EVALUATION OF THE GROWTH PERFORMANCE OF EUCALYPTUS TREE HYBRIDS PLANTED IN VARIOUS AGROCLIMATIC AREAS IN KENYA

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DECLARATION

Candidate's declaration

This thesis is my original work and has not been presented for any other award. No part of this thesis may be reproduced without prior permission from the author and/or Kenyatta University.

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Declaration by supervisors

I/We confirm that the work reported in this thesis was carried out by the candidate under my/our supervisors.

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DEDICATION

To my loving wife **Wangari Wambugu** for her support and inspiration which kept me going.

To my three daughters **Cynthia, Diana and Doreen** for their patience and love they have shown in the course of the study.

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ABSTRACT

The unprecedented rate of deforestation and forest degradation in Kenya has resulted in acute wood shortage. To address this problem, eucalyptus tree hybrids clones were donated to Tree Biotechnology Project in Karura, Kenya by Mondi Forest of South Africa. To evaluate the best planting eucalyptus germplasm, five long-term trials consisting of both eucalyptus hybrid clones and the local progeny in Karura, Machakos, Kabage, Embu and Gede were studied. The study sought to establish the height and diameter growth, stem formation, self-pruning ability, straightness, branching and crown formation of the introduced eucalyptus hybrid clones and the non-hybrid eucalyptus germplasm in different sites. In each trial, 20% of the trees in each plot were selected randomly and height and diameter measurements were taken by use of a sunto and diameter tape respectively. Observations were made on stem form, crown size, branching, self-pruning and survival rate. Analysis was carried out by use of descriptive and inferential statistics. The Genstat Statistical Package was used to carry out both the ANOVA and LSD tests on both DBH and height in all eucalyptus varieties under study. In Karura site there was significant mean height growth variation between the introduced eucalyptus clones and the non-hybrid E. *tereticornis* and E. *saligna*, with the clones exhibiting, high survival rates and high level of straightness (95% and 65% respectively). *E. grandis* exhibited similar growth to clones but with low survival rate. In Embu, the eucalyptus hybrid GCs 642 and 15 achieved significantly high mean height than the non-hybrid varieties. Similarly, the eucalyptus hybrid clones achieved high survival rates (above 95%) compared to E. *grandis, E. saligna and E. camaldulensis*. In Machakos, *E. grandis* achieved similar mean height to eucalyptus hybrids apart from eucalyptus hybrid GC 10. Survival rate for all the eucalyptus germplasms in this site apart from *E. saligna* was over 85%. *E. grandis* attained relatively high level of straightness (90%) with eucalyptus hybrids GCs 642, 14, 15 and 581. In Kabage, Nyeri, there were no significant difference for both mean height and mean DBH (LSD 1.3 and LSD 1.67) between the non-hybrid *E. grandis* and hybrid GUs. The high survival rate and straightness of *E. grandis* was comparable to that of GU 7 (89%), GU 8 (96%) and TAG 5 (pure *grandis*) respectively. In Gede, significant variation in mean height was observed between progenies. However, eucalyptus hybrids GCs 785, 581, 167 and 584 achieved a significantly high mean height compared to the rest of eucalyptus germplasms. For the mean DBH, eucalyptus hybrid GCs 785, 581, 167 and 584 compared favourably with non-hybrid *E. camaldulensis*, hybrid GU 21 and hybrid GC 540. The survival rate was high (over 85%) for all the progenies apart from hybrid GC 796 which failed. Crown diameter for the non-hybrid progenies were small compared to those of GUs and GCs, and apart from the hybrids GC 785 and GC 167, all others achieved high branching (over 60%). From the results, the GCs performed well in height, DBH and survival rate than local land races in Karura and Embu, the *E grandis* exhibited exceptional performance among the local land races in all sites it was planted and GCs are the suitable progeny for a number of agro climatic zones across the country as *E tereticornis* comes out as the least suitable among the local land races. The study recommends aggressive extension strategy for the suitable hybrids, monitoring of their health as well as continued research and silvicultural studies to find more on their effect on hydrology and soils as well as market reliance.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACIAR	-	Australian Centre for International Agricultural Research
ANOVA	-	Analysis of Variance
DBH	-	Diameter at Breast Height
FAO	-	Food and Agricultural Organization
GC	-	*Grandis* and *Camaldulensis* eucalyptus hybrid
GU	-	*Grandis* and *Urophylla* eucalyptus hybrid
IUCN	-	International Union for Conservation of Nature
KEFRI	-	Kenya Forest Research Institute
KFMP	-	Kenya Forestry Master Plan
KPLC	-	Kenya Power and Lighting Company
KTDA	-	Kenya Tea Development Agency
LSD	-	Least Significant Difference
MADI	-	Mean Annual Diameter Increment
MAHI	-	Mean Annual Height Increments
MAI	-	Mean Annual Increment
ODA	-	Overseas Development Agency
TELKOM	-	TeleCommunication of Kenya
USDA	-	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.0 Background to the Problem

Forests are one of the world's most vital natural resources. An approximately 14.6 million hectares was lost every year between 1990 and 2000 in Africa while annual planting rate has been estimated at 5.2 million hectares per year (FAO, 2001). Major causes of forest loss include human activities such as illegal encroachment, excisions, charcoal burning, illegal cultivation, overgrazing, unsustainable exploitation of forest produce, poaching of timber and frequent fire outbreaks. In Kenya, forest is in a deplorable state due to wanton destruction. The unsustainable exploitation of forest resources has greatly reduced productivity and forest cover in Kenya leading to a projected wood supply deficit of 3 million M^3 by the year 2010 (FAO, 2001).

Timber market surveys indicate that a tone of cypress timber, which cost on average Kshs. 8,000 in mid 1990s, is currently being sold at Kshs. 25,000 (Luvanda and Kareko, 2000). Some of the consequences of forest loss include: inadequate supply of timber and other wood products which has affected industrialization and hence employment; loss of biodiversity, and destruction of water catchment function, which is manifested in; reduced water supply for domestic and industrial consumption. Thus the main mitigating factor is the enhancement of farm forestry using superior germplasm and encouraging the establishment of long-term commercial forestry plantations and farm woodlots to supply raw materials to rural-based cottage industries as well as to support cheap and renewable wood fuel supply. This can provide the necessary support to rural livelihood and thus alleviate poverty.

The Kenya Forestry Master Plan (KFMP) Survey in 1997 (MENR, 1994), on wood biomass status revealed that about 40% of the woody biomass are from planted trees and that the total volume of planted trees by farmers equals that of the closed canopy indigenous forest and government forests plantations combined. By the year 2020, the KFMP estimated that the farms and settlements would produce about 17.8 million M^3 wood which approximates 80% of the total wood production in the country.

Species like Eucalyptus are widely grown due to their fast growth, good stem form, coppicing ability, reasonably durable wood, tolerance to water logging, multipurpose use (firewood, poles and posts, timber and essential oils) and ready markets for its products.

There are many species, which the majority of the farmers are familiar with, which include *Eucalyptus saligna, Eucalyptus grandis, Eucalyptus globules, Eucalyptus camaldulensis, and Eucalyptus tereticornis*. During the last three to five years, *Eucalyptus grandis* and *Eucalyptus camaldulensis* hybrids were introduced in the country from South Africa in an attempt to provide farmers with planting materials which meets their quest for fast and reliable source of income.

The eucalyptus hybrid clones were donated by the Mondi Forest, which is a leading private company, based in South Africa free of charge to the Tree Biotechnology Project – Karura (Annual Report 2003). The trials were established on a wide range of sites including Naivasha, Timboroa, Embu, Machakos, Karura, Laikipia, Hombe, Malindi, Kwale, Kitui, Baringo, Nyeri, Muguga and Kakamega. Unfortunately their growth performance is not yet assessed.

1.1 Statement of the Problem

The introduction of eucalyptus hybrids in the country in 1998 was meant to address the fuel wood and other wood products shortage caused by forest depletion in Government forests, trust lands and farmlands. IUCN (1995) estimated that forest loss in the country was 5000 hectares per year. The ban on timber harvesting from Government forests in 1999, coupled with lack of clear policy and registration on forest management has aggravated the situation and consequently led to accelerated demand for wood product and hence the need for eucalyptus hybrid planting materials. Farmers have already perceived them as the window of hope in addressing their wood requirement needs.

However, it has become increasingly difficult for farmers to identify the most suitable eucalyptus hybrid for their area and this has made most of them to be discouraged, as quite often than not the planted hybrids performance does not commensurate with the yields predictions. The challenge therefore is to ensure that the farmers access the most suitable eucalyptus hybrid for planting in their particular area out of all introduced eucalyptus hybrid. This study, therefore, attempted to identify the best performing eucalyptus hybrid clones for specific areas.

1.2 Justification

Apart from wood products, eucalyptus tree species like other species provide valuable environmental benefits. These include protection of soil and the sequestration of the greenhouse gases among other services. They support a wide range of livelihood and subsistence needs, including the basic needs for fuel, timber, poles, medicine as well as pulp among others. Fuel wood remains the main source of energy in Sub-Saharan Africa.

In Kenya, 93% of rural households energy need is met from fuel wood (MENR, (1994). Eucalyptus tree hybrids are perceived as a new opportunity in addressing these needs. This explains the high demand for these eucalyptus hybrids during the last five years. There is, therefore, an urgent need to evaluate the performance of these eucalyptus hybrids in various sites where they have been planted for trial to develop a catalogue of the most suitable eucalyptus progeny for planting by farmers in these areas.

1.3 Research Questions

This study sought to answer the following questions: -

(a) How does the height and diameter growth of the various introduced eucalyptus hybrid clones under study compare to the locally growing non-hybrid eucalyptus germplasm?

(b) How do the different eucalyptus hybrid clones compare with non-hybrid eucalyptus germplasm in survival rate, crown formation, branching, straightness and self-pruning ability?

(c) Which of the introduced hybrid eucalyptus hybrid clones could be the most suitable or best performer in each trial site under study?

1.4 Hypotheses

(a) There is height and diameter growth variation between the introduced eucalyptus hybrid clone and non eucalyptus species planted in all the sites trials under study.

(b) There is significant growth variation of different hybrid clones in the same site.

(c) There is variation in survival rate, crown formation, self-pruning characteristics, branching and straightness between the introduced eucalyptus hybrid clones and the locally growing eucalyptus germplasm.

1.5 Research Objectives

The main objective of this research was to find out the most suitable eucalyptus germplasm for Karura, Kabage, Embu, Kitui and Gede so as to mitigate wood deficiencies. Specifically, the study attempted to: -

(a) Assess the height growth variation between the introduced eucalyptus hybrid clones and the locally known non-hybrid eucalyptus germplasm planted in these sites.

(b) Asses the diameter growth between introduced hybrid eucalyptus hybrid clones and the locally known eucalyptus germplasm in the above sites.

(c) Assess the straightness, self-pruning ability, branching, and crown form of both the hybrid eucalyptus hybrid clones and the non-hybrid ones planted in the sites.

(d) Assess the survival rate of different hybrid clones and the non-hybrid ones in the sites.

1.6 Significance of the Study

Evaluation of the performance of the introduced eucalyptus hybrids and comparison with the non-hybrid progeny will generate information on various growth parameters which are used to site match the species across various agro climatic zones in Kenya. This ensures that farmers in these zones will access the most suitable Eucalyptus progenies for planting in their farms. This improves yields and consequently the level of returns in tree farming investment

1.7 Conceptual Framework

The study aimed at establishing the growth performance of the eucalyptus hybrids and the widely known non-hybrid species. Growth performance is directly linked to site climatic conditions, genetic make up of the species and on site management. The inherent indicators of growth are normally the diameter and height. However, the tree resistance to pests and diseases, crown form, self-pruning ability and the general stem form, among others, are important indicators of growth. The sites variations in growth of the eucalyptus progeny under study could be directly influenced by both genetic make up and site conditions. It is, however, assumed that all the sites received the same management treatment, which includes weeding, spacement and fertilization. Therefore, the sites variations in terms of growth performance could be associated with both genetic make up of the progeny as well as climatic conditions. Also, very few hybrids were replicated between the sites to enable one make informed comparison of between-site growth performance. The degree of branching, self pruning ability, crown formation and stem straightness is a reflection of genetic variations of each progeny within-site. This interrelationship could be depicted as follows:

As shown in Figure 1.1, growth performance of each eucalyptus progeny in each study site, is determined by the climatic condition for each site, genetic composition of each progeny and the state of tree management. The diameter and height growth, crown formation, stem form, branching level and survival rate are all dependent on the inherent genetic composition of each progeny. By assessing these parameters in the five different sites, each with its unique climatic conditions and management, it was possible to determine the eucalyptus species that performed well under each set of conditions. These conditions, however, ensure that inherent trait in each of these progeny is fully expressed during growth.

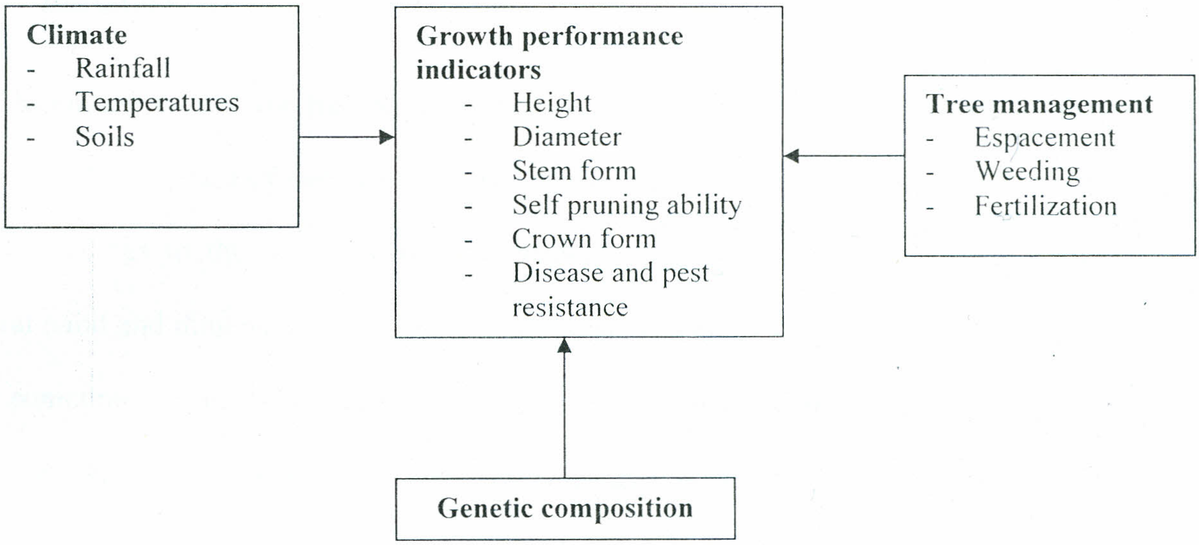

Figure 1.1 Eucalyptus Growth Performance Indicators and Factors Influencing Them

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The Australian Centre for International Agricultural Research (ACIAR) has identified more than 600 species of eucalyptus. New ones are yet to be identified. Eucalyptus tree species belongs to the family *myrtaceae*. However, each species is distinguished by general habit and dimensions; its bark in adult stage; seedlings, juvenile and adult leaves and sometimes transitional leaves between these two latter phases known as "intermediate leaves" young branches; inflorescences; bud shape; stamens; fruits and seeds. The species are found in almost all of the major habitat types in their native Australia. A few species occur as natural in Papua New Guinea, Indonesia and Philippines (Davidson, 1978).

The evolution of the eucalyptus has produced species and provenances fitted to an enormous range of environmental conditions within the natural range of the genus. On the other hand, the outbreeding characteristics of the eucalyptus result in great deal of genetic variability even within a local population. This implies a capacity both for the individual phenotypes to adjust to changes in the environment and for an introduced population to adopt over successive generations by natural selection. This variability permits changes in structure or function to conform to changed environmental conditions. This has given the eucalypts their reputation for adaptability or "plasticity". The most widely used species for both commercial and social forestry are *Eucalyptus grandis*, *Eucalyptus camaldulensis*, *Eucalyptus tereticornis*, *Eucalyptus urophylla*, *Eucalyptus* *vimiadis, Eucalyptus saligna, Eucalyptus degluple, Eucalyptus exserta, Eucalyptus citriodora, Eucalyptus paniculata and Eucalyptus robusta.*

In the tropics and subtropics, eucalyptus is often judged to be fast growing and most likely to survive in harsh climatic conditions (FAO, 2001). The species are believed to out perform indigenous species. They are easy to cultivate, unpalatable to livestock (and therefore easy to protect), they tolerate sites of low inherent nutrients status, they are draught resistant, coppice readily and produce a superior short fibre. In Asia, eucalyptus is being used to rehabilitate millions of hectares of land, which experienced severe deforestation between 1981 and 1990 (FAO, 1993). Over four million hectares of eucalyptus now exist in India, Thailand, Vietnam, among others in the Asian region.

2.1 Common Eucalyptus Tree Species in Kenya

2.1.1 *Eucalyptus camaldulensis*

It has proved useful for afforesting semi-arid tracts. It is one of the first species to be introduced in the country. The species is dominant around Mediterranean. Its general characteristics and site requirements are normally associated with the provenances from the Murray Darling systems (i.e., ecosystems of the Murray River Forests in New South Wales). Most of these characteristics include: ability to thrive and produce acceptable yields on relatively poor soils with a prolonged dry season, ability to tolerate periodic water logging, production of harder heavier and more deeply coloured wood, a vigorous coppice and usually crooked and thinly crowned. Plantations are managed on coppice rotation and the length of rotation varies from country to country depending on the final products. It is easily propagated by cuttings and hybridizes freely with a number of species. In good sites Mean Annual Increment (MAI) of 2m in height and 2cm in diameter has been achieved while volume yields of 20 to 25m³ per hectare/yr has been reported from good sites in Argentina while in Israel 30m³ has been obtained under irrigation.

2.1.2 *Eucalyptus globulus*

It is commonly known as Tasmanian blue gum occurs naturally in coasts of Victoria. In Australia it has been known to achieve 45 – 55m thus attaining massive trunk and heavy spreading crown. Its early success outside Australia made it the most extensively planted eucalyptus species in the world. It is mostly planted in Portugal and Spain on suitable sites. It is considered the fastest growing species in India. According to Jacobs (1970), its widespread and popularity was attributed to its unpalatable juvenile leaves. Cattle sheep and goats seldom browse it. The species is also easy to propagate, generally of good stem form, grows fast; closes canopy rapidly, coppice vigorously and is wind firm. It seeds well at relatively early age and produces seeds of high germination percent; it is best suited where mean annual precipitation is above 900mm. It is known to hybridize with a number of species and the well-known species are *compacta and coronifera.* Yield of 40m³/ha/yr has been reported in Portugal and as much as 70m³/ha/yr in Spain under irrigation. In best sites MAI of the range 20 – 23m³/ha/yr at age 10 of merchantable wood has been reported (FAO, 1979). The subspecies is widely grown on rather short rotations of 8-12 years or 10-15 years. In Ethiopia it is planted at a short rotation of 5 – 7 years.

2.1.3 *Eucalyptus grandis*

This is another popular species of wide distribution. It has its natural occurrence in Australia. It is commonly known as flooded gum. It is widely confused with *Eucalyptus saligna* due to their similarity. However, distinct differences are found with their barks, buds, flowering season, fruits, roots and the branches response to shade. In terms of timber quality, *Eucalyptus saligna* is denser, however, it tends to develop wider splits and also its radial shrinkage is greater than the *Eucalyptus grandis*. Sapwood of *Eucalyptus saligna* is more susceptible to attack by larvae of the powder post beetle. It is widely planted in South Africa- introduced in 1885 and by 1973; over 275,000 ha had been planted. The *Eucalyptus grandis/saligna* complex is unquestionably the most widely planted eucalypts in the world. What makes it the best among other species when grown in best sites is its annual height growth (2-3m/yr for the first 10 years), its natural self punning ability, dense crown, flowering and seeding normally after 4 or 5 years and its free coppicing when young. It prefers a minimum of 800 mm of rainfall with best growth achieved with rainfall of over 1000mm. It is diseased when subjected to uniformly high temperatures and does not withstand severe frost.

Hybridization of the species has been undertaken and clonal seeds orchards established. In countries like South Africa mean annual increment of $40m^3$ per hectare has been achieved. However in better sites in Kenya (Muguga), MAI of $32m^3$ especially for the coppice have been achieved even without irrigation (FAO, 1979). However, reported annual yields varied from country to country and from one site to another.

2.1.4 *Eucalyptus regnan*

It naturally occurs in Australia and is known to grow up to 90m. It has magnificent trunk and is rough and fibrous at the base. The wood is pale brown with prominent growth rings. It forms a magnificent forest and is considered the tallest hardwood forest in the world. It is however not a coppicing species. In Kenya (about 3000m altitude) a plantation of this species had a top height of 80m in 30 years (Height growth of approximately 2.5 m/year).

2.1.5 *Eucalyptus tereticornis*

In Australia, it is commonly known as forest red gum. It occurs naturally throughout Australia and Savannah woodlands of the Papuan Coast of New Guinea. It is considerably more draught resistant with light, narrow crown and varies considerably according to provenance. It coppices vigorously and begins to produce seed at 3-6 years. It requires rainfall of between 800 and 1500 mm. It has, however, been planted in higher rainfall areas. It will grow on a variety of soils preferably in deep, well-drained soils of fairly light texture including alluvial soils, silts and sandy clays. Through research, two promising hybrid species have evolved by artificially crossing it with *Eucalyptus camaldulensis*. The hybrids have displayed striking degree of hybrid vigour in both height and diameter growth and have produced at the early age of 4 years nearly three times wood volume of *Eucalyptus tereticornis*. Also promising is the cross with *Eucalyptus grandis* in Kerala State of India and in Zambia. The use of lignotuberous, branch cutting and epicormic shoots from order trees has been a success in its propagation.

The species rotation varies with site quality and the objects of management. It ranges from 5-7 years in Congo, 9-12 in Argentina, 7-15 years in India and 16 years in Uruguay. It has registered 1-3 m height growth per year and diameter of 4 cm per year in best sites. A mean annual increment of 18-25m^3/ha/year has been registered in best sites in Congo, Argentina, Ivory Coast, India and 11 Uruguay. It is fairly free from pests and diseases.

2.1.6 *Eucalyptus citriodora*

It is also a widely grown species and is reported to attain a height of 30-40m especially in Australia. It is a tree of excellent form with strong hard and fairly durable wood. It has succeeded where *Eucalyptus grandis* has failed due to high temperatures (max 35°C min 5°C). It is widely grown in Asian countries of Pakistan, China and Thailand. In Kenya, 19 species were tried out between 1903 and 1906 mainly to provide firewood for railway engines. *Eucalyptus saligna* and *Eucalyptus globulus* were selected as the best yielding trees. However, through several trials conducted during 1950s, *Eucalyptus saligna* was found to achieve the highest yields (24 m^3/ ha/yr). Other eucalyptus species yielded less than 15m^3/ ha/yr (FAO 1979). Further trials showed that *Eucalyptus grandis* performed better than *Eucalyptus saligna*. They, however, would show slow growth as compared to *Eucalyptus regnans* and *Eucalyptus fastigata* in elevation of over 2400m above see level (Gottneid and Thogo, 1975; Konuche 1989; Oballa, 1989).

2.2 Eucalyptus Species Utilization

Eucalyptus species have a very wide utilization, at least classified as follows:

2.2.1 Products

Eucalyptus superior short length fibre makes it extremely useful in paper making and charcoal production. Moreover, eucalyptus has many uses in social forestry as it is extensively used as source of firewood and poles. The non-hybrid *Eucalyptus tereticornis*, *Eucalyptus saligna*, *Eucalyptus grandis* and *Eucalyptus camaldulensis*) are widely used for fuel wood. They burn well and when air-dried leave little ash.

A market survey carried out in 2000 revealed that the species are widely used for furniture production in many parts of the country due to the current indigenous and exotic wood shortage. In addition, major companies like KPLC and Telkom use eucalyptus species for power transmission poles and telephone posts. Kenya Tea Development Agency (KTDA) has made a major strategic plan to change from furnace oil to wood energy, to fire their boilers for tea drying. This will save tea farmers up to approximately Kshs. 1 billion in addition to other environmental benefits (KEFRI 2003).

Eucalyptus tree has been described as an all-purpose tree and is depicted as the tree for industrialists, agriculturalists and environmentalists. It is a viable source of raw materials for agrochemical industries - a technology currently in use in Australia, Spain and Italy. The oils in the bark, leaves, flowers and buds are being used in many countries for the manufacture of medical pharmaceutical products and perfumery production. Essential oils used for the manufacture of medicine have a chemical called Cineole, which kills disease-causing agents such as bacteria and fungi. Eucalyptus oil contains 70% of this cineole. *Eucalyptus dives* grown in Australia contains 45 – 50% pipperitone, a chemical used in the manufacture of thymol and menthol. Thymol is a preservative for gums, poster glues, distempers and furs. Menthol is an ingredient in the manufacture of cigarettes and in the local anaesthetic in dental pastes.

2.2.2 Services

Due to their huge branching and rooting network they have been used as shelter belt and erosion controls. A species like *Eucalyptus globulus* has been used for amenity and roadside planting due to its attractive dark green and glossy leaves. It has also been widely used for erosion control due to its wide spreading and dense root system. *Eucalyptus camaldulensis* and *Eucalyptus grandis* are also commonly used for shelterbelts, shade and amenity planting in wet and dry areas respectively. Most of these species are also used for reclaiming marshy or flooded areas as they have high water uptake capacity.

2.3 Eucalyptus Controversy

It is, however, a reverse when Shiva and Bandyopadhyay (1981) compare it with traditional trees in their contribution to the rural life supports systems. They see traditional trees as sources of medicines, wood, soil conservation, fodder as well as playing an important role of replenishing sole nutrients. On the other hand, they question the eucalyptus species capacity in soil and water conservation as well as its use in nutrients cycling. They emphasize that without the last two roles, the tree cannot stand the test of sustaining life for rural communities. It only deprives what the land had stored (nutrients) without replenishing it. This lowers the land productivity and consequently affects the lifeline of the rural communities.

In a report entitled 'Ecological Audit of Eucalyptus Cultivation', Shiva and Bandyopadhyay (1981) argue that the spread of eucalyptus on rain-fed land is nothing but unscientific prescription for desertification. They claim that eucalyptus depletes water supplies and does not regulate the flow of water as well as the native vegetation they may have replaced, depletes the soils nutrients and produce toxins that kill neighbouring crops, compete aggressively with other vegetation and displace indigenous species.

The dilemma over the use of eucalyptus for social economic and environmental purposes has been of major concern in countries where there has been wide spread planting of eucalyptus species for commercial and domestic purposes. In Ethiopia, for example, 477,000ha provide a vital role in supplying wood, poles and fuel wood needs of the country (Demel, 2003). In the wet zones, there is no apparent conflict between income generation and ecological functions; income generation from eucalyptus is 2-3 times higher than from cropping. Furthermore, there is growing evidence that biodiversity has increased under the eucalyptus plantations in some situations. Consequently, there is a strong interest to introduce the new hybrids to Ethiopia.

In South Africa, (eucalyptus plantations stands at 250,000ha) which is relatively dry country and is particularly dependent on limited areas of high rainfall mountain catchments as reliable sources of streams and rivers, the experience is quite different. Despite the forestry importance to the natural economy, eucalyptus plantations continue to attract severe criticism for alleged excessive use of the precious water resources of the country. The change in land use from natural forests and grasslands to evergreen forest plantations has brought about decline in stream flow over large parts of the country. To mitigate this, the country has embarked on new strategies aimed at increasing the sustainability of catchment water yields and reducing the impact of afforestation such as the removal of plantations from riparian zones, encouragement of natural grasslands, removal of invasive alien trees by unemployed people as well as enhancing the use of clonal species with higher draught resistance and increased water use efficiency (Gush and Dye, 2003).

In India, controversy over eucalyptus plantations and declining water tables mainly in the Karnataka State where eucalypts cultivation was being developed through World Bank and ODA funding was resolved in the early 1990s. These debates to resolve the eucalyptus development took coignance of the scientific information on its ability to survive in waste lands and poor sites, coppicing and its ability to survive grazing as well as perception of various stake holders (mainly farmers) on the potentiality of eucalyptus in regions experiencing dramatic decline in forest cover and facing a growing deficit in wood energy.

In Thailand, a million citizens have been displaced in a move to convert natural forest and farmlands into eucalyptus plantations. This move has, however, faced serious criticism from environmentalists, as it has been associated with devastating ecological effects. However, as the demand for wood chips soars, large companies are being encouraged to rent large blocks of national forest reserve to establish *Eucalyptus camaldulensis* plantations. The plantations have been extended to farms, communal grazing areas and wood lands.

According to Gush and Dye, (2003), eucalyptus have had very little impact on river flow and declining water table, however, its extension must be carefully planned to avoid dense stands in water catchment areas. Any tree that produces a lot of wood must take a lot of water. To promote eucalyptus, distinction, however, must be made between group of species suitable for a given climatic and soil conditions such as arid, wet and highlands. When selecting species, it is advisable to match the species suitable for the objectives.

In a FAO funded study on the ecological effects of eucalyptus later published as the eucalyptus dilemma, Poore and Fries (1985) conclude that "there is no universal answer either favourable or unfavourable to the planting of eucalyptus; each case should be examined on its individual merits". Eucalyptus should not be planted, especially on a large scale, without careful and intelligent assessment of the social and economic benefits of such undertaking.

2.4 Characteristics of Seedlings and Clonal Eucalyptus Tree Orchards

Over the years, the standing stock of the eucalyptus has either been from seedlings or stump coppice characterized by low yields and un-uniform stands. A number of individuals and companies have established eucalyptus fields using seedlings but the results are disheartening because of low survival. The trees results in uneven stand which is difficult to manage, low productivity due to crop variability and poor form characteristics making selection vital. The cost of extraction and limitation in utilization of such wood reduces per capita productivity and eventually income at household level.

The use of tissue culture and clonal hedge propagation are technologies, which offer potential to grow more trees with desirable traits. Clonal technology has provided a faster development of genetic gains from breeding programmes as compared to seed orchards. The technology stimulates uniform growth of the stock in terms of height and diameter keeping volume variation at minimum. This adds to high quality product and ensures great efficiency in terms of harvesting and marketing and consequently maximum returns on the investment.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.0 Introduction

This study is part of a long-term experimental trial that was planted on five trail sites within the country. These sites are in Embu, Karura, Kabage, Machakos and Gede. The trials were planted on varying dates in different agro climatic zones in the country. The eucalyptus hybrid materials planted in all these sites were *Eucalyptus grandis and Eucalyptus camaldulensis* cross (GC) as well as *grandis and Eucalyptus urophylla* (GUs) that were supplied by Mondi Forest Company of South Africa. (Wakhusama, Kanyi, 2002) The Kenya Government provided the land for field trials under provision for temporally land allocation (25 years). The objective of the trials was to assess the performance of the eucalyptus hybrid in comparison with the non-hybrid eucalyptus progeny.

3.1 Study Sites

3.1.1 Kabage

Kabage site is located 40km from Nyeri town along the Nyeri - Kabage Road. The area mean annual rainfall is 1100mm. The mean annual temperature is 17°C. It is approximately 1,800m above sea level (Forest Department, 2003). The area is well forested and soils are as alfisols and spodsols (United States Department of Agriculture).

3.1.2 Karura

Karura site is located in Nairobi along Nairobi - Kiambu Road, approximately 1½ km from Muthaiga turn-off. The area mean annual rainfall is 900mm and the mean annual temperature is 23°C (Forest Department, 2003). The area is also forested hence the soils occurs in two orders i.e. the *alfisols* and the *spodsols*. However, patches of clay soils- the vertisols could be obtained. The trial was planted in 1998 (United States Department of Agriculture).

3.1.3 Embu

This site is situated in Embu Municipality, approximately 10 km from Embu town, along Embu - Chuka Road. The area mean annual rainfall is 1400mm and the mean annual temperature is 20°C (Forest Department, 2003). The soils are basically *Oxisols* i.e., intensively weathered soils of tropical environment that experience high precipitation and temperatures. It is characterized by strong chemical weathering and heavy leaching. It is approximately 1300m above sea level. The trial was established in 1998 (United States Department of Agriculture).

3.1.4 Machakos

The Machakos trial is located in Iveti Hills, and was planted in May 1999 at an altitude of 2066m. The area is reasonably wet with a mean annual rainfall of between 1200 and 1600mm (Forest Department, 2003). Mean maximum and minimum temperatures is 25°C and 15°C, respectively. The soils are well-drained, very strongly weathered, brown clay with very thick dark top soil and loamy deeper subsoil (United States Department of Agriculture).

3.1.5 Gede

The site is situated along Kilifi- Malindi Road in Gede Forest Station. This is part of the wider Arabuko-Sokoke Forest Block. The mean annual rainfall is 850mm and the mean annual temperature is 25^0C (Forest Department, 2003). The soils are well-drained, deep yellowish red, friable, fine sandy loam to fine sandy clay loam. The site was established in 2002 (United States Department of Agriculture).

3.2 Distribution of Eucalyptus Germplasm Measured in the Five Trial Sites of Karura, Embu, Machakos, Kabage and Gede

Table 3.1 shows that in Karura site (which was planted in 1998), a sample size of 20% (15 trees) was consistently achieved for all the representative species apart from *E. grandis* and *E. saligna.* The two species had relatively low survival rates during the early stage of establishment and were also subject to poaching after establishment probably due to initial fast growth. In Gede site (planted in 2002), a consistent sample size of 12 was achieved due to extremely high survival rate of the representative germplasms and minimum human damage. For Kabage site, which was also planted in 2002, a sample size of between 15 and 16 was obtained for most of the trees, apart from GU 21, for which only 14 trees were sampled. This consistency was due to high survival rate and minimum human and wildlife damage. A consistent sample size of 9 trees was obtained in Embu (planted in 1999), apart from *E. saligna* where few trees were measured due to low survival in replicate three In Machakos (planted in 1999), a sample size of 8 and 9 trees was obtained apart from GC 14, which was highly poached, and hence few trees were measured.

Table 3.1 *Number of trees measured for each representative eucalyptus progeny in each study site*

Species	Number of trees measured in each trial site					Total
	Karura	Gede	Kabage	Embu	Machakos	
Eucalyptus hybrid GC 642	15			9	9	33
Eucalyptus hybrid GC 14	15	12		9	6	42
Eucalyptus hybrid GC 15	15			9	9	33
Eucalyptus hybrid GC 10	15				9	24
E. grandis	12		16	9	9	46
E. tereticornis	14	12		9	8	43
Eucalyptus hybrid GC 581	15	12		9	9	45
Eucalyptus hybrid GC 12	14					14
Eucalyptus hybrid GC 522	14				9	23
E. saligna	13			7	7	27
E. urophylla		12				12
Eucalyptus hybrid GC 785		12				12
Eucalyptus hybrid GU 21		12	14			26
E. camaldulensis		12		9	8	29
Eucalyptus hybrid GC 784		12	16			28
Eucalyptus hybrid GC 514		12	15			27
Eucalyptus hybrid GU 7		12	16			28
Eucalyptus hybrid GC 167		12				12
Eucalyptus hybrid GC 540		12	16			28
Eucalyptus hybrid GU 8		12	15			27
Eucalyptus hybrid GC 584		12				12
TAG5 (pure grandis)			15			15
Total	**142**	**168**	**123**	**70**	**83**	**586**

3.3 Experimental Design and Data Collection Method

The five trials sites under study were planted on varying dates and laid out in a completely randomized block design with a uniform espacement of 2.5m x 2.5m. Each representative hybrid (*Eucalyptus grandis/camaldulensis/urophylla*) as well as the non-hybrid progeny was planted in a plot, which was randomly selected and replicated (Appendices) accordingly to minimize the error. Guard rows of the non-hybrid progeny as well as the hybrid clones were used in all the trials. This was meant to reduce the plot edges effect.

To effectively collect representative sample from each trial plot, 20% of the trees were randomly selected. This was repeated in every replicate and the total trees made the sample for each trial site. A sunto was used to measure tree heights in metres while a diameter tape was used to measure the Diameter at Breast Height (DBH) in centimetres. Observations on survival rate, crown form, and stem form; branching characteristics, self-pruning ability and resistance to pests and diseases were made for each representative tree in each sample.

To establish the survival rate, the percentage of the number surviving against the total number planted was obtained for each germplasm represented in the trial. The crown form was obtained through measurement of crown diameter and crown depth of each tree sample, calculating its average and consequently the average of the whole sample. Straightness was obtained by calculating the proportion of the total height of each tree sample which was straight and then obtaining the average for the whole sample. Similarly, the proportion of the tree which was branched below the crown was obtained and hence for the whole sample.

3.4 Data analysis

Data obtained were entered in the computer and analyzed using Genstat for Computer software. Both descriptive and inferential statistics were used. The mean heights, mean diameters, and mean annual increments for height were computed and reported for each representative progeny. Observations on stem form, self-pruning ability, survival rate and branching were presented as percentages while crown form was presented in metres.

To test the three hypotheses of the study, the One-Way Analysis of Variance at the 0.05 level of significance and LSD test was used. Data were summarized and results presented in form of tables and figures.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the calculated mean diameter and height growth for each representative species as well as their mean annual increments. Results are also presented on the survival rate, branching, straightness, self-pruning ability and crown formation for each representative eucalyptus progeny in each trial site. For survival rates, pruning ability, branching and straightness, the results are presented in form of percentages whereas crown formation is presented as length in metres. Analysis of Variance (ANOVA) and Least Significant Difference (LSD) tests are employed to establish the significance of any mean differences in both height and diameter of each eucalyptus progeny in each site.

4.1 Height and Diameter Growth of Eucalyptus Hybrid Clones and Non-Hybrid Species at Karura Trial Site

Analysis of variance test revealed that the eucalyptus progenies measured in Karura trial site differed significantly ($p<0.05$) in height.

Table 4.1 presents the mean heights and diameter at breast height for the eucalyptus hybrid clones and non-hybrid germplasm in Karura trial site at the age of seven years.

The mean heights for the trees ranged between 12.5m and 19.9m (Table 4.1). GC 522 was found to have the largest mean height of 19.9m, followed by GC 10 with a mean height of 19.5m. This was then followed by GC 10 at 19.0m while GC 12 had a mean height of 17.9m. Locally growing germplasms had the lowest mean heights i.e. 12.5m

(*E. tereticornis*), 14.9m (*E. saligna*) and 16.9m (*E. grandis*). In India, where *E. tereticornis* is widely planted, a relatively low height has been reported (FAO, 2001) as a result of low growth rates in all the sites. The relatively moderate temperatures and moderate rainfall in Karura might have contributed to better height and diameter growth for the different GCs and non-hybrid tree species

E. tereticornis and *E. saligna* attained significantly lower mean –heights than the GCs. It was only *E. grandis* whose height was not significantly different from GC 12, but its height was significantly different from all other GCs. These results are comparable to performance of these species as reported in the field in India, for *E. tereticornis* and in Brazil, South Africa, Australia, among other regions for *E. grandis* and *E. saligna* where they are known to perform well (FAO, 1979). The latter is reported to perform well in high altitude where rains are above 1800mm per year and mean annual temperatures do not exceed 18°C.

Table 4.1 Mean Height and diameter at breast height for the seven year old eucalyptus progenies measured in Karura trial site

Species	Mean height (m)	Mean DBH (cm)
Eucalyptus hybrid GC 522	19.9a	16.1a
Eucalyptus hybrid GC 10	19.5ab	14.4b
Eucalyptus hybrid GC 14	19.1abc	13.4bc
Eucalyptus hybrid GC 15	19.0abc	13.5bc
Eucalyptus hybrid GC 642	18.7abc	13.1bc
Eucalyptus hybrid GC 581	18.5bc	13.5bc
Eucalyptus hybrid GC 12	17.9cd	13.1bc
E. grandis	16.9d	13.5bc
E. saligna	14.8e	12.3c
E. tereticornis	12.5f	9.2d
Mean	**17.7**	**13.2**
LSD	**1.24**	**1.53**

Means in columns followed by the same letter are not significantly different at 5 percent level based on LSD test.

From the same table, GC 522 had the highest mean height (19.9 metres). This mean height did not differ significantly from the heights of GC 10, GC 14, GC 15 and GC 642 (LSD = 1.24). However, GC 522 had a significantly higher mean height than that for GC 581, GC 12, *E. grandis*, *E. saligna*, and *E. tereticonis* (LSD = 1.24). The second best progeny in Karura in terms of height emerged to be GC 10, with a mean height of 19.5 metres. While it did not differ significantly in height with GC 14, GC 15, GC 642 and GC 581, its mean height was significantly higher than the means of GC 12, *E. grandis*, *E. saligna*, and *E. tereticornis*. The mean heights of *E. grandis, E. saligna* and *E. tereticornis* were significantly lower than the heights of all the GCs, apart from GC 12, which did not differ significantly with *E. grandis*.

For DBH, the progenies differed significantly ($p<0.05$) based on ANOVA test. Eucalyptus hybrid GC 522 had the highest mean DBH of 16.1cm, which was significantly higher than the DBH of the rest of the progenies in Karura trial site (LSD = 1.53). *E. grandis* did not differ significantly in DBH with the GCs apart from GC 522. The DBH of *E. tereticornis* was significantly lower than all the other progenies in the trial site. These results show that while the non-hybrid *E grandis* performance in terms of DBH was as good as the GCs there was significant decrease in mean height. This could have been as a result of wide espacement of the species created after establishment by human damage through poaching of the standing stock.

In Zambia, hybrids of *E. grandis* and *E. tereticornis* have been found to grow better than that of either parent, however, the form was found to be as good as that of the non-hybrid progeny of *E. grandis* but with better resistance to draught (FAO, 1979).

Table 4.2 presents the mean annual height and diameter increments for the different hybrid clones and non-hybrid germplasm of eucalyptus hybrid clones at Karura trial site. ANOVA test showed that the progenies differed significantly ($p<0.05$) in MAHI. The table indicates that GC 10 and GC 522 eucalyptus hybrid clones had the highest mean annual height increments (MAHI), each achieving 2.8 metres annually. This was followed by GC 642, GC 14, and GC 15, hybrid clones which achieved a MAHI of 2.7 metres each. GC 581 and GC 12 each had a MAHI of 2.6 metres. *E. grandis, E. tereticornis,* and *E. saligna* achieved the lowest mean annual height increments, achieving 2.4 metres, 1.8 metres and 2.1 metres per annum respectively. It can also be seen that GC 522 achieved the largest mean diameter increment of 2.3cm per year, followed by GC 10 at 2.1 cm annually, while *E. tereticornis* achieved the least mean annual diameter increment of 1.3cm annually.

Table 4.2 Mean annual height and diameter increment for the seven year old eucalyptus progenies measured in Karura trial Site

Species	**Mean Annual height Increment (MAHI)**	**Mean Annual Diameter Increment (cm/yr)**
Eucalyptus hybrid GC 642	2.7	1.9
Eucalyptus hybrid GC 14	2.7	1.9
Eucalyptus hybrid GC 15	2.7	1.9
Eucalyptus hybrid GC 10	2.8	2.1
E. grandis	2.4	1.9
E. tereticornis	1.8	1.3
Eucalyptus hybrid GC 581	2.6	1.9
Eucalyptus hybrid GC 12	2.6	1.9
Eucalyptus hybrid GC 522	2.8	2.3
E. saligna	2.1	1.8
Total	**2.5**	**1.9**

4.2 Height and diameter growth of eucalyptus hybrid clones and the non-hybrid species in Embu trial site

Table 4.3 presents the mean heights and diameter at breast height for the hybrid clones and non-hybrid germplasm in Embu. The table shows that GC 642 and GC 15 had the highest mean height of 23.5m, followed by GC 14 and GC 581 with mean heights of 21.4m each. *E. tereticornis* had the lowest mean height of 12.4 metres. The mean DBH for the various species in Embu ranged from 18.8cm for GC 581 to 7.8cm for *E. tereticornis*. These differences in height and diameter at breast height were significant at $p<0.05$ based on ANOVA test. GC 642 and GC 15 had significantly higher mean height (at LSD 3.86) than all the non-hybrid progenies in Embu trial site. Mean height of GC 581 and GC 14, however, had no significant difference with those of *E. grandis*, and *E. saligna*. *E. tereticornis* had significantly low mean height compared to the GCs and the rest of the non-hybrid species.

For DBH, (LSD 3.038, $p<0.05$) GCs achieved significantly high mean DBH than the non-hybrid species. Mean DBH for *E. camaldulensis*, *E. saligna* and *E. grandis* had no significant difference. *E. tereticornis* had significantly low mean DBH compared to the GCs and the rest of the non-hybrid species.

From these findings, the GCs 642 and 15 appeared to perform better in Embu trial site in both height and diameter compared to the non-hybrid species. The climate (mean annual rainfall of 1400mm and mean annual temps of 20°C) and the altitude of 1500m above sea level for this area present the minimum requirement for *E. grandis* and *E. saligna* good establishment for Kenya (FAO, 1979). It could therefore be inferred that the difference in both mean heights and diameter between GCs 642 and 15 and the two non-hybrid species could have been due to climate as well as site factors like soils, pest and disease which was noted especially for *E. grandis* where (five plants were dry while standing), human and animal damage, as well as weeds tolerance for each progeny. Similarly, *E. tereticornis* is known to be successful in relatively low altitude (less than 1000m ASL), less acidic soils, moderate to fairly severe dry season and mean annual rains of up to 1200mm (FAO, 1979).

The slow growth of both height and diameter in the site for this species could be attributed to the unfavourable climate among other factors. As has been reported earlier before, *E. camaldulensis* performs well in relatively dry areas with high temperatures and low altitude. It is therefore expected that GC (hybrid) would perform well in moderate climatic conditions.

Table 4.3 Mean Height and diameter at breast height for the measured six year old eucalyptus progenies in Embu site

Species	**Mean height (m)**	**Mean DBH (cm)**
Eucalyptus hybrid GC 642	23.5a	16.8a
Eucalyptus hybrid GC 15	23.5a	18.7a
Eucalyptus hybrid GC 581	21.4ab	18.8a
Eucalyptus hybrid GC 14	21.4ab	16.4a
E. grandis	17.7bc	12.2b
E. saligna	17.7bc	12.1b
E. camaldulensis	16.4c	9.3b
E. tereticornis	12.4d	7.8c
Mean	**19.3**	**14.1**
LSD	**3.86**	**3.04**

Means in columns followed by the same letter are not significantly different at 5 percent level based on LSD test.

Table 4.4 presents the mean annual height and diameter increments for the representative hybrid clones and non-hybrid germplasm in Embu trial. The difference in mean annual increment in height and diameter at breast height were found to be significant at $p<0.05$ based on ANOVA test. As shown in the table, GC 642 and GC 15 had Mean Annual Height Increments (MAHI) of 3.9 metres each. *E. tereticornis* had the lowest MAHI (2.1 metres per year). GC 15 and GC 581 had the highest mean annual diameter increment (3.1 cm/year) while *E. tereticornis* had the lowest Mean Annual Diameter Increment (MADI) of 1.3 cm per year.

Table 4.4 Mean annual height and diameter increment for different eucalyptus progenies in Embu trial site

Species	**Mean annual height increment (m/yr)**	**Mean annual diameter increment (cm/yr)**
Eucalyptus hybrid GC 642	3.9	2.8
Eucalyptus hybrid GC 14	3.6	2.7
Eucalyptus hybrid GC 15	3.9	3.1
E. grandis	2.9	2.0
E. tereticornis	2.1	1.3
Eucalyptus hybrid GC 581	3.6	3.1
E. saligna	2.9	2.0
E. camaldulensis	2.7	1.6
Total	**3.2**	**2.4**

4.3 Height and diameter growth of eucalyptus hybrid clones and non-hybrid species at Machakos trial site

Table 4.5 shows that in Machakos trial site, *E. grandis* mean height did not differ significantly with the GCs apart from GC 10. This implies that it performed as well as GC 14, GC 15, GC 642, GC 522 and GC 581. In terms of height (LSD = 4.14) *E. saligna* mean height on the other hand was not significantly different to that of GC 522, GC 581 and GC 10. Height growth for GC 10 could be said to have had no significant difference to that of *E. tereticornis* and *E. saligna*.

The significantly low height of both *E. tereticornis* and *E. camaldulensis* (LSD 4.14, $p<0.05$) may be as a result of the relatively high elevation of the Iveti Hills where this trial was established. The high altitude provides a relatively humid condition, which traditionally favours *E. grandis* traits more than *E. camaldulensis* or *E. tereticornis*. The two species, naturally thrives well in dry lowlands. The relatively similar performance in height for GC 14, GC 15, GC 642, GC 522 and GC 581 and *E. grandis* could be due to *grandis* genetic material in the hybrid. For DBH (LSD 4.21, $p<0.05$), *E. grandis* and *E. saligna* had no significant difference in mean DBH with the GCs apart from GC 10. However, *E. grandis* had relatively higher mean DBH than the GCs and the rest of non-hybrid progenies.

In a paper on performance of inter specific F1 eucalyptus hybrids in Zimbabwe (FAO, 1979) the GCs were reported to have performed better than the non-hybrid *E. grandis* and *E. camaldulensis* in low rainfall areas of Zimbabwe. The relatively high altitude and moderate rainfall of the Machakos site could have restricted the growth performance of *E. camaldulensis* but enhanced the growth of the GCs and the non-hybrid *E. grandis* and the *E. saligna*. Similar trends have been observed with the species in Nepal and Myanmar- South East Asia. In Pakistan *E. camaldulensis* has proven to be the most adaptable in areas characterized by extreme temperatures, low relative humidity and erratic and irregular rains.

The Forest Research Institute Dehra in India has developed very promising hybrids of *E. tereticornis* and *E. camaldulensis* with striking degree of hybrid vigour in both height and diameter growth. At 4 years E. *tereticornis* + *E. grandis* cross had produced four times the amount of wood produced by the non-hybrid *E. tereticornis.* The hybrid had also been found to be resistant to the pink disease known to cause a lot of death on *E. grandis* in India.

The reported performance of *E. grandis* in Karura, Embu and Machakos is in line with the findings of Gottneid and Thogo (1975); Konuche (1989) and Oballa (1989) who found that the species was doing exemplary well between 600m and 2500m above sea level. A trial planted in Hombe, Nyeri District, at an altitude of 2300m above sea level has shown tremendous DBH growth but comparative growth in height with the hybrid clones. This is comparable to the Machakos trial at 2066m above sea level where the non-hybrid *E. grandis* mean height and DBH were comparable to those of most of the hybrid clones measured.

Table 4.5 Mean height and diameter at breast height for the six years old eucalyptus progenies measured in Machakos site

Species	Mean height (m)	Mean DBH (cm)
Eucalyptus hybrid GC 14	20.8a	16.7a
Eucalyptus hybrid GC 15	20.6a	15.5ab
E. grandis	20.5a	17.6a
Eucalyptus hybrid GC 642	20.4a	17.2a
Eucalyptus hybrid GC 522	19.4ab	16.7a
Eucalyptus hybrid GC 581	17.9abc	15.2abc
E. saligna	16.1bcd	14.6abc
Eucalyptus hybrid GC 10	15.1cd	11.9bc
E. tereticornis	12.0de	11.3c
E. camaldulensis	8.7e	5.7d
Mean	**17.2**	**14.3**
LSD	**4.14**	**4.21**

Means in columns followed by the letter are not significantly different at 5 percent level based on LSD test

Table 4.6 presents the mean annual height and diameter increments for the hybrid clones and non-hybrid germplasm in Machakos trial. The table shows that GC 14 achieved the highest MAHI of 3.5 metres, followed by *E. grandis* and GC 642, each with a MAHI of 3.4 metres. *E. grandis* and GC 642 achieved the highest MADI of 2.9cm each, while *E. camaldulensis* achieved the least MAHI of 1.4 metres, and the least MADI, of 1.0cm. These differences for MAHI and MADI were found to be significant at $p<0.05$ based on ANOVA test.

Table 4.6 Mean annual height and diameter increment for measured eucalyptus progenies in Machakos trial site

Species	Mean annual height increment (m/yr)	Mean annual diameter increment (cm/yr)
Eucalyptus hybrid GC 642	3.4	2.9
Eucalyptus hybrid GC 14	3.5	2.8
Eucalyptus hybrid GC 15	3.4	2.6
Eucalyptus hybrid GC 10	2.5	2.0
E. grandis	3.4	2.9
E. tereticornis	2.0	1.9
E. saligna	2.7	2.4
E. camaldulensis	1.4	1.0
Eucalyptus hybrid GC 581	3.0	2.5
Eucalyptus hybrid GC 522	3.2	2.8
Total	**2.9**	**2.4**

4.4 Height and diameter growth for eucalyptus hybrid clones and non-hybrid species at Gede trial site

Table 4.7 shows that GC 785, GC 581 and GC 167 achieved the highest mean heights of 15.3, 15.1 and 15.0 metres, respectively. GU 7 and GU 8 achieved the lowest mean heights, of 8.1 and 8.6 metres, respectively.

In terms of DBH, GC 581 achieved the highest (10.7cm) followed by GC 167 (10.5cm) and GC 584 (10.4cm); while GU 8 (6.4cm) and GU 7 (7.0cm) achieved the lowest. These differences in height and diameter were significant at $p<0.05$ based on ANOVA test. GC

785, GC 581, GC 167 and GC 584 had relatively a significantly high mean height (LSD = 1.43) compared to the rest of GCs and non-hybrid species. *E. camaldulensis*, a non-hybrid species had significantly high mean height than the E. *urophylla* and *E. tereticornis* as well as GC 540, GU 8 and GU 7. It was however not significantly different from GU 21, GC 14, GC 514 and GC 784.

For mean DBH, the GCs 785, 514, 784, 581, 540 and 14, GU 21 as well as *E. camaldulensis* did not differ significantly. On the other hand, *E. camaldulensis* attained a significantly higher mean DBH (LSD = 1.69) than the rest of the non-hybrid progenies, that is, *E. urophylla* and *E. tereticornis*. GU 7 and GU 8 showed no significant difference on mean DBH. Crosses of *E. grandis* x *E. tereticornis*, *E. grandis*, *E. camaldulensis* and *E. grandis* x *E. urophylla* have been found to out perform *E. grandis* in moderate rainfall and low altitude conditions (van Wyk, 1987; van Wyk and Muganga, 2003; Pierce, 1991).

Table 4.7 Mean height and diameter at breast height for the measured 3 years old eucalyptus progenies in Gede Trial

Species	Mean height (m)	Mean DBH (m)
Eucalyptus hybrid GC 785	15.3a	9.6abcde
Eucalyptus hybrid GC 581	15.1ab	10.7a
Eucalyptus hybrid GC 167	15.0ab	10.5ab
Eucalyptus hybrid GC 584	14.8ab	10.4abc
Eucalyptus hybrid GC 14	13.7bc	8.6def
Eucalyptus hybrid GC 514	13.3c	8.9bcde
Eucalyptus hybrid GC 784	13.2c	8.8cde
E. camaldulensis	12.8c	9.1abcde
Eucalyptus hybrid GU 21	12.5cd	9.3abcde
Eucalyptus hybrid GC 540	11.3de	10.1abcd
E. urophylla	11.3de	8.4ef
E. tereticornis	10.4e	8.2ef
Eucalyptus hybrid GU 8	8.6f	6.4g
Eucalyptus hybrid GU 7	8.1f	7.0fg
Mean	**12.5**	**9.0**
LSD	**1.43**	**1.69**

Means in columns followed by the same letter are not significantly different at 5% level based on LSD test

Table 4.8 presents the Mean Annual Height Increments (MAHI) and Mean Annual Diameter Increments (MADI) for the various species in Gede. The table shows that GC 785 had the largest MAHI (5.1 m) followed by GC 581 and GC 167 (5.0 m). GU 7 and GU 8 had the lowest MAHI (2.7 and 2.9 m respectively). GC 581 had the largest MADI of 3.6cm while GU 8 had the lowest (2.1cm). These differences on MAHI and MADI were found to be significant at $p<0.05$ based on ANOVA test.

Table 4.8 Mean annual height and diameter increments for the measured progenies in Gede Trial

Species	**Mean annual height increment (m/yr)**	**Mean Annual Diameter increment (cm/yr)**
Eucalyptus hybrid GC 14	4.6	2.9
E. tereticornis	3.5	2.7
Eucalyptus hybrid GC 581	5.0	3.6
E. urophylla	3.8	2.8
Eucalyptus hybrid GC 785	5.1	3.2
Eucalyptus hybrid GU 21	4.1	3.1
E. camaldulensis	4.3	3.0
Eucalyptus hybrid GC 784	4.4	2.9
Eucalyptus hybrid GC 514	4.4	3.0
Eucalyptus hybrid GU 7	2.7	2.3
Eucalyptus hybrid GC 167	5.0	3.5
Eucalyptus hybrid GC 540	3.8	3.4
Eucalyptus hybrid GU 8	2.9	2.1
Eucalyptus hybrid GC 584	4.9	3.5
Total	**4.2**	**3.0**

4.5 Growth performance of eucalyptus hybrid clones and non-hybrid species at Kabage Site, Nyeri

The mean height and DBH for the species in Kabage trial site are as shown in Table 4.9. *E. grandis*, which is a non-hybrid progeny, achieved the highest mean height growth of 13.2m followed closely by GU 21 with a mean height growth of 12.4m. GU 7 and GU 8 performed relatively well in height and DBH. On the other hand GC 514, GC 540 and

GC 784 performed the least with mean heights of 9.8 m, 10.6 m, and 11.4 m respectively. The mean DBH for these three GCs were also low. ANOVA test showed significant difference at p<0.05 on mean heights and mean DBH.

Table 4.9 Mean Height and diameter at breast height for the measured representative progenies in Kabage trial site

Species	Mean height (m)	Mean DBH (cm)
E. grandis	13.2a	12.3ab
Eucalyptus hybrid GU 21	12.4ab	12.8a
Eucalyptus hybrid GU 8	12.2ab	12.0abc
Eucalyptus hybrid GU 7	12.1ab	11.8abc
TAG 5 (Pure grandis)	12.1ab	12.1abc
Eucalyptus hybrid GC 784	11.4bc	10.9bcd
Eucalyptus hybrid GC 540	10.6cd	10.4cd
Eucalyptus hybrid GC 514	9.8d	9.7d
Mean	**11.7**	**11.5**
LSD	**1.3**	**1.68**

Means in columns followed by the same letter are not significantly different at 5% level based on LSD test.

From the same table, the *E. grandis* and TAG 5 (the pure *grandis*) showed no significant differences for both mean height and DBH growth (LSD=1.3 and LSD=1.678 respectively). Similarly, the GUs and TAG 5 did not differ significantly for both parameters. The *E. grandis* attained significantly higher mean height growth (p<0.05) than the GCs, but did not differ significantly with them in DBH growth. This was the same for TAG 5. The GUs, *E. grandis,* and TAG 5 had significantly higher mean heights (p<0.05, LSD=1.3) than the GCs.

In a paper on silvicutural techniques for short rotation eucalyptus plantation in Brazil presented at intensive cultural forestry conference in Albama, USA, McNabb (1994) observed that *E. grandis*, *E urophylla* combination (hybrid) has been used in Brazil to scale down the stem canker associated with pure *E grandis* (FAO, 1979), reported high performance in growth and straightness of inter-specific F1 eucalyptus hybrid of *E grandis/E urophylla* combination as compared to non-hybrid *E. grandis* and *E. urophylla* in Zimbabwe. The GUs in Brazil have shown very promising results in several parts of the country in terms of stands homogeneity, resistant to pest and diseases and yields. The performance of *E. urophylla* is in line with trials at Loudima, Congo where the species displayed outstanding performance by achieving mean height of 7.18m within one year (FAO, 1979). For DBH growth, GU 21 attained significantly higher mean height ($p<0.05$, LSD=1.678) than all the GCs. Its mean DBH growth did not differ significantly with *E. grandis,* TAG 5 and the GUs. The GC 784, unlike GC 540 and GC 514, did not differ significantly in DBH with *E. grandis*, which was the second best performing progeny in Kabage trial site for this parameter.

In Chinese State of Dongmen, with mean annual temp of 21°C and mean annual rainfall of 1300mm, the GUs introduced in 1980s saw annual wood volume increasing significantly (FAO, 1979). A four-year old *E. urophylla* provenance in this state registered mean height increment of over 16m, annual height growth of more than 4 metres and an annual DBH growth of more than 2 cm.

Table 4.10 presents the mean annual height and DBH increments for the various eucalyptus progenies in Kabage. Just like the mean height and diameter growth, the mean annual increment on the two parameters for the *E. grandis* and the GUs were the highest.

Table 4.10 Mean annual height and diameter increments for eucalyptus progenies in Kabage trial

Species	Mean annual height increment (m/yr)	Mean annual diameter increment (cm/yr)
E. grandis	4.4	4.1
Eucalyptus hybrid GU 21	4.1	4.3
Eucalyptus hybrid GC 784	3.8	3.6
Eucalyptus hybrid GC 514	3.3	3.2
Eucalyptus hybrid GU 7	4.0	3.9
Eucalyptus hybrid GC 540	3.5	3.5
Eucalyptus hybrid GU 8	4.1	4.0
TAG 5 (Pure Grandis)	4.0	4.0
Total	**3.9**	**3.8**

4.6 Survival rate of the eucalyptus germplasms in the five study sites

Survival count was carried out on each representative eucalyptus progeny in each trial site. Survival rate in general is influenced by several factors, which include site management, especially the weeding frequency and the protection of the seedlings from pest and diseases. Drought and seedling handling during planting period also contribute significantly to the survival rate.

Table 4.11 shows the mean survival percentage for each progeny in Karura trial site. From these results, the hybrid clones had better survival rate percentages than all the non-hybrid progenies in the site. According to FAO (1979), the *E. camaldulensis* traits (in GCs) which express drought resistance may have contributed to the exemplary performance in terms of survival for the GCs in this trial. The trait could cope with moisture stress associated with low rainfall condition which is sometimes experienced in the area. Termite attack could also have contributed significantly to the relatively low survival rate of *E. grandis* and *E. saligna.*

Table 4.11 Survival rate for different eucalyptus germplasms in Karura trial site

Species	No. Planted	No. Surviving	Survival %
Eucalyptus hybrid GC 642	75	75	100
Eucalyptus hybrid GC 14	75	74	99
Eucalyptus hybrid GC 15	75	71	95
Eucalyptus hybrid GC 10	75	74	99
E. grandis	75	57	76
E. tereticornis	75	66	88
Eucalyptus hybrid GC 581	75	75	100
Eucalyptus hybrid GC 12	75	74	99
Eucalyptus hybrid GC 522	75	72	96
E. saligna	75	57	76

Table 4.12 presents the results for survival rate of the germplasms in Embu trial site. In this site, GC 642, GC 14, GC 581 and *E. tereticornis* achieved 100% survival. *E. grandis* and *E. saligna* had low survival rates of 67% and 50%, respectively. A number of *E grandis* were dead standing mostly as a result of disease. Termite attack was observed, a factor which could have also contributed to the low survival count. Just like *E. grandis*, *E. saligna* also showed termite attack. Also, one of its replicates might have been browsed as only one tree had survived. This contributed significantly to its relatively low survival rate in this site.

Table 4.12 Survival rate for different eucalyptus germplasms in Embu trial site

Species	No. Planted	No. Surviving	Survival %
Eucalyptus hybrid GC 642	18	18	100
Eucalyptus hybrid GC 14	18	18	100
Eucalyptus hybrid GC 15	18	17	94
E. grandis	18	12	67
E. tereticornis	18	18	100
Eucalyptus hybrid GC 581	18	18	100
E. saligna	18	9	50
E. camaldulensis	18	16	89

Table 4.13 shows that in Machakos, GC 642, GC 14, GC 15, GC 10, *E. grandis*, *E. tereticornis*, and GC 522 achieved 100% survival rate. *E. camaldulensis* and GC 581 had equal survival rates of 83%. *E. saligna* had the lowest survival rate of 67%. The Iveti Hills conditions appeared to have favoured the survival of all the representative eucalyptus progenies.

Table 4.13 Survival rate for different eucalyptus germplasms in Machakos trial site

Species	No. Planted	No. Surviving	Survival %
Eucalyptus Hybrid GC 642	18	18	100
Eucalyptus Hybrid GC 14	18	18	100
Eucalyptus Hybrid GC 15	18	18	100
Eucalyptus Hybrid GC 10	18	18	100
E. grandis	18	18	100
E. tereticornis	18	18	100
Eucalyptus Hybrid GC 522	18	18	100
E. camaldulensis	18	15	83
Eucalyptus Hybrid GC 581	18	15	83
E. saligna	18	12	67

For Kabage trial site (Table 4.14), the survival rates for all the eucalyptus progenies was less than 90% apart from GU 8 which had 96% and GU 7 which had 90% survival rate. TAG 5 and GU 21 had the lowest survival rates of 50% and 46%, respectively. *E grandis,* which was the only non-hybrid progeny established in this site, achieved a relatively high survival rate of 79%. The generally low survival rates in this site may be attributed to poor site management. It was observed that the site had not been weeded for along time. Tag 5 (pure E. *grandis*) was assumed to have been nipped by antelopes at the seedling stage and a number of them had died.

Table 4.14 Survival rate for different eucalyptus germplasms in Kabage trial site- Nyeri

Species	No. Planted	No. Surviving	Survival %
E. grandis	48	38	79
Eucalyptus hybrid GU 21	48	22	45
Eucalyptus hybrid GC 784	48	37	77
Eucalyptus hybrid GC 514	48	27	56
Eucalyptus hybrid GU 7	48	43	90
Eucalyptus hybrid GC 540	48	34	71
Eucalyptus hybrid GU 8	48	46	96
TAG 5 (Pure Grandis)	48	24	50

Table 4.15 presents the survival rates results for the various eucalyptus germplasm in Gede trial site. In this site, GC 581, GC 785, GC 514, GC 584 and GU 21, GU 7, and GU 8 achieved respective 100% survival rates. The non-hybrid germplasms *E. tereticornis, E. urophylla* and *E. camaldulensis* achieved survival rates of 85%, 90%, and 88%, respectively.

Table 4.15 Survival rate for different eucalyptus germplasms in Gede trial site – Malindi

Species	No. Planted	No. Surviving	Survival %
Eucalyptus hybrid GC 14	48	46	96
E. tereticornis	48	41	85
Eucalyptus hybrid GC 581	48	48	100
E. urophylla	48	43	90
Eucalyptus hybrid GC 785	48	48	100
Eucalyptus hybrid GU 21	48	48	100
E. camaldulensis	48	42	88
Eucalyptus hybrid GC 784	48	46	96
Eucalyptus hybrid GC 514	48	48	100
Eucalyptus hybrid GU 7	48	48	100
Eucalyptus hybrid GC 167	48	48	100
Eucalyptus hybrid GC 540	48	47	98
Eucalyptus hybrid GU 8	48	48	100
Eucalyptus hybrid GC 584	48	48	100
Eucalyptus hybrid GC 796	0	0	Nil

The high survival rates for progenies in this site could be attributed to timely weeding noted during data collection as well as good moisture levels, among others. It is, however, worth noting that even with these favourable conditions, GC 796 failed to establish at the site. This failure had also been reported in a trial in Msambweni (KEFRI, 2003). This could mostly be attributed to unfavourable climatic condition at the coast for this particular hybrid.

4.7 Self-Pruning, branching, straightness and crown formation of hybrids GCs and non-hybrids in the five study sites

Observation on the performance of both the hybrid clones and the non-hybrid germplasm on branching, self-pruning ability, crown formation and straightness of the trunk was made. For branching, the percentage of the total tree height branched was determined, (Ht br/ht-total x100). Self pruning ability was determined by obtaining the length of the branchless trunk in metres as a fraction of the total tree height (ht-total) and then multiplied by 100 to obtain the percentage. For straightness, an estimate of the length (m) of the trunk that appeared straight was made and calculated as percentage of the total length of the trunk. For crown size, the depth and width in metres were estimated and average for each tree was taken as the crown size.

Table 4.16 presents the results regarding observations made on crown diameter, straightness, branching and self-pruning ability for various progenies of eucalyptus in Karura. *E grandis* and GC 581 showed excellent performance in straightness and crown diameters, whereas GC 15 performed well in both straightness and self pruning ability– a good characteristics for trees grown for poles and posts requirement (FAO, 1979). The *E. tereticornis* performed poorly for crown diameter as well as straightness. GC 15 had the highest self-pruning ability followed by GC 581. All the progenies showed low branching characteristics in this site. The straightness ability shown by *E. grandis* and GC 581 and self pruning ability shown by GC 642, GC 15 and GC 581 are desirable traits by these species for use in timber production (Shepherd, 1986).

Table 4.16 Crown size, branching, straightness, and self-pruning ability for the different eucalyptus germplasms in Karura trial site

Species	**Average crown size (m)**	**Branching (average %)**	**Straightness (average %)**	**Self-pruning (average %)**
Eucalyptus hybrid GC 642	3.0	20	65	80
Eucalyptus hybrid GC 14	3.2	50	85	50
Eucalyptus hybrid GC 15	3.8	15	85	85
Eucalyptus hybrid GC 10	3.4	35	65	65
E. grandis	3.8	50	90	50
E. tereticornis	0.4	60	10	40
Eucalyptus hybrid GC 581	3.8	30	95	70
Eucalyptus hybrid GC 12	2.6	70	70	30
Eucalyptus hybrid GC 522	3.4	60	80	40
E. saligna	1.7	60	75	60

For Embu trial (Table 4.17), GC 642, GC 14, GC 15, GC 581 and the non-hybrid species *E. grandis* and *E. tereticornis* exhibited excellent straightness and uniformity with GC 642, GC 15 while *E camaldulensis* presents high percentage of self pruning ability. Generally the GCs had better crown formation than the non-hybrid progenies. The GC 642, GC 15, would provide knotless wood desirable for timber production. The heavy branching due to low survival rate of *E. grandis* could have contributed to low self-pruning ability of this species.

Table 4.17 Crown formation, branching, straightness, and self-pruning ability of different eucalyptus germplasms in Embu trial site

Species	Average crown size (m)	Branching (average %)	Straightness (average %)	Self-pruning (average %)
Eucalyptus hybrid GC 642	3.2	45	85	75
Eucalyptus hybrid GC 14	3.4	65	78	45
Eucalyptus hybrid GC 15	3.3	30	85	70
E. grandis	2.9	70	85	30
E. tereticornis	2.0	45	85	55
Eucalyptus hybrid GC 581	3.6	55	85	45
E. saligna	3.2	55	65	45
E. camaldulensis	2.5	25	65	75

In Machakos trial site (Table 4.18) all the progenies maintained high percentage of straightness apart from GC 10 and E *camaldulensis*. *E. tereticornis* had the smallest crown whereas GC 10 had the lowest self pruning ability. It is, however, important to note that *E. camaldulensis* and *E. tereticornis* tend to exhibit vertical canopy (FAO, 1979) and hence small crown diameter. While the low self-pruning ability for GC 10 and *E. tereticornis* could be as a result of expression of this trait in them, that of *E saligna* could be as a result of open canopy due to low survival rate at establishment stage.

Table 4.18 Crown formation, branching, straightness, and self pruning ability for the different eucalyptus germplasms in Machakos trial site

Species	Average crown size (m)	Branching (average %)	Straightness (average %)	Self-pruning (average %)
Eucalyptus hybrid GC 642	2.7	35	90	65
Eucalyptus hybrid GC 14	2.9	35	90	65
Eucalyptus hybrid GC 15	2.4	30	90	70
Eucalyptus hybrid GC 10	3.4	35	65	65
E. grandis	3.2	35	90	65
E. tereticonis	1.2	55	60	45
E. saligna	2.3	40	70	60
E. camaldulensis	2.0	35	55	65
Eucalyptus hybrid GC 581	2.7	30	90	70
Eucalyptus hybrid GC 522	3.4	60	85	40

In Kabage site, GU 7 and 8 and GC 540 exhibited excellent branching characteristics, a desirable trait for trees planted for fuel wood production. The two GUs together with *E. grandis* and TAG 5 showed excellent straightness and crown formation as shown in Table 4.19. The good performance in these parameters at the age of 3 years could be associated with relatively high rainfall, cool temperatures and good quality soils found in this site. *E. grandis & urophylla* provenances are found to perform well in these conditions (FAO, 1979). Just like in other sites the high level of straightness exhibited by the above species is considered a desirable trait for all purposes. It increases the value and volume of commercially useful part of the stem. It also reduces the cost of handling and transport.

Table 4.19 Crown formation, branching, straightness, and self-pruning ability for the different eucalyptus germplasms in Kabage trial site

Species	**Average crown size (m)**	**Branching (average %)**	**Straightness (average %)**	**Self-pruning (average %)**
E. grandis	4.0	65	100	35
Eucalyptus hybrid GU 21	3.2	75	60	25
Eucalyptus hybrid GC 784	3.3	75	75	25
Eucalyptus hybrid GC 514	2.8	65	60	35
Eucalyptus hybrid GU 7	3.6	90	98	10
Eucalyptus hybrid GC 540	2.6	90	50	60
Eucalyptus hybrid GU 8	3.6	90	98	10
TAG 5 (Pure Grandis)	3.8	40	98	60

Table 4.20 presents the summary of the average crown diameter, branching level, straightness and self-pruning ability for the representative eucalyptus progenies in Gede trial. At the age of 3½ years, all the eucalyptus species showed excellent straightness. Most had low self-pruning ability apart from GC 785 and GC 167, which showed relatively high self-pruning ability. GUs were highly branched, heavy branching increases the number of knots. These will cause the loss of wood quality. They increase the risk of wood damage by environmental factors, fungi as well as insect and pest attack.

GC 785 showed the highest self-pruning ability. Shepherd (1986) observed that rapid early growth, a characteristic observed in this GC, results in early canopy closure. The reduced light levels for the lower canopy inhibits branch growth and induce senescence hence promote self-pruning. Self-pruning ability is a desirable trait as it reduces knots and hence possibilities of wood damage. The warm wet climate, uniform spacing and the young age of these progenies may have contributed to this observation among other factors.

Table 4.20 Crown size, branching, straightness, and self-pruning ability for the different eucalyptus germplasms in Gede trial site

Species	Average crown size (m)	Branching (average %)	Straightness (average %)	Self-pruning (average %)
Eucalyptus hybrid GC 14	2.3	80	95	20
E. tereticornis	1.7	65	70	35
Eucalyptus hybrid GC 581	3.2	60	85	40
E. urophylla	1.9	90	70	10
Eucalyptus hybrid GC 785	2.3	10	75	90
Eucalyptus hybrid GU 21	3.0	90	80	10
E. camaldulensis	1.5	95	70	5
Eucalyptus hybrid GC 784	3.0	90	85	10
Eucalyptus hybrid GC 514	3.4	70	75	30
Eucalyptus hybrid GU 7	2.2	95	85	5
Eucalyptus hybrid GC 167	2.8	40	95	60
Eucalyptus hybrid GC 540	3.0	90	60	10
Eucalyptus hybrid GU 8	2.4	95	85	10
Eucalyptus hybrid GC 584	3.2	85	95	15

4.8 The best performing eucalyptus hybrid clones for each trial site under study

For each of the trial sites under study, the performance of the hybrid clones in terms of mean height and DBH growth, survival rate, branching, crown formation, self-pruning ability and straightness were the factors considered for coming up with the most suitable hybrid clones for a particular site.

For Karura site, GC 522, GC 10, GC 14, GC 15 and GC 642 were considered the best hybrids among the progenies in Karura at the age of seven years in terms of height growth with GC 10 and 522 showing the highest mean annual height increment. They had a survival rate of above 90% and also showed relatively high level of straightness as well as balanced branching and self-pruning. *E. grandis*, however, showed vigour in crown form and performed well in straightness although its survival rate was low as compared to the hybrid clones probably as a result of persistent termite attack that was observed at the site.

In Embu trial, GC 642, GC 15, and GC 581 performed well in both height and diameter growth. Survival rate for these progenies was more than 95%. They were highly straight (above 70%) and uniform and also achieved a high self-pruning ability than others. A number of *E grandis* had died while others were dead standing and this significantly affected their survival as well as height and DBH growth.

In Machakos site, GC 14, *E. grandis* and the GC 642 performed well in terms of mean height growth and showed no significant difference with GC 15, GC 522 and GC 581. The *E grandis* and GC 642 presented the highest diameter increment. The progenies had 100% survival apart from GC 581, which had 85% which was attributed to human damage at an early age. They achieved high level of straightness (90%) and above average (50%) self-pruning ability.

The GC 785, GC 167 and GC 581 performed well in terms of height growth in Gede site while the GC 785 and GC 581 achieved the best DBH growth. However, the low height growth by GC 584 was not significantly different from the height growth of the above GCs. *E. camaldulensis*, GC 514 and GU 21 performed as good in terms of diameter growth. The hybrid progenies achieved a 100% survival rate and over 70% straightness. They also attained high branching apart from GC 785, which had a high self pruning ability.

For Kabage, the E grandis, GU 21, GU 7, GU 8 and the pure *grandis* (TAG 5) performed well in height and diameter growth as well as their mean annual increment. It was, however, established that *E grandis* had significantly high mean height growth than other hybrid progenies. It had also performed well in terms of survival rate and straightness compared to other progenies.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the results presented in chapter four on the five trial sites studied, the following conclusions could be made-:

In Karura and Embu trial sites, eucalyptus hybrids (GCs) performed better in mean height, mean diameter, mean annual increament and survival rate as compared to non-hybrids *E. saligna*, *E grandis* and *E. tereticornis*. Total tree height and diameter growth for the GCs were consistently higher than those of the local land races.

The *E grandis* exhibited exceptional performance in mean height, diameter growth and straightness among the local land races planted in Karura, Embu, Iveti Hills in Machakos and Kabage in Nyeri.

The GCs generally performed well in a number of trial sites. This shows that the *grandis-camaldulensis* cross is a more suitable progeny for a variety of sites and agroclimatic zones in Kenya.

The E. tereticornis exhibited poor growth in all the sites it was planted compared to the other local land races and the hybrids

The findings provide a set of choice of eucalyptus hybrid clones farmers would propagate in Nairobi (where Karura site is situated), Embu, Kabage, Machakos (Iveti Hills) and Gede. Farmers are also able to choose the best non-hybrid eucalyptus species (land races) for diversification on each site.

5.2 Recommendations

Long-term trials of appropriate GCs with non-hybrid *E. saligna* should be established in high altitudes sites of Kabage so that their performances are compared.

Long-term trials of appropriate GCs with non-hybrid *E. camaldulensis,* which is known to be draught resistant, should be started in the dry zones of Machakos (Iveti is 2,060m above sea level) for purposes of making comparisons in terms of growth performance.

Further research should be carried out to establish the calorific value of wood from GCs and be compared with non-hybrid progeny for purposes of establishing the best firewood species.

Aggressive extensions strategy must be carried out by all the stake holders involved in establishment and distribution of eucalyptus hybrid (clones) seedlings to inform farmers in Machakos (around Iveti), Kabage, Embu (upper zone), Karura area and Gede on the best hybrid clones for these areas.

The Embu and Karura trial should be closely monitored for pests and diseases.

Similar trials should be established in other agro climatic zones of Kenya for purposes of identifying the most suitable eucalyptus species for planting in these areas.

In sites where hybrid clones appear to perform better than the non-hybrid germplasm, diversification with the best non-hybrid germplasm would be a strategy to safe guard risks associated with pests and diseases and changing weather conditions.

Continued research and silvicultural studies should be carried out on the GCs to enhance further understanding especially on farmer sensitization, intensive short rotation and effects on hydrology and soils and economic studies of growing hybrid *Eucalyptus* clones, market reliance and stability and product mix for various market needs.

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APPENDIX 1

EXPERIMENTAL TRIAL DESIGN FOR KARURA

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x
x

REP III				REP II		REP I			
28 GC 15	27 GC 10	22 GC 522	21 *E. saligna*	16 GC 522	15 *E. tereticornis*	10 GC 12	9 GC 15	4 *E. grandis*	3 GC 581
29 GC 14	26 *E. grandis*	23 GC 12	20 GC 642	17 GC 12	14 GC 14	11 *E. saligna*	8 *E. tereticornis*	5 GC 14	2 GC 522
30 GC 642	25 *E. tereticornis*	24 GC 581	19 *E. grandis*	18 GC 581	13 GC 15	12 GC 10	7 *E. saligna*	6 GC 642	1 GC 10

x
x
x

The perimeter (xxx) is skirted by local Eucalyptus species viz *E. grandis*, *E. saligna* and *E. tereticornis*. Distance from one tree to the other is 2.5 m.

Tree arrangement per plot

25	⇒	24	⇒	23	⇒	22	⇒	21
								⇑
16	⇒	17	⇒	18	⇒	19	⇒	20
⇑								
15	⇐	14	⇐	13	⇐	12	⇐	11
								⇑
6	⇒	7	⇒	8	⇒	9	⇒	10
⇑								
5	⇐	4	⇐	3	⇐	2	⇐	1

APPENDIX 2

EXPERIMENTAL TRIAL DESIGN FOR EMBU

X X
X X
X X

REP. III		REP. II				REP. I	
22 GC 14	21 *E. saligna*	16 *E. grandis*	15 *E. tereticornis*	10 GC 642	9 GC 15	4 *E. grandis*	3 GC 581
23 *E. camaldulensis*	20 GC 15	17 GC 642	14 GC 14	11 *E. saligna*	8 *E. tereticornis*	5 GC 14	2 *E. camaldulensis*
24 GC 581	19 *E. tereticornis*	18 *E. grandis*	13 *E. camaldulensis*	12 GC 581	7 *E. saligna*	6 GC 642	1 GC 15

X X
X X
X X

The perimeter (xxx) is skirted by local Eucalyptus species viz *E. grandis*, *E. saligna* and *E. tereticornis*. Distance from one tree to the other is 2.5 m.

4 → 5 → 6
↑
3 ← 2 ← 1

Tree arrangement per plot

APPENDIX 3

EXPERIMENTAL TRIAL DESIGN FOR GEDE

E.U.	E.T.	E.C.	GC 540	GU 8	GU 21	GC 514	GC 796	GC 14	G 5… / G 78…

E.U.

REP. III					REP. II					REP. I				
43 GC 796	40 GC 14	37 GC 584	34 GC 540	31 GC 784	28 GC 784	25 GU 21	22 GC 167	19 GU 7	16 GC 581	13 GU 8	10 GC 581	7 GC 514	4 GU 21	1 E.T.
44 E.T.	41 E.C.	38 GC 784	35 GC 581	32 GU 21	29 GC 584	26 GC 514	23 E.T.	20 E.U.	17 GC 14	14 GC 584	11 GC 167	8 GC 14	5 E.C.	2 E.U.
45 GC 514	42 GU 8	39 E.U.	36 GC 167	33 GU 7	30 GC 540	27 GU 8	24 GC 796	21 GC 785	18 E.C.	15 GC 796	12 GC 540	9 GU 7	6 GC 784	3 GC 785

G 16… GU… G 58…

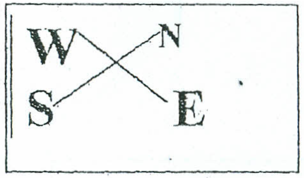
TAG 5	GC 642	GC 10	GC 15

E.U.

Key:
E.U. = *Eucalyptus urophylla*
E.T. = *Eucalyptus tereticornis*
E.C. = *Eucalyptus camaldulensis*
GU = *E. grandis* X *E. urophylla*
GC = *E. grandis* X *E. camaldulensis*
TAG 5 = Pure grandis clone

16		9	⇐	8		1
⇑		⇓		⇑		⇓
15		10		7		2
⇑		⇓		⇑		⇓
14		11		6		3
⇑		⇓		⇑		⇓
13	⇐	12		5	⇐	4

Tree arrangement per plot



Espacement = 2.5 m x 2.5 m

APPENDIX 4

EXPERIMENTAL TRIAL DESIGN FOR KABAGE

I

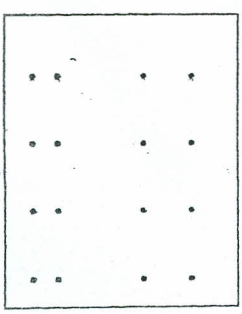
TAG 5	GC 514	GU 21	GC 784	GU 21	GU 7
GU 8	LOCAL GRANDIS	GC 784	GC 540	TAG 5	GU 8
GC 540	GU 7	GU 21	GC 514	LOCAL GRANDIS	GU 8
LOCAL GRANDIS	GC 540	TAG 5	LOCAL GRANDIS	GC 540	GC 784
GU 7	GC 784	GU 8	GU 7	GU 21	TAG 5
LOCAL GRANDIS FILLER	GC 514	LOCAL GRANDIS FILLER	LOCAL GRANDIS FILLER	GC 514	LOCAL GRANDIS FILLER

IV

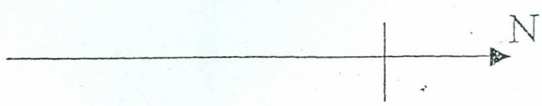
III

II

3 GUARD ROWS



ONE CLONE REP



APPENDIX 5

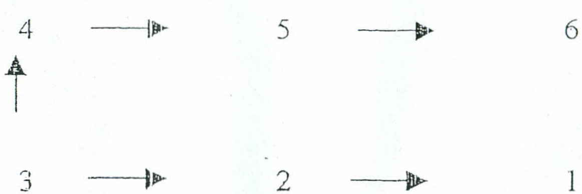
EXPERIMENTAL TRIAL DESIGN FOR MACHAKOS

X X
X X
X X

REPLICA III				REPLICA II		REPLICA I			
28 GC15	27 GC10	22 GC522	21 E. Saligna	16 GC522	15 E. Tereticornis	10 E. Camaldulensis	9 GC15	4 E. Grandis	3 GC581
29 GC14	26 E. Grandis	23 E. Camaldulensis	20 GC642	17 E. Camaldulensis	14 GC14	11 E. Saligna	8 E. Tereticornis	5 GC14	2 GC522
30 GC642	25 E. Tereticornis	24 GC581	19 E. Grandis	18 GC581	13 GC15	12 GC10	7 E. Saligna	6 GC642	1 GC10

X X
X X
X X

The perimeter (XXX) is skirted by local eucalyptus species viz E. grandis, E. saligna and E. tereticornis. Distance from one tree to other is 2.5m.



Tree arrangement per plot