% deviation of the prescribed stems per ha is generally acceptable (SAIF, 2000).

7.3 Thinning Schedules

A thinning schedule indicates for given species and ages the number of stems to remove and retain as well as the rotation age. The current thinning schedules for public and private sectors forest plantations are shown in **Table 7.1**. The main end use for all the species shown in Table 7.1 is sawlogs. The thinning schedules are within the levels considered appropriate for the various

species and compare favourably with those in other East African countries (Chamshama, 2011). **Figure 7.1** shows an unthinned stand.

Table 7.1: Thinning regimes for different tree species in public and private sector industrial forest plantations in Tanzania (FBD, 2003; Bekker et al., 2004; GR, 2008; TANWAT, n.d)

Plantation owner	Species	Age (years)	Stems per ha
Public sector	<i>P. caribaea</i> <i>P. elliotii</i> <i>P. patula</i> <i>P. tecunumanii</i> <i>C. lusitanica</i>	0	1,111
		10	650
		15	400
		25-30	0
	<i>T. grandis</i>	0	1,600
		5	800
		10	400
		15	300
		30-40	0
Green Resources	<i>P. patula</i>	0	1,600
		10	800
		14	500
		18	300
		25	0
KVTC	<i>T. grandis</i>	0	1,111
		+/-5 (10m)	500
		+/-10 (20 m ²)	250
		+/-15 (20 m ²)	150
		20-25	0
TANWAT	<i>P. patula</i> <i>P. elliotii</i> <i>P. radiata</i>	0	1,111
		4	800
		12-13	400-500
		20-23	0



Figure 7.1: Unthinned *Pinus patula* stand at West Kilimanjaro forest plantation

7.4 Conclusion

Thinning is an important silvicultural tool in managing plantation forests for sawn timber and veneer wood. Thinning must be done at the right time, in the right way and at the right intensity so that a mean breast height diameter of 40 cm predicted in most thinning schedules is achieved. Where maximum wood production is the objective and quality is not that important e.g. wood for firewood, pulpwood or rough poles, thinning may not be needed. Plantations intended to protect soil and prevent soil erosion are often not thinned. Thinning trials should be established for new tree species currently being used in plantations.

8. FOREST HEALTH

8.1 Introduction

When plantation establishment started in Tanzania in the 1950s, trees were initially free of pests and pathogens. Over time, attacks by various indigenous and exotic pests and pathogens started. As plantations were expanded, trees were also destroyed by fires. Evans and Wood (1993) showed that although there are some examples where plantations have faced major disease or insect problems that have stopped the use of a particular species, diseases and pests have not caused such widespread damage as to seriously question plantation silviculture as a practice. Possible impact of climate change on range of pests and diseases might have an impact on determining the optimal range of a given species and need to be monitored.

8.2 Status of Pest and Disease Problems

A detailed review of past and present status of pests and diseases in Tanzania is given by Madoffe and Petro (2011) and Ndomba et al. (2011) respectively. Some pests and pathogens attacking forest plantations/woodlots are shown in **Table 8.1**. **Figure 8.1** shows attacks by various pests.

8.3 Pest and Disease Control in Forest Plantations

The control of pests and diseases is critical to maintaining the health and productivity of forest plantations. Good silviculture will reduce stress and promote healthy trees less susceptible to pests and diseases in the following ways (ITTO, 1993; FAO, 2001; SPGS, 2009):

- (a) Giving proper attention to species/site matching as “offsite planting” results in trees growing under stress;
- (b) Using planting stock from broad genetic base;
- (c) Planting only robust, healthy plants and beating up early;
- (d) Good weeding especially pre and post planting;
- (e) Maintaining optimum stocking levels and tree vigour through timely thinning; and
- (f) Diversifying tree species planted.

Integrated pest/disease management (IPM), which relies on sound selection of species, provenances or hybrid materials with genetic traits tolerant to damaging biotic agents, improved silviculture and actions of natural enemies and cultural control can substantially reduce the risk of pest and disease outbreaks (ITTO, 1993; FAO, 2006). Integrated pest/disease management programmes are also economically sustainable as they reduce the planted forest manager’s dependence on expensive procured inputs. However, in instances of major outbreaks, use of chemicals may be necessary (FAO, 2006).

Effective monitoring will result in early pest/disease detection and early action before the problem is out of control. A recent study showed that there is inadequate capacity to monitor forest health and consequently, there is limited information on species and areas affected by pests and diseases in Tanzania (Chamshama, 2011). Recently, a National Health Monitoring Forum based at TAFORI has been established, and all pests/diseases should be reported as soon as they are found in plantations/woodlots.

Table 8.1: Pests and pathogens attacking forest plantation/woodlot species in Tanzania (Madoffe and Petro, 2011; Ndomba et al., 2011)

Pests	Species attacked	When first noted	Place of origin
Cypress aphid (<i>Cinara cupressivora</i>)	<i>Juniperus procera</i> and <i>Cupressus lusitanica</i>	1987	Southern Europe
Leucaena psyllid (<i>Heteropsylla cubana</i>)	<i>Leucaena</i> (<i>Leucaena leucocephala</i>)	1992	Central and South America
Pine woolly aphid (<i>Pineus boernerii</i>)	<i>Pinus patula</i> and <i>P. elliottii</i>	1968	Europe
Eucalyptus bark beetles (<i>Phoracantha semipunctata</i> and <i>P. recurva</i>)	Eucalyptus species	1980s	Australia
Pine needle aphid (<i>Eulachnus rileyi</i>)	<i>Pinus patula</i> and <i>P. elliottii</i>	1970s	Europe and North America
Blue Gum Chalcid (<i>Leptocybe ivasa</i>)	<i>E. camaldulensis</i> , <i>E. saligna</i> and <i>E. grandis</i>	2004	Australia
Termites	<i>Eucalyptus</i> , <i>Grevillea</i> , <i>Senna</i> , <i>Acacia</i> , <i>Gmelina</i> , <i>Leucaena</i> and <i>Terminalia</i>	NA	Indigenous
Ambrosia beetles (<i>Oemedia gahani</i>)	<i>Cupressus lusitanica</i> and <i>Milicia excels</i>	NA	Indigenous
Mahogany shoot borer (<i>Hypsipyla sp</i>)	<i>Khaya anthotheca</i>	NA	Indigenous
Phacopteroid leaf gall (<i>Pseudophacopteron</i> (=Phacosema))	<i>Khaya anthotheca</i>	NA	Indigenous
Rodents, monkeys and livestock	<i>Various species</i>	NA	Indigenous
Botryosphaeria stem canker	<i>E. grandis</i> and <i>E. camaldulensis</i>		??
Diplodia dieback (<i>Sphaeropsis sapinea</i> then <i>Diplodia pinea</i>)	<i>Pines</i>	1980s	??
Root rot disease (<i>Armillaria mellea</i> root disease)	<i>Pines</i> and <i>Grevillea robusta</i>	1984	??
Foliage disease (<i>Mycosphaerella molleriana</i> species)	<i>E. maidenii</i>	1991	??

NA = Not Applicable



Figure 8.1(a) *Eulachnus rileyi* seriously infesting pine needles in Itimbo West, Sao Hill forest plantation



Figure 8.1(b) *Pinus patula* affected by *Pineus boernerii* in Irundi range, Sao Hill forest plantation

8.4 Fire Problems in Forest Plantations/woodlots

There is no recent review of fire problems although it is a major problem in forest plantations/woodlots. During the year 2009/10, information provided by some Plantation Managers showed that a total of 3898 ha were destroyed by forest fires (Kiangi, 2010; Mussami, 2010) (**Figure 8.2**). Fire is a serious threat to forest plantations and woodlots and necessary precautions must therefore be taken to make the forests safe. Fire is considered the most important danger facing a newly established plantation before canopy closure as ground vegetation has not yet been suppressed (Evans and Turnbull, 2004).



Figure 8.2: *P.patula* plantation burned at Sao Hill forest plantation, Iringa region

8.4.1 How to Plan Plantation Establishment to Minimize Fire Danger

Proper plantation planning at establishment will make the plantations safer. The following should be considered at the time of establishing a forest plantation/woodlot (GR, 2008; SPGS, 2009):

Compartment size: one block or compartment should have an average area of 30 ha. Space between compartments should be 7.5 - 8.0 m. There may also be internal firebreaks within the compartment. A compartment register will keep a record of dates and costs of each activity including the exact seed origin used.

Roads: should be spread as much as possible to reach/or be near all compartments.

Firebreaks: external firebreaks on the outer side of the plantation should be wide enough to stop a normal fire by themselves. The width depends on the risk; however, a minimum width of 10 m clear of vegetation is recommended (**Figure 8.3**). Internal firebreaks (i.e. those made within the plantation) are narrower than the external ones. They should have a width of 5 to 10 m depending on slope. For conservation zones, a firebreak width of 60 m is recommended (GR, 2008).



Figure 8.3: A plantation of *P. patula* showing internal and external firebreaks

8.4.2 Causes of Forest Fires

Although some forest fires are caused by lightning, most are caused by people, either accidentally or deliberately. The main causes of forest fires include (Zobel et al., 1987; Evans and Turnbull, 2004; SPGS, 2009):

- (a) **Arson:** this may be caused by workers or neighbours. Unhappy workers and neighbours may set fires to vent their anger. Fair and timely payments to workers according to government regulations and resolving disputes amicably with workers and communities are ways to prevent arson;
- (b) **Self-inflicted:** these are fires occurring due to poorly planned controlled burning during land preparation or negligence with cooking and/or warming fires. There should be clear rules stipulating when burning is permitted as well as rules regarding any fire on one's land;
- (c) **Fire spreading from surrounding land:** this is caused by farmers burning crop residues

and/or preparing land for planting or encouraging new grass for domestic and wildlife grazing. There should be good relations among communities and between communities and large plantation owners. Communities should be educated on fire danger and good fire management and should seek assistance from forest extension officers or forest plantation management before setting fires. Communities should also develop by-laws on fire prevention and control;

- (d) **Honey hunters:** those collecting honey illegally within the plantation area, or legally in village woodland area may cause fire as the smoky rag to placate bees can cause fire. Honey hunters should be encouraged to seek assistance from plantation staff; and
- (e) **Other:** cigarettes thrown from car windows can cause fires. There should be warning signs on major roads passing through forest plantations.

8.4.3 Fire Prevention and Control

There are various ways to prevent and control forest fires. Preventive actions include (Evans and Turnbull, 2004; SPGS, 2009):

- (a) **Annual preparation of firebreaks:** firebreaks must be prepared in advance of a fire season. Firebreaks can be cleared manually, by use of a tractor (ploughing or disking) or by controlled burning when the surrounding vegetation is green and not highly flammable. Manual clearance of strips on either side of the firebreak can be combined with burning the remaining vegetation when dry. Alternatively, vegetation can be slashed as close to the ground as possible, stacked in the middle of the firebreak and burned when dry. Staff and equipment must be there to control the fire in case it jumps out of the firebreak;
- (b) **Reduction of combustible material on forest floor:** in older plantations, branches, litter and undergrowth accumulate (fuel load) and can be a serious fire hazard. Most of this material can be removed by prescribed burning. Prescribed burning requires favourable weather with little wind. Grazing and clean weeding are other ways of reducing fuel load. Grazing must be timed during the dry season to minimize soil compaction; and
- (c) **Planting less susceptible species at high risk locations:** generally broad leaved species are less flammable than conifers, though some conifers e.g. *P. caribaea* have high recovery after fire.

Fire control is by fire fighting and is explained below:

- (a) **Fire-fighting and suppression:** a fire will only burn in presence of oxygen, heat and combustible material (fire triangle). If one factor is eliminated, fire goes out. Fire-fighting involves (i) use of water (from back packs, portable pumps or vehicles). There must be reliable water supply available to replenish water dispensing units; (ii) fire beaters are used to exclude oxygen in surface fires while rake hoes are used to scrape the ground clean, and (iii) constructing temporary breaks to contain fire by use of bulldozers or backfiring. After the main fire is extinguished, guards should be left to patrol and continue damping down to prevent the fire re-starting;

- (b) **Communication:** rapid detection and movement of fire-fighting teams to the scene will greatly reduce damage. Early detection is by use of fire towers (**Figure 8.4**) or observers posted at good vantage points or the recently established fire satellite at TAFORI, Morogoro. Alarm is raised and information about the fire, its location and possible size relayed to fire-fighting teams. Fire-fighting crews must be well trained and should be provided with good fire-fighting equipment and transport to reach the scene quickly. A planned and coordinated attack is more effective than individuals working separately. Everyone must have somewhere to escape to when the fire gets too strong.

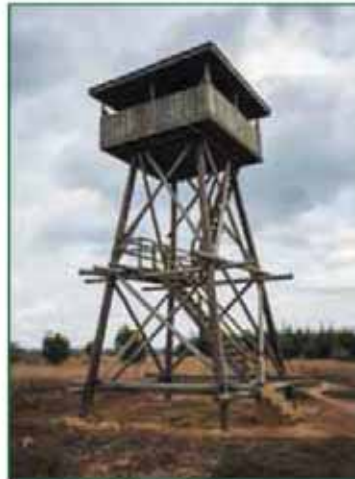


Figure 8.4: A fire tower at Sao Hill

8.5 Conclusion

Forest health monitoring is key so that its impact can be timely assessed and appropriate control measures taken. Stricter quarantine and inspection at port of entry will reduce possible future insect pest/disease importation.

9. MAINTAINING LONG TERM FOREST SITE PRODUCTIVITY

9.1 Introduction

While in a number of instances new areas are being opened up for plantations/woodlots, in other situations, future wood needs will have to be obtained from existing sites i.e. second and subsequent rotations. The productivity of the second and subsequent rotations will have to be maintained or increased to meet the increasing domestic and international demand for wood and wood products. Maintaining or increasing plantation productivity can be achieved by adopting appropriate soil and site management practises namely nutrient retention (nutrient removals in harvesting and post-harvest slash management) and protection of the soil structure.

9.2 Nutrient Removals in Harvesting

The amount of and rates at which nutrients are removed from the site in biomass depends on the species grown, the degree to which biomass is utilised and the rotation age of the crop. Nutrient removals can be substantial where whole or total tree harvesting is practised as against conventional harvesting (bole wood and bark harvesting). The percentage increase in nutrient removal is greatest when harvesting young stands where relatively more of the nutrients in above ground biomass are stored in the components of the canopy. However, total tree harvesting is not commonly practised in Tanzania and Evans (1996) has shown that harvest of forest products when confined to stem wood, generally represents a small export of nutrients from a site over time and over the entire rotation there are not always net losses of key elements from the system.

9.3 Soil Compaction

Site preparation of wet soils or using harvesting equipment during the rainy season may result in soil compaction and thus reduced site productivity. Reductions in tree height, diameter and volume growth are often observed where soils have been compacted (FAO, 2001). Proper harvesting planning among others should include harvesting during the dry season and careful re-use of extraction routes to minimise compaction and soil erosion (FAO, 2001).

9.4 Soil Erosion

Soil erosion may occur before or after canopy closure depending on site preparation and weeding techniques, slope and species differences on suppression of undergrowth. When soil erosion has been noticed, it should be controlled using appropriate soil conservation measures like retaining contour strips of ground cover, digging contour trenches, erecting barriers e.g. rock piles to slow runoff and for areas with gullies, building check dams.

9.5 Post-harvest Slash Management

The manner post-harvest slash is managed after harvesting affects site productivity. When slash and litter from the previous crop is left on site, it can act as a long term source of nutrients through mineralization. In some forest plantations in Tanzania, post-harvest slash is burned to ease access for site preparation and planting or to allow Taungya farmers to plant food crops (Chamshama and Lupala, 2012). Whereas burning may be a useful tool for site preparation and weed control, it may also result in rapid nutrient release, increased leaching losses, volatilisation of some

nutrients, and enhanced nitrogen mineralization. Moreover, burning can alter physical and hydrological soil properties, affecting subsequent site productivity. In other situations, slash and litter are raked or gathered (FAO, 2001). This also results in nutrients from the slash not being made available to the subsequent crop and there is also risk of erosion.

Few studies in the tropics have investigated the effect of post-harvest slash management on tree survival and growth. In a recent trial in northern Tanzania, the effect of post-harvest *Cupressus lusitanica* slash on early growth of *Pinus patula* was investigated (Chamshama and Lupala, 2012) (Table 9.1).

Table 9.1: Effect of slash management on 3 year growth of *Pinus patula* at Shume, Tanzania (Chamshama and Lupala, 2012)

Treatment	DBH (cm)	Height (m)	Volume (m ³ ha ⁻¹)
Control-slash retained	9.38	6.81	23.68
Slash removed	9.06	6.54	21.09
Slash burned	8.66	6.22	18.39

Table 9.1 shows that effects of slash management treatments on seedling growth were significantly different (the Table has been simplified, significant levels are not shown). Results have only been presented for the final assessment but differences were significant at all assessment occasions (6, 12, 18, 30 and 36 months). The results of the study are consistent with those reported elsewhere (FAO, 2001). Thus, in order to maintain site productivity, slash burning which is commonly used by Taungya farmers for site preparation should be discontinued as the technique has negative effects on site productivity. Further, soil for nursery use should not be collected from plantation areas, as this will also result in reduced site productivity.

9.6 Conclusion

Proper management of plantation sites during and after harvesting is key to maintaining long-term productivity. Vehicular traffic must be planned to minimise compacted areas. Nutrient rich biomass (fine branches and foliage) should be left on site. Site preparation techniques must ensure retention of slash as well as avoidance of re-distribution of top soil. For new plantation sites, baseline data should be collected, and these sites should be monitored for changes in soil physical and chemical characteristics.

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GLOSSARY

- Afforestation:** The establishment of a forest, naturally or artificially on an area, whether previously forested or not.
- Clone:** A group of genetically identical individuals.
- Commercial/plantation forestry:** The practice of forestry with the objective of producing timber and other forestry products as a business enterprise.
- Compartment:** Smallest sub-division of the forest area for purposes of silvicultural operations and defined by permanent boundaries.
- Conservation:** Protection, improvement and use of natural resources according to principles that will assure their highest economic and social use.
- Diameter at breast height (DBH):** The diameter of the stem of a tree measured at breast height (1.3 m) above the ground.
- Dormancy:** Seed fails to germinate even when conditions for germination are ideal.
- Dominant height:** The average height of 100 largest trees per ha.
- Fire break:** A strip of open space in a forest to obstruct fire.
- Forest management:** The practical application of scientific, economic and social principles to the administration and working of a specific forest area for specific objectives.
- Forestry:** The scientific management of forests for the continuous production of goods and services.
- General combining ability:** Ability of an individual tree to form good progeny when crossed with any other individual tree.
- Germination test:** Measures the proportion of seeds that are capable of germinating.
- Increment:** The increase in circumference, diameter, basal area, height, volume, quality or value (over an arbitrarily selected period of time) of individual trees or groups.
- Integrated pest/disease management (IPM):** Includes sound selection of planting materials with genetic traits tolerant to damaging biotic agents, improved silviculture and actions of natural enemies and cultural control.
- Mineralization:** Decomposition of organic matter to release nutrients.
- Natural forest:** A group of indigenous trees whose crowns are largely contiguous.
- Plus tree/good phenotype:** A tree selected on the basis of its outstanding phenotype (characteristics).
- Pollen dilution zone:** Space between a seed orchard site and other similar species to minimize contamination from unwanted pollen.
- Prescribed burning:** A controlled fire is allowed to burn when the vegetation has started to dry. It does not cause complete destruction of existing vegetation.
- Progeny:** Offspring of a particular tree – as in progeny testing.
- Protection/preservation:** The maintenance of biological diversity by subordinated resource utilization.
- Provenance:** The original geographic source of seed or propagules (of a tree).
- Provenance trial:** A well-designed comparison of population sampled from a range (preferably the whole range) of species. Each 'provenance' is a potential 'ecotype' of that species. Should be established in two or more environments to enable assessment of provenance x environment interaction.
- Pruning:** The artificial removal of the branches of standing trees in order to increase the quality of the finished product.
- Pruning schedule:** Indicates the timing of pruning as well as pruning height.
- Purity:** The percentages (by weight) of pure seed, other seed and inert matter in a sample (and by inference the composition of the seed lot).

Recalcitrant Species: Species whose seed cannot be dried below 40% moisture content.

Roguing: Removing trees of poor genotype (genetic constitution) after progeny test.

Rotation: Period in years between establishment of a stand of timber and the time when it is considered ready for final harvest.

Regeneration: The re-establishment, either naturally or artificially, of a forest, plantation or stand of trees after felling.

Seed: Morphologically the structure developed from fertilized ovule in seed plants.

Seed orchard: A plantation of genetically superior trees, isolated to reduce pollination from genetically inferior outside sources, and intensively managed to produce frequent, abundant, easily harvested seed crops. It is established by setting out clones (as grafts or cuttings) or seedling progeny of trees selected for desired characteristics. **Unrogued First Generation Orchard** is formed by phenotypically selected parents when grafted in the orchard; **Rogued First Generation Orchard:** after progeny test, removal from the orchard of those trees that produce undesirable progeny; **Greatly Improved First Generation Orchard:** orchard developed from good general combiners, (i.e. parents that produce good progeny with a number of other parents) from a number of orchards of similar geographic backgrounds and bringing them together into a new orchard; **Second Generation Orchard:** consists of best trees of the best families selected from progeny test.

Seed stand: A plus stand that is generally upgraded and opened by removal of undesirable trees and then cultured for early and abundant seed production.

Seedling: a plant (tree) grown from seed. i.e. a very young tree not yet at sapling stage.

Silviculture: The growing and tending of trees as part of forestry.

Site Class: A measure of the relative productive capacity of a site, considering the crop, based on height, volume or mean annual increment at a given age.

Soil compaction: The method of mechanically increasing the density of soil.

Spacing: Space provided between individual trees during establishment.

Species trial: A well-designed comparison of different tree species.

Species-site matching: Ensuring that a species is planted in its appropriate environment for best survival and growth.

Stocking: A quantitative measure of stocking expressed in terms of number of trees, basal area or volume per unit area.

Swaziland bed: A bed on an impervious layer 1-1.2 m wide and up to 20 m long edged with cement bricks or timber for production of bare root seedlings.

Taungya: Involves the growing of annual agricultural crops along with forestry species in a public or private sector plantation during the early years of establishment of the forestry plantation.

Thinning: The removal of a proportion of individual living trees from a stand before clear felling.

Thinning schedule: Indicates for given species and ages the number of stems to remove and retain as well as the rotation age.

Transplant: A plant (tree) seedling that has been replanted (pricked out), in the nursery, to provide it more space for development.

Viability: Seed is classified as either alive (viable) or dead (non-viable).

Weeding: Reduction or elimination of competition for light, soil moisture and nutrients from undesirable species - which have grown around seedlings or young trees.

Woodlot: A group of trees of less than 25 ha in extent, with a limited variety of products, primarily grown to meet basic needs, though sometimes for economic gain.

Yield: The total amount of wood available for harvesting from stand at any time.

