EFFECTS OF TREE NURSERY GROWING MEDIA AND FARMERS' MANAGEMENT TECHNIQUES ON SEEDLING QUALITY IN MOUNT KENYA REGION

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Declaration

I, Job Kihara, declare that this thesis is my original work and has not been presented for a degree in any other university or any other award.

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DEDICATION

This work is dedicated to my LORD who cleared the way for me to this end; and to my brother and his family for praying and encouraging me to pursue further studies.

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ABSTRACT

Low survival and slow growth rate of trees as a result of poor quality tree seedlings hamper effort by small-scale farmers in development of agroforestry systems. These may be attributed to the chemical and physical properties of the growing media used and the management practices adopted. With the growing demand for quality agroforestry trees, farmers have increasingly attempted to raise planting stock on-farm. However, insufficient technical knowledge has often hindered success. Insufficient growth medium quality has been identified as one of the factors contributing to low seedling qualities. Such growing medium contributes to physical and chemical conditions that may be inappropriate for quality seedling development. Slow growth rate and survival rate lead to extra costs in replacement planting as well as delayed benefits.

With this knowledge, this study attempted to find out the effect of growing media chemical and physical properties used by farmers to raise seedlings of *Tamarindus indica* on-farm and the management practices adopted. This was necessitated by the need to determine parameters that make a good tree nursery growing medium that can be used by farmers on their on-farm nurseries for appropriate seedling quality. The study also monitored the quality of the seedlings during the nursery period.

On-farm tree nurseries in two agro-ecological zones in mount Kenya region-main coffee and marginal coffee zones were studied. Samples of the growing media used were analyzed for chemical and physical properties. Seedlings were produced in the media and their root diameter and seedling height measured periodically. Data collected were analyzed for variance (ANOVA) and tested for correlation.

Aeration pore volume, total pore volume and wet bulk density were the physical properties that had greatest influence on seedling quality parameters. These had more effect at initial period of growth. Chemical properties affected seedling growth and quality parameters at later stages of growth. Important nutrients were observed to be nitrogen, organic carbon, magnesium and calcium. From the findings of this study, farmers can curtail nursery period from 130 days to as little as 75 days.

There is need for further research to determine the cause of too much phosphorus concentration in the growing media tested and understand ways of ameliorating its negative effect on seedling development.

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ABBREVIATIONS

AEZ	Agro-ecological zone
BDd	Dry bulk density
BDw	Wet bulk density
DS	Density of substrate
ICRAF	International Centre for Research in Agroforestry
MC	Mineral component
OC	Organic carbon
RCD	Root collar diameter
RDW	Rood dry weight
SH	Seedling height
SDW	Shoot dry weight
S/R	Shoot/root ratio
SQ	Sturdiness quotient
UM2	Upper midland 2
UM3	Upper midland 3
WHC	Water holding capacity
ANOVA	Analyses of variance
ISHS	International Society for Horticultural Science
WW	Wet weight
TPV	Total pore volume

DEFINITION OF TERMS

Ashing: Heating of growing media sample at high temperature (550^{o}c) for 5 hours to completely destroy organic carbon

Sturdiness quotient: Ratio of seedling height in centimeters to root collar diameter in millimeters

Substrate: growing medium mixture used in tree nurseries

Upper midland: Agro-ecological zone characterized by rainfall between 1400mm and 2400mm and mainly grows coffee in Mt. Kenya region

Survival rate: Seedlings remaining in tree nursery after 130 days of growth as a percentage of germinated seedlings

Shoot/root ratio: Measure of seedling quality derived from seedling shoot dry weight divided by root dry weight

CHAPTER ONE

INTRODUCTION

1.1 Background to the problem

Low survival and slow growth rate of trees as a result of poor quality tree seedlings often hamper efforts by small-scale farmers in developing successful agroforestry systems. Tree nursery growing media may have sub optimal physical and chemical properties that will lead to low seedling quality (Wightman 1999). There is no standard tree nursery growing medium in use by small-scale farmers. Quite often, the different growing media used affect seedling physical quality and survival in the field (Jaenicke 1999) and vary from one farmer to another. This may be attributed to different physical and chemical properties in different growing media. Balanced supply of nutrients is needed in tree nurseries for supporting healthy and vigorous plant growth while ensuring adequate root development and plant hardiness (Mason and Aldhous 1994). The basic goal of having quality seedlings is to achieve the best growth possible and have the highest amount of desired output such as timber, food, fodder and fuel (Jones 1993).

Tree nurseries indicate farmers' efforts to integrate trees on their farmland and are fundamentally important to long-term development of agroforestry. With increasing demand for high value trees, farmers have attempted to raise them but often with insufficient knowledge for assuring high quality. This is because many of the species that are now popular have grown in the natural population and nobody has raised them in a tree nursery before. This demand therefore has neither been matched with diffusion of knowledge on modern techniques for raising high quality agroforestry trees nor has any effort been made to find out what the farmers do and compare it with seedling development.

In retrospect, seedling quality varies among farmers using the same growing medium possibly due to different farmer nursery management techniques. Nursery management techniques such as pricking time, watering regimes, date and period of shading, weeding and pest control, vary from farmer to farmer. Such variations may be due to different factors such as workload, previous nursery experience or contact with farmers' extension agents. Consideration of farmer management aspects is therefore necessary in efforts towards optimization of seedling quality.

1.2 Statement of the problem

Farmers complain frequently about insufficient technical knowledge of nursery practices. One factor that has been identified for low seedling growth and survival rate in the nursery and on-farms is sub optimal tree nursery growing media used. Quite often, farmers encounter high seedling mortality. Sometimes seedlings produced on-farm exhibit symptoms of mineral deficiency. Many tree nurseries produce seedlings that have weak stems and lose leaves prematurely.

The ratios of substrate ingredients used by farmers in their nursery growing media contribute to chemical and physical conditions that can be inadequate for optimal seedling development. The effect could be extremely high or extremely low shoot/root ratio and unfavourable above ground versus below ground balance of the seedlings, which may result in low seedling growth rate. Low seedling survival and growth rates in the field lead to extra costs in replacement planting as well as delayed benefits.

Organic material such as sheep, goat, cattle and chicken manure and compost are particularly known to improve the soils chemical and physical properties. Such organic materials are readily available to small-scale farmers who have traditionally used them in their tree nurseries. Incorporation of only partially decomposed organic matter however, leads to toxicity and consequently seedling mortality. The level of organic matter to be incorporated in the nursery growing media for optimum chemical and physical properties depends on the species. This study aimed at determining growing media properties appropriate for the generation of quality seedlings of *Tamarindus indica*.

Growing media properties change over time as seedlings deplete nutrients and as the substrate compacts due to development of roots. However, there is an optimal length of time for seedlings to remain in the nursery when the nutrient status is still sufficient for rapid growth and the physical properties support healthy root development. Therefore, this study was geared toward monitoring the quality of *Tamarindus indica* seedlings during the nursery period and to propose the optimal planting time.

Seedling quality is also influenced by the management practices employed by the farmers. Watering regimes, for example may lead to water logging and hence low seedling development when practiced too often or at extremely long intervals. Untimely weeding or no weeding at all may lead to poor seedling development due to nutrient competition between tree seedlings and weeds. The current study also attempted to monitor nursery management practices of small-scale farmers and determine how these affected the development of *Tamarindus indica* seedlings.

This study, therefore, was an attempt to determine the effect of growing media's chemical and physical properties used by small-scale farmers to raise agroforestry tree seedlings on-farm, and the management practices they adopt. This was necessitated by the need to determine parameters that make a good tree nursery soil mixture that can be used by farmers on their on-farm tree nurseries for optimal seedling quality.

1.3 Research questions

1 What is the influence of nursery growing media chemical properties on seedling growth and quality?

2 What is the influence of nursery growing media physical properties on seedling growth and quality?

3 What is the optimal seedling planting time based on the shoot and root ratio?

4 What is the influence of farmers' management techniques on seedling quality?

1.4 Objectives of the study

The broad objective of the study was to determine growing media and farmer management practices on tree seedling growth performance. Specifically, the objectives of the study were to determine:

1 The influence of nursery growing media chemical properties on seedling quality and growth rate.

2. The influence of nursery growing media physical properties on seedling quality and growth rate.

3. The optimal seedling planting time based on shoot and root ratio.

4. The influence of farmers' management techniques on seedling quality.

1.5 Research rationale

High seedling quality, which is a goal for most nursery operators, can be influenced through the growing medium. Organic matter is one of the substrate components readily available to the farmers at low cost. It has profound influence on the chemical and physical properties of the growing media. Inorganic fertilizers involve a high cost that most small-scale farmers cannot afford. Chemical and physical properties of nursery soil mixtures mainly determine the physical quality and survival rates of seedlings.

The current upsurge in agroforestry and demand for high value trees need to be matched with availability of high quality tree seedlings. This study was in response to the increasing demand for high value agroforestry tree seedlings.

By working with a large number of farmers (replicates), important insights in the functioning of nursery technical operations under different farm situations would be gained. While this study achieved the stated objectives, it also acted as a diffusion channel for modern nursery technologies to the farmers.

1.6 Research significance

This study was geared towards improving current on-farm tree nursery techniques. It would increase farmers' knowledge on the choice of nursery soil substrates and mixtures for improved quality of seedlings. Knowledge of contributions made by different nursery substrates on seedling physical quality and survival rate would influence appropriate choice of materials and their mix ratios. Improved nursery techniques would lead to availability of better planting material, higher productivity on the farms and improved economic situation of small-scale farmers. On-farm research would in itself enable farmers' own evaluation and enhance understanding on how to improve tree nurseries.

1.7 Research hypotheses

1. Physical and chemical properties of growing media do not influence seedling growth.
2. The physical and chemical properties of growing media do not determine the optimal planting time for seedlings.
3. Farmers' tree nursery management techniques do not influence seedling growth.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The effect of tree nursery growing media on seedling growth has gained much interest in the recent past. This interest is prompted by the increased demand for on-farm high value agroforestry trees on-farm. Several studies have made contributions towards optimizing seedling quality. Most of these studies have however concentrated on temperate species and provenances but are nevertheless important indications of seedling growth for tropical species.

2.1 Seedling quality

The basic goal of having quality seedlings is to achieve the best growth possible (Jones 1993). This can be achieved through efficient production of seedlings using techniques affordable to the farmer. Seedling quality is gauged by the genetic make-up of the parent stock and by the physical growth, which is influenced by the seedlings immediate environment-nursery conditions and practices (Jones 1993; Jaenicke 1999; Wightman 1999). Nursery conditions and practices are within the farmer's control (Jones and Miller 1995). Furthermore, growth varies with edaphic conditions –ecology and adaptability (Iqbal and Shafiq 1997) –and with species (Wightman 1997). Nursery practice therefore influences the type of the nursery stock produced and species growth response.

Seedling quality in afforestation has received considerable attention in Europe and the US. This is because after seedlings are planted, they have to survive without irrigation or fertilizer, as is also the case in tropical smallholder agroforestry sites. Many studies have shown that field survival and productivity are related to the quality of the seedlings used (Jaenicke 1999). It is important to note that most of the studies on seedling development have focused on large-scale afforestation projects with little focus on small-scale on-farm nurseries.

Many poor nursery practices have become common leading to poor seedling quality and low survival rate in the field as well as to farmers' frustration (Jaenicke 1999). Quite often, on-farm tree nurseries operate with minimal inputs and outdated techniques. Poor quality seedlings discourage people from planting trees and reduce the productive potential of the land due to failure in field establishment of the stock thus raised (Wightman 1999). Farmers are then left with the only option of growing less valued trees that are easier to raise and which become predominant in their fields. There is thus need to improve current on-farm tree nursery techniques and to make tree raising economically feasible for small-scale farmers.

The solution to improvement of seedling quality lies with the farmers themselves. A cross-section of farmers have, through experience and struggles with recurrent nursery problems come up with solutions to those problems. Such farmers may have good nursery practices, which may be, however, little known beyond their farm boundaries.

2.2 Measures of seedling quality

The shoot/root ratio, which is an important measure for seedling survival, relates the transpiring shoot and root area to the uptake (root) area through their dry weights (Duryea and Landis 1984). Seedlings with more roots outperform those with less roots (Duryea 1985) and a good ratio is 1:1- 1:2 shoot/root mass according to Jaenicke (1999) and Wightman (1999). Shoot/root ratios within the range of 1:1.5-1:2.2 should result in optimum survival and growth. Plant partitioning of photosynthetic assimilates is the main determinant of these ratios (Fitter and Hay 1987; Porter and Marshall 1991). Shoot/root ratio depends on species and varies accordingly (Felker 1986).

According to Duryea (1985) and Jaenicke (1999), the sturdiness quotient which indicates the ability to withstand damage in all stock-types relates inversely with seedling survival rate and becomes undesirable when higher than six. Diameter is the best single predictor of field survival and growth of seedlings in the field (Duryea 1985; Dierauf and Garner 1996).

A weakness in the use of morphology for measuring seedling quality has been noted by Duryea (1985). He points out that physiological condition can override morphology and therefore morphology alone does not predict all the variability seen in field survival and growth. Morphology can however be of great comparative value when the physiological status of the seedlings is equal or similar i.e. different nurseries but similar lifting dates (Duryea 1985).

2.3 Growing media properties

In the optimization of seedling production, Wightman (1999) noted that due consideration should be made to the physical and chemical properties of the growing media since they contribute to seedling quality, health and survival rate. This is based on the fact that the different seedling production media used by farmers affect seedlings differently. The type of medium affects the plants' ability to uptake oxygen, nutrients and water (Swanson 1998). A good nursery tree seedling production medium has both chemical and physical properties that promote healthy and rapid plant growth. These properties work together.

2.3.1 Growing media composition

The growing media used such as topsoil, vermiculite, perlite, compost and tropical peat influence nutrient supply to seedlings. Growing media quality is determined by the mix ratio (Awang and Taylor 1993; Wightman 1997). Weber (1977) notes that good results have been achieved by mixing plain sand with sieved cattle manure at a ratio of 1:1. Tiwari and Barholia's study (1994) on some fruit and forest species recorded better growth with 4:2:4 ratios of soil: sand: compost. An unevenly mixed growing medium may result in irregular seedling growth (Awang and Taylor 1993). Growing media used vary from place to place depending on availability of the ingredients. These differ in nutrient availability and release as well as in their structure. The optimal growing medium should have an appropriate balance of the various components for optimal growth.

2.3.2 Nutrient supply

Balanced supply of nutrients is needed in tree nurseries for supporting healthy and vigorous plant growth while ensuring adequate root development and plant hardiness (Mason and Aldhous 1994). The extent to which nutrients are retained in the growing media in forms available to the plants depend on its Cation Exchange Capacity (CEC) (Mason and Aldhous 1994; Swanson 1998). Nitrogen and phosphorus fertilizers are of particular importance and plants suffering from their deficiencies are weak. Plants can take up these nutrients from organic compost, animal manure and green manure.

The level of nutrient application determines seedling quality. Below optimum levels, plant nutrient supply is marginal and growth may be slightly reduced without any visual signs of deficiency. As plant nutrient levels decline, visual symptoms appear and growth is markedly reduced or ceased (Mason and Aldhous 1994).

According to Wightman (1999), medium for raising seedlings should ideally possess the optimal chemical properties such as fertility, acidity and cation-exchange capacity. Different nursery mixtures possess these qualities in differing proportions and are affected by their origin and organic matter content. Nutrients of importance in nursery operations include macronutrients such as nitrogen, phosphorus and potassium, and micronutrients such as magnesium, iron and zinc. Seedlings need these nutrients, in the right proportions, as soon as the cotyledon reserves are exhausted.

Research on the best nutrient levels for forest tree seedlings is limited and reference is often drawn on horticultural plant species. Some tentative guidelines for the major nutrients (Table 1) have been developed for tree seedlings. Provision of nutrients is highly enhanced by incorporation of organic components in the growing media.

Table 1. Optimum mineral nutrient levels for tree seedlings

Mineral nutrient	Optimum range
NH_4-N	15-65 mg/kg
P	35-95 mg/kg
K	25-115 mg/kg
Ca	30-60 mg/100g
Mg	15-35 mg/100g

Source: Landis *et al.* (1989).

2.3.3 Organic matter

Chemical fertilizers which are used in tree nurseries to supplement farm soil are expensive and therefore, organic manure offers a good substitute. Organic matter such as goat, sheep, cattle and chicken manure are available to many farmers. Compost may be prepared from farm and household remains by most farmers. However, according to Khan (1987), the type of organic matter applied in tree nurseries is determined by what is locally available to the farmers.

Organic matter improves growing media's physical and chemical properties (Altieri 1995; Wightman 1999). Mason and Aldhous (1994); Jones and Miller (1995) argued that as organic matter decomposes, plant nutrients are released thus giving rise to outstanding growth of plants. Moreover, as noted by Mason and Aldhous (1994), humus in the soil holds moisture and nutrients similarly to clay but without it's stickiness. Farmers have often used various levels of organic matter in their growing media. However, studies have not been done to establish what these levels are or their effect on the soil moisture and subsequent seedling quality in on-farm tree nurseries.

A potting medium composed of a high percentage of organic matter is light in weight, well drained and aerated (Woode *et al.* 1998) and yet able to retain significant amounts of water. Peat moss, vermiculite, perlite and other manufactured products that are appropriate and predominantly used as potting media in the temperate zone are unaffordable to majority of the tropical small-scale farmers (Wightman 1999). Fortunately, organic materials have proven to be quite adequate for use as potting media to these small-scale farmers (Jones and Scott 1992). Organic matter must, however, be well decomposed (Woode *et al.* 1998) if the best results are to be achieved before incorporating into the growing media.

2.3.4 Porosity and texture

Physical properties have been shown by Bohne and Gunther (1997) and Argo (1998) to play an important role in the quality control of nursery growing media. Proper shoot and root growth of seedlings is aided by the ability of the growing media to provide water, supply nutrients, permit gas exchange and provide for plant support (Argo 1998).

Studies such as those by Bohne and Gunther (1997), Argo (1998) and Swanson (1998) have revealed that texture greatly influences soil moisture, total pore space and bulk density, which increases with decreasing particle size. Good seedlings can be produced only in the right type of soil. In addition, Soil with high organic matter content form ideal texture (Khan 1987) and good porosity.

A good porosity is needed to allow sufficient oxygen to reach the roots (Swanson 1998) and prevent rotting (Bunt 1988; Jaenicke 1999). All living cells including plant roots need oxygen for respiration and growth (Jones 1993; Bunt, 1988; Jaenicke 1999) and a temporary shortage can reduce root and shoot growth while anaerobic conditions for only a few days can result in death of some roots (Bunt 1988). To maintain adequate oxygen and carbon dioxide levels in the growing media, gas exchange with the atmosphere must be guaranteed (Landis *et al.* 1990). Soils low in clay but relatively high in organic matter are probably ideal from the point of view of texture for tree nurseries (Mason and Aldhous 1994). According to Bilderback (1982) and Jaenicke (1999), oxygen content below 12% in the growing media inhibits new root initiation; between 5 and 10% the levels are too low for established roots to grow; and levels below 3%, roots do not function and eventually die. Good aeration pore volume for container seedlings is 20- 35% of total volume (Bilderback 1982; Landis *et al.* 1990). Desirable total porosity values are around 50-80% by volume (Khan 1987; Mason and Aldhous 1994; Jones and Miller 1995). The values have been empirically determined for temperate seedlings such as Pinus. Optimal values for tropical seedlings are not known but are assumed to be in the same range.

2.3.5 Moisture

Adequate moisture during the nursery stage is essential for proper seedling growth (Awang and Taylor 1993). Moisture is a function of texture, weather and irrigation. Regular supply of clean water in the right amount is essential for plant growth (Awang and Taylor 1993; Wightman 1999). Watering regime depends on temperature, humidity, wind velocity, rainfall, evaporation, tree species and size, and the growing media.

Container volume and depth further influence moisture of potted growing media. First, since container volume is small, the growing media should have a large available water holding capacity without causing waterlogging (Bilderback 1982; Jones and Miller 1995). Second, soil water assumes different tensions with depth in the medium (Bunt 1988). In shallow containers, the media has a higher water holding capacity than in deep containers (Bunt, 1988).

Moisture affects the seedling's shoot/root ratio. Plants under water stress allocate a greater proportion of their assimilate to root production (Gupta and Mohan 1990).

Nursery development in Meru, where this study was done, is limited by availability of water. During dry seasons, the immediate household needs for water are naturally of the highest priority and as such the water needs of the seedlings may well not be met. It is therefore particularly important to use a growing medium with a well-balanced water-holding capacity.

2.3.6 Structure

Structure describes the way soils are aggregated. Clay particles in the soil have the ability to hold or combine with nutrients required by plants. This property has a major influence on the structure of the soil and the ability to form aggregates (Mason and Aldhous 1994). In sandy soils, aggregates are weakly developed and therefore break down easily. Good soil structure ensures good drainage and aeration (Mason and Aldhous 1994) and leads to development of fine feeder roots and mycorrhizae thus increasing efficiency of nutrient uptake (Young 1990; Munyaziza *et al.* 1998).

2.3.7 Growing media pH

The right growing media pH is very important for healthy plant development since it affects the availability of nutrients to plants (Duryea and Landis 1984). The optimum pH is about 5.5 for organic soil and around 6.5 for mineral soils.

According to Mason (1994), pH varies with the time of the year and crop. The effect of pH on seedlings tends to be higher in cool, moist weather and changes with the addition of fertilizers depending on the soil texture and the buffer capacity. A strongly buffered soil is likely to provide a more constant environment for plants than a soil that is weakly buffered.

2.4 Nursery management

Tree nursery management influences seedling growth (Gupta 1991) and outplanting success (Kannan and Paliwal 1995). The management practices applied such as watering (Vinaya *et al.* 1995), reduction of stress, shading, mulching (Hayashi and Carsky 1997), weeding, fertilization (Gupta 1990; Kannan and Paliwal 1995) potting up and transplanting enhance root growth and seedling survival (Gupta and Mohan 1990; Gupta 1991). Such practices differ from farmer to farmer depending on the experience and access to knowledge on nursery operations.

Levels of light and temperature also affect seedling growth. According to Itoh *et al.* (1999), seedlings grow most rapidly in partial sunlight. Temperature affects the photosynthetic rates of seedlings and may cause direct damage to living cells. Shading easily controls light and temperatures. The degree of light sieving and seedling cushioning depends on how translucent or opaque the covering is. Again, the time and period of shading differ with farmers.

Water, on the other hand, affects all metabolic processes in seedlings. Watering is therefore an important management practice for ensuring favourable moisture throughout the nursery period. Light, temperature, humidity and wind affect evapotranspiration from the nurseries.

Another important part of the process of growing high quality tree nursery stock is weed control. It helps achieve the maximum height, diameter and survival of the seedlings (Singh and Dhiman, 1999) as it minimizes competition for light and nutrients (Longman and Wilson, 1998).

2.5 Tamarindus indica

Tamarindus indica is one agroforestry tree that has received much attention in the Indian subcontinent but little has been done in Africa. *T. indica* yields wood (Ambwani and Kar 1995), fruits (Feungchan *et al.* 1996) and fodder (Hentgen 1985; Gupta 1988) and is also useful ornamental tree (Broschat and Donselman 1983). This tree legume does not form association with nitrogen fixing bacteria and has been found to lack in nodules (Allen and Allen 1936; Athar and Mahmood 1982;

Balasundaram 1987; Van Kessel *et al.* 1988; Chiemsombat *et al.* 1996; Towprayoon *et al.* 1996). Chiemsombat *et al.* (1996) found microvilli on the active region of Tamarind roots and postulated that they may be helping in minerals or water absorption or other activities. The species is colonised by mycorrhizae (Reena and Bagyaraj 1990). Guissou *et al.* (1998) found mycorrrhizal dependency of *Tamarindus indica* reaching no more than 36%, while after screening the species for ectomyccorrhizal association Sidhu and Behl (1990) found it to be colonised by two mycorrhizal species (*Glomus fasciculatum* and *Scutellospora calospora*). Selvaraj, et al., (1996) did not record any significant seedling growth response by *Tamarindus indica* to inoculation with three Vesicular-arbarscular mycorrhizal fungi viz. *Glomulus fasciculatum*, *G. Mosseae* and *Gigaspora margarita.*

2.6 Conclusions

From the foregoing, studies on tree nurseries have been done in temperate countries while little is done in tropical countries. These studies have been done on-station leaving a wide gap of on-farm research and understanding of farmers' management techniques. In an attempt to contribute towards improvement of on-farm tree nurseries, the current study combined both on-farm survey and on-station experiments as discussed in subsequent chapters.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Study areas

This study was carried out in Meru Central and Meru South districts in Eastern Province of Kenya as an on-farm survey and in Nairobi as an on-station experiment. Meru South and Meru Central districts (0° 3′ 45′′N-0° 2′ 30′′S; 37°-38°E) straddle the equator and lie east of Mt. Kenya whose peak cuts through the Southwest border of the former Meru District. Their total area is estimated to be 3012 sq. km. Two agroecological zones; upper midland 2 (UM2) and upper midland 3 (UM3) were the main areas of study. Rainfall pattern in these areas is bimodal with long rains occurring from mid March to May and short rains from October to December (Jaetzold and Schmidt, 1983). Annual rainfall ranges between 1500 mm to 2400 mm in UM2 and 1400-2200mm in UM3. Variation in mean annual temperature is low (20.6°C -18.2°C in UM2 and 20.6°C -19.2°C in UM3) because these districts lie on the equator (Jaetzold and Schmidt 1983).

ICRAF nursery is located in Nairobi at 01° 14′ 14′′S and 36° 49′ 02′′E. The mean annual rainfall recorded is 937mm. Mean monthly temperature is about 23.8°C.

High population density in Meru Central and Meru South has put a lot of stress on forest resources. An increasing need for wood and non-wood forest products contributes to high rates of deforestation in the area. This has engendered to environmental degradation of this area, which is a major watershed in Kenya.

Forestry and agroforestry are key sectors in the economy of these districts. Both hardwoods and softwoods are planted in the area resulting in the establishment of sawmills and furniture workshops that have offered employment to many people. Agroforestry has also facilitated bee-keeping, making it an important economic activity. The main products from agroforestry are timber, wattlebark, firewood and charcoal.

The rise in population and resultant high demand for forest products has led to a rise in forest development activities, which are carried out under forest extension services. In each division, centrally located nurseries have been established by the forest department for demonstration purposes in order to facilitate agroforestry activities by individual farmers, organized social groups and institutions. Several private and group tree nurseries have been initiated for producing ornamental, fruit and timber trees of different species.

3.2 Sampling procedure

A reconnaissance survey preceded the study and identified 60 potential farmers out of whom 18 were chosen for inclusion in the study following the procedure below. Stratified random sampling method identified the farmers based on conformity to the agroecological zones upper Midland 2 (UM2) and Upper Midland 3 (UM3). The on-farm tree nurseries were further classified according to whether the growing medium they used was primarily sand, compost or farm soil. A growing medium was classified as compost when the level of organic component added exceeded 20%, sand when the amount of sand in the medium was more than 20% and farm soil when the level of organic matter used or its sand content did not exceed 20 %. Equal numbers of growing media (3 substrates) in each category and agroecological zone were chosen and included in the study to enable analyses and comparison.

Table 2 shows the different categories of on-farm tree nurseries (named after the owners or locality). Kaburu and Muungano growing media were classified as sand because of the profound effect of sand on physical properties though they could also be classified as compost-based growing media. Forest soil was classified as compost due to the high amount of organic matter it contained.

Table 2. Classification of growing media and their farm soil, sand and compost percentage

	UM2				UM3			
Growing media type	Name Nursery	Soil (%)	Compost (%)	Sand (%)	Name Nursery	Soil (%)	Compost (%)	Sand (%)
Farm soil	Kiangondu	100	0	0	Majarene	85	0	15
	Nyweri	83	16	0	Wendo	100	0	0
	Umoja	100	0	0	Njogune	100	0	0
Compost	Kierera	67	33	0	Mwiti	71	28	0
	Njaina	75	25	0	Njuri	0	100*	0
	Mwenda	61	30	0	Ntomba	67	22	11
Sand	Joyce	65	15	20	Kinoti	29	14	57
	Kaburu	50	25	25	Muthee	67	0	33
	Karamani	66	0	33	Muungano	40	40	20

Key: * forest soil

3.2 Experiment design

This work involved surveying a total of 18 small-scale on-farm individual and group tree nurseries within the two agroecological zones (9 from each zone). It also compared seedling growth using six growing media types at ICRAF headquarters (Nairobi). Five of these media types were sampled from the 18 small-scale on-farm tree nurseries considered for study in Mount Kenya region while one was an ICRAF standard. Choice of the five was based on appropriate representation of the growing media types used in Mount Kenya region and commitment of the farmers using them. The study was undertaken between the months of May 2000 and February 2001.

The experiment at the ICRAF headquarters nursery was a randomized complete block design (RCBD) with six treatments of three replicates each. Each treatment had 20 seedlings (one seedling per 4×6″ polythene bag) of the experimental tree (*Tamarindus indica*) arranged in 4 rows and 5 columns and the treatments were separated from each other by a few inches using timber. The treatments were:

1 Forest soil (100%) - Njuri

2 Farm soil (100%) - Umoja

3 Standard [forest soil and compost (2:1)] - ICRAF

4 Compost and farm soil (3:1) - Njaina

5 Farm soil, humus and sand (6:2:1) - Ntomba

6 Sand, farm soil and humus (4:2:1) - Kinoti.

These are shown in the experimental design in Figure 1.

Replicate 1	Plot No.	1	2	3
	Treatment assigned	6	5	2
	Plot No.	4	5	6
	Treatment assigned	4	3	1

Replicate 2	Plot No.	7	8	9
	Treatment assigned	4	5	3
	Plot No.	10	11	12
	Treatment assigned	6	2	1

Replicate 3	Plot No.	13	14	15
	Treatment assigned	3	4	5
	Plot No.	16	17	18
	Treatment assigned	1	6	2

Figure1. Experimental layout at ICRAF Nairobi

Seedlings were watered alternate days during germination and thereafter every morning. Weeds were removed out immediately they were noticed.

3.4 Growing media and seedling sampling

3.4.1 Growing media sampling

For each on-farm tree nursery, approximately 5kilograms of substrate were sampled by scooping randomly from a thoroughly mixed substrate batch using half-kilogram containers. For those tree nurseries whose growing medium was tested on-station, approximately 38 kilograms of growing media was collected. The farmers were asked to use the same growing media throughout.

3.4.2 Seedling sampling

Seedling selection for measurements was done using systematic random sampling. In each on-farm tree nursery, ten seedlings were selected for measurements while all seedlings on-station were measured. Sampling was done monthly for on-farm nurseries and fortnightly on-station and the final measurement was done at 130 days of growth (Figure 2). In addition, stratified random sampling was done after every 6 weeks for destructive sampling for root and shoot dry weights of seedlings.

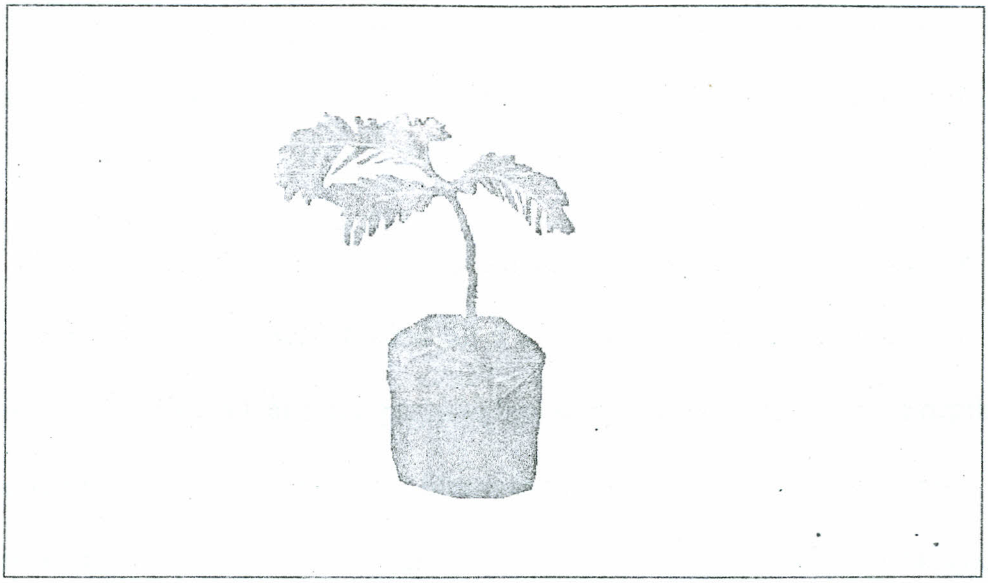

Figure 2: Tamarindus indica tree seedling at 130 days of growth.

3.4.3 Seedling measurements

Diameter was measured twice in opposite directions 1-2 cm above the growing media surface using vernier calipers (0.1 mm accuracy). Seedling height was measured from the growing media surface to the highest growing tip using a ruler (1 mm accuracy). The number of leaves and nodes were also counted.

Root and shoot dry weights of seedlings were derived through careful root washing followed by separation of the root and the shoot using secateurs. These were then oven dried at 60°C for 24 hours (Duryea 1985) and their respective weights taken using an electronic weighing balance (0.0001 g accuracy).

3.5 Growing media analyses

3.5.1 Physical analyses of the growing media

Soil physical properties analyzed included; total pore space, aeration porosity, waterholding capacity and bulk density. These were determined using modification of the International Society for Horticulturae Science (ISHS) reference method (Gabriels and Verdonck, 1991).

Pore volume and water holding capacity (WHC) were determined by using moist growing media slowly drained on a sand bed (50 mesh, 4 cm depth). Moist growing media was put in three pre-weighed sample containers of 20cm depth with perforated bottom and hit on a table fifteen times to settle it to the same density as the density that would be achieved during normal potting of seedling containers. The sample containers with filled samples were weighed and placed into a water container that was then filled slowly with water upto 19.5 cm and left standing for sixteen hours. The same was done for the sand bed. The sample containers were then placed on the sand bed and left to drain for eight hours. The resultant sample wet weight (WW) (0.1 g accuracy) and the wet bulk density (BDw) were determined using the volume of the sample (V2) as $V2=\pi r^2h$. Where, πr^2 is the circumference of the container, and h is the container height.

The samples were oven-dried at 105°C for 48 hours to determine their dry weights and find the dry bulk density (BDd).

Percentage water holding capacity was calculated using the following formula:

WHC=% Weight*BDd,

Where water content (% weight)=((WW-DW)/DW*100.

Total pore volume (TPV) was determined by ashing the samples in a muffle furnace at 550°C for five hours and then calculated using the formulae:

TPV (%)=(1-(BDd/DS)*100. Where,

Density of sample (DS)=100/((%OC/1.65)+(%MC/2.65)),

Organic component (%OC)=100-Mineral component (%MC), and

MC (%)=(Sample after ashing/dry sample before ashing)*100.

Aeration porosity (APV) was then calculated as: APV=TPV-WHC

Further, sample pH was determined using a standard method (ICRAF 1997) that uses a soil/water ratio of 1:2.5. In this case 25 ml of distilled water was added to 10 ml of growing medium sample, stirred for 10 minutes and left to stand for 20 minutes before stirring again for 2 minutes. The pH meter was calibrated using pH 7 and pH 4 buffer solutions. Immediately before making measurements using pH meter (0.1 unit accuracy), each sample was stirred for 5 seconds using a glass rod.

3.5.2 Chemical analyses

3.5.2.1 Exchangeable Calcium, Magnesium and Sodium

The extraction procedure for these nutrients used 1 N KCl extractant at 10:1 soil solution ratio. Exchangeable sodium was determined only when pH in water was 7.5 or higher. The extraction solution was prepared by adding 25 ml of 1N KCl to 2.5 ml of soil and stirring for 10 minutes before gravity filtration through Whatman No.5 filter paper. Dilution for calcium and magnesium was prepared by dispensing 1 ml of the filtered extract and 9 ml deionised water and then adding 10 ml of 1% lanthanum solution. Calcium and magnesium concentration values (me/ 100g of soil) were determined using an atomic absorption spectrophotometer (Buck scientific, 200A). Sodium dilution was done using 2 ml of filtered extract and 8 ml of deionised water. Sodium concentration (me/ 100g) was determined using a Flame photometer (Corning, 410).

3.5.2.2 Total Organic Carbon

The total organic carbon in samples was determined colorimetrically by the modified Mebius method (Heanes 1984) using wet oxidation by acidified dichromate (Anderson and Ingram 1993). 2 ml deionized water was added to 0.5 g of growing medium sample (0.3 mm). 10 ml of 5% potassium dichromate ($K_2Cr_2O_7$) solution was added to the samples and allowed to completely wet them. 5 ml concentrated sulphuric acid (H_2SO_4) was added while swirling and the mixture digested at 150°C for 30 minutes before adding 50 ml 0.4 % barium chloride solution. The mixture was left to stand overnight before reading the concentration at 600 nm on the spectrophotometer (Buck scientific, 200A).

3.5.2.3 Nitrate and Ammonium

Nitrate determination was done using copper-coated cadmium granules by diatomizing the nitrite produced with sulphanilic acid (4-aminobenzene sulphonic acid) and coupling with 5-amino 2-naphthalene sulphonic acid (5-2 ANSA) solution to form a highly coloured azo dye that was measured colorimetrically. 3 ml of sample were pippeted and transfered into a column containing cadmium granules, allowed to drain through slowly (1.8 ml/sec) into tubes, shaken well and then allowed to stand for five minutes. Samples in the tubes were then topped with 5 ml of 5-2 ANSA solution and left to stand for 30 minutes before measuring absorbance at 525 nm using a spectrophotometer (Buck scientific, 200A) (Dorich and Nelson, 1984).

For ammonium determination, 2 ml of sample were added to 5.0 ml of salicylate nitroprusside (reagent N1), mixed and left to stand for 15 minutes. 5.0 ml of sodium hypochrolite (reagent N2) were then added, mixed and left to stand for one hour for full colour development. Sample absorbance was read at 655 nm from a spectrophotometer (Buck scientific, 200A).

3.5.2.4 Total Nitrogen determination

Total nitrogen was determined by wet oxidation based on a Kjeldahl digestion (Anderson and Ingram 1993) with sulphuric acid in a modified Kjeldahl method. 0.4g finely ground substrate (50 mesh) was mixed with 1.8g potassium sulphate (K_2SO_4)

and added with 7.5ml of digestion mixture (1g selenium + 1 Litre concentrated H_2SO_4 + 72g salicyclic acid) before swirling gently to moisten the sample and heating at 100°C for 1 hr. After cooling, hydrogen peroxide (1ml 30%) was added three successive times. The mixture was digested at 360°C for 2 hrs. The volume of this sample solution was topped to 75ml total volume with deionised water. Sample absorbance for total nitrogen was read at 655 nm using a spectrophotometer (Buck scientific, 200A).

3.5.2.5 Available Potassium

Extraction of available potassium was done following the modified Olsen method. 25 ml of the extracting solution (0.5 M $NaHCO_3$ +0.01 M EDTA, pH 8.5) was added to 2.5 ml of substrate and stirred for 10 minutes. Gravity filtration through Whatman No 5 filter paper was done. 2 ml of the filtrate sample was diluted with 8 ml of deionized water and swirled gently to mix. Potassium concentration (me K/100ml soil) was determined using a Flame photometer (Corning, 410).

3.5.2.6 Total phosphorus determination

Determination of total phosphorus was based on Kjeldahl digestion (Anderson and Ingram 1993) with sulphuric acid. 4.0 g of growing medium (0.3 mm) was mixed with 0.24 g K_2SO_4 per ml of H_2SO_4 and 7.5 ml of digestion mixture, mixed gently and left to stand overnight. After heating for 2 hours at 100°C, H_2O_2 was added and the sample reheated for another 2 hours at 360°C. The sample was then topped to 75 ml using deionized water.

Ascorbic acid solution (4.0 ml) was added to 0.5 ml of sample solution. Molybdate reagent (3.0 ml) was then added and the solution mixed before leaving for one hour for full colour development. The phosphorus concentration (%) was determined colorimetrically using a spectrophotometer (Buck scientific, 200A) at 880 nm.

3.5.2.7 Available Phosphorus

Extraction of available phosphorus was done following the modified Olsen method (Anderson and Ingram, 1993). 25 ml of the extractant solution (0.5 M NaHCO3 +0.01 M EDTA, pH 8.5) was added to 2.5 ml of substrate, stirred for 10 minutes and then filtered through Whatman No 5 filter paper. 2 ml of the filtrate sample was diluted with 8 ml of deionized water and 10 ml of working phosphorus colour reagent added. After full colour development, sample absorbance was read at 880 nm from the spectrophotometer (Buck scientific, 200A).

3.5.2.8 Micronutrients (Iron, Zinc, Copper and Manganese) determination

Extraction of micronutrient concentration was done according to the modified Olsen method using sodium bicarbornate 0.1M followed by atomic absorption spectrophotometry at different wavelengths using an atomic absorption spectrophotmeter (Buck scientific, 200A).

3.6 Data analyses

Germination percentage and survival rates from different growing media were analyzed using binomial regression. On-farm and on-station seedling measurements were subjected to correlation with the physical and chemical properties of the growing media. In the on-station ICRAF experiment, growing media physical and chemical properties and seedling measurements were also subjected to analyses of variance using Genstat 4.1. Pairwise comparisons between the standard (ICRAF) and each of the other growing media were done using the Student Newman-Keuls test for comparison of means.

CHAPTER FOUR
RESULTS AND DISCUSSION

Introduction

This chapter presents and discusses research findings obtained in the study. It is divided into two sections. The first part focuses on seedling growth in farmers' small-scale tree nurseries and the influence of farmer management on seedling growth. The second part presents and discusses research findings from the on-station experiment at ICRAF headquarters tree nursery. Seedling quality parameters considered in this chapter include seedling height, collar diameter, sturdiness quotient, shoot dry weight, root dry weight and Shoot/root ratio.

4.1 Growing media and seedling growth in the on-farm experiment

Three types of growing media classified as compost, sand and farm soil used in on-farm tree nurseries are considered in this section. These exhibited different physical and chemical properties.

4.1.1 Physical properties of the growing media used

The physical properties of the growing media are shown in Tables 3 and 4. The standard growing medium (ICRAF) composed of forest soil and compost at the ratio of 2:1.

As shown in Table 3, the different growing media varied in their physical properties though the differences were not significant ($p = 0.05$). Compost medium recorded slightly higher aeration pore volume as compared to farm soil and sand. However, this was lower than the standard. This could be due to the higher level of organic matter that could have contributed to aggregate formation and thus increased pore space. On the other hand, sand recorded low aeration pore space due to lack of internal pore spaces in the high proportion of solid particles present. Other factors such as high proportion of clay or fine sand could contribute to low aeration of sand medium (Bilderback 1982; Landis *et al.* 1990).

Table 3. Physical properties observed from different growing media used by different farmers

Agro-ecological zone	Growing media	Substrate	Wet Bulk Density	Water Holding capacity	Total pore Volume	Aeration Pore Volume
	Standard	ICRAF	1	47	76	29
UM2	Farm soil	Kiangondu	1.3	51	68	17
		Nyweri	1.3	45	66	21
		Umoja	1.2	42	67	26
	Compost	Kierera	1.3	50	68	18
		Mwenda	1.2	43	69	26
		Njaina	1.1	41	71	30
	Sand	Joyce	1.4	55	66	11
		Kaburu	1.2	40	68	28
		Karamani	1.2	49	70	21
UM3	Farm soil	Majarene	1.4	50	64	14
		Njogune	1.1	42	73	31
		Wendo	1.3	46	67	22
	Compost	Mwiti	1.1	39	69	30
		Njuri	1.2	43	67	24
		Ntomba	1.4	45	63	18
	Sand	Kinoti	1.2	44	68	24
		Muthee	1.3	44	66	22
		Muungano	1.3	48	66	18
Medium s.e.d			0.06	2.59	1.51	3.46

Compost medium had slightly lower water holding capacity than farm soil and sand. There could probably be a high proportion of clay in the soil and sand media resulting to a high water holding capacity. Unlike farm soil and sand, compost had water holding capacity levels within the range recommended by Landis *et al.* (1990) for forest tree seedlings (see also Table 4). High substrate water holding capacity may cause reduced seedling growth due to water logging and increased chances of disease attack such as dumping off.

The slight differences in water holding capacity levels could be explained by the ability of organic incorporations to enhance an appropriate balance between aeration and water holding capacity in compost as opposed to farm soil and sand. This is demonstrated in the current study by the fact that, while total pore space was similar for the three media, water holding capacity and aeration were different (Table 3). This finding is in agreement with the finding by Bilderback (1982) that substrates such as soil and sand, which create very small air spaces, retain large quantities of water. The finding is also in agreement with Landis *et al.*'s (1990) assertion that organic matter incorporation leads to a properly balanced growing medium structure for good gaseous exchange.

On the other hand, the standard substrate had higher water holding capacity and aeration pore volume due to its high pore space. The high level of organic matter in this standard medium could give it a high water holding capacity while still maintaining high aeration pore volume.

Compost had slightly lower average wet bulk density than both farm soil and sand. This could be due to the high proportion of mineral component in sand and farm soil. Organic matter on the other hand is light thus giving compost a lower bulk density. The standard medium, which had more organic matter, was lighter than all the other growing media.

As shown in Table 4, the observed average aeration pore volume and water holding capacity for farm soil and sand deviated from the recommendations for forest tree seedlings by Landis *et al.* (1990). Average total porosity for all media however, was within the recommended range. Unlike total pore space, deviations of aeration and water holding capacity from the recommended demonstrate the inappropriate balance between them. Since these deviations were observed more in sand and farm soil than in compost, it can be concluded that compost provides a better combination of physical properties than both sand and farm soil.

Table 4. Average physical properties of the different on-farm tree nurseries growing media and recommendations by Landis et al. (1990)

Agro-ecological zone	Growing medium	Wet bulk density (g/cm^3)	Total pore space (%)	Water holding capacity (%)	Aeration pore volume (%)
UM2	Farm soil	1.27	67.3	46.0	21.3
	Compost	1.23	69.4	44.7	24.7
	Sand	1.27	68.0	48.0	20.0
UM3	Farm soil	1.27	68.3	46.0	22.3
	Compost	1.20	66.3	42.0	24.0
	Sand	1.27	66.7	45.4	21.3
Standard (ICRAF)		1.00	76.0	47.0	29.0
Landis *et al.* (1990)			**50 - 80**	**25 - 45**	**25 - 35**

On the other hand, though the standard medium had higher water holding capacity than the recommended, it still maintained high aeration pore volume. This is because the standard growing medium had the highest total pore space due to its high level of organic matter.

4.1.2 Chemical properties of the growing media used

As shown in Table 5 chemical properties of the growing media varied from one medium to another though the differences were not significant ($p = 0.05$). For example growing media pH differed from one medium to another and by agro-ecological zones possibly due to the effect of the components used as the organic incorporations.

Compost had slightly higher levels of organic carbon and potassium as compared to other growing media. Nitrogen levels in farm soil in both agro-ecological zones and in sand in UM2 was below the level recommended by Landis *et al.* (1990) for forest tree species (Table 5). Farm soil and sand in UM2 had potassium levels below the recommended level. The low level of most nutrients recorded in farm soil as compared to compost could be due to the low levels of organic matter in the farm soil. Organic matter is known to have higher nutrient concentration which when released enrich the medium. Organic matter in growing medium has higher cation exchange capacity and hence the ability to retain high level of nutrients as observed in compost medium (Landis et al 1990).

On the other hand, the standard substrate had slightly higher levels of all nutrients apart from phosphorus which was below the level recommended by Landis *et* *al.* (1990) (Table 5). Such deficiency of a major nutrient could reduce seedling growth even if all other nutrients are adequately available. This could have resulted from the quality of organic matter composing the standard.

Average nitrogen content in sand medium from UM3 was higher than all the other media. This could be due to the rich chicken manure used in one tree nursery (Kinoti). This sand based tree nursery recorded the highest nitrogen and demonstrates the ability of chicken manure to improve nitrogen content in tree nursery growing medium.

Table 5. Chemical properties of growing media observed in Upper midland 2 and Upper midland 3 in Mt. Kenya region

AEZ	Growing medium	Nursery name	Chemical properties of the on-farm tree nursery growing media										
			pH	K (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	P (mg/kg)	Organic C	N. (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
ICRAF			7.0	4.4	35.2	13.0	18.6	54.9	171.1	0.1	38.5	104.3	11.0
UM2	Farm soil	Kiangondu	6.3	1.0	23.6	6.2	34.9	24.0	16.8	11.5	52.5	44.8	23.6
		Nyweri	6.3	0.7	23.4	6.4	91.2	17.1	51.1	6.2	64.1	91.8	19.6
		Umoja	5.3	0.4	8.8	3.6	10.6	14.1	11.3	2.0	100.4	145.6	6.8
		Average	**6.0**	**0.7**	**18.6**	**5.4**	**45.6**	**18.4**	**26.4**	**6.6**	**72.3**	**94.1**	**16.7**
	Compost	Kierera	4.4	1.5	3.4	2.0	23.1	26.1	121.9	0.8	250.0	149.7	6.2
		Mwenda	5.5	2.4	12.4	5.8	17.9	23.9	119.0	2.0	294.7	141.0	14.9
		Njaina	7.1	4.6	21.2	7.0	39.5	26.4	67.4	40.9	47.6	128.4	26.3
		Average	**6.5**	**3.2**	**16.0**	**6.3**	**108.4**	**24.5**	**74.3**	**8.8**	**120.4**	**98.7**	**15.2**
	Sand	Joyce	4.9	1.1	5.0	1.8	33.9		28.3	1.0	113.0	107.5	6.2
		Kaburu	6.9	1.9	22.6	7.8	55.0	23.2	16.0	3.1	45.5	19.4	38.0
		Karamani	5.7	1.6	7.8	3.2	6.5		54.1	2.2	114.0	56.5	9.4
		Average	**5.8**	**1.5**	**11.8**	**4.3**	**31.8**	**23.2**	**32.8**	**2.1**	**90.8**	**61.1**	**17.9**
UM3	Farm soil	Majarene	7.0	2.9	24.2	12.2	9.9		26.0	5.0	56.3	26.0	14.6
		Njogune	7.3	3.0	22.0	7.4	19.9	20.6	25.1	0.2	36.1	12.2	19.3
		Wendo	6.5	3.0	19.2	6.3	11.3	15.2	24.3	2.1	35.3	23.1	9.8
		Average	**6.9**	**3.0**	**21.8**	**8.6**	**13.7**	**19.6**	**25.2**	**2.4**	**42.6**	**20.4**	**14.6**
	Compost	Mwiti	8.2	4.5	24.8	12.2	345.5	22.5	112.9	1.6	41.4	34.1	28.4
		Njuri	7.0	1.3	37.0	11.6	26.4	38.0	85.5	2.3	25.6	70.3	4.5
		Ntomba	8.0	4.4	21.0	5.2	287.2	17.4	122.5	3.6	27.5	101.1	36.6
		Average	**7.4**	**3.2**	**28.3**	**10.1**	**198.5**	**27.9**	**88.8**	**3.3**	**34.0**	**60.3**	**15.8**
	Sand	Kinoti	7.5	5.3	27.4	12.0	127.0	31.5	186.2	0.8	42.6	43.1	6.4
		Muthee	6.7	2.5	26.2	9.4	53.1	22.3	83.9	2.2	39.2	40.8	15.8
		Muungano	5.3	0.8	9.0	3.2	5.6	16.6	50.9	0.4	43.0	151.6	4.7
		Average	**6.5**	**2.9**	**20.9**	**8.2**	**61.9**	**23.5**	**107.0**	**1.1**	**41.6**	**78.5**	**9.0**
Landis *et al.* (1990)				**2.5-11.5**	**30- 60**	**1.5-20.0**	**35.0-95.0**		**50.0-150.0**				
Medium s.e.d			**0.67**	**0.87**	**2.82**	**1.09**	**55.3**	**0.32**		**5.65**	**45.0**	**28.6**	**6.56**

4.2.1 Effect of growing media on seed germination in on-farm tree nurseries

As shown in Table 6, seeds of *Tamarindus indica* germinated differently in different growing media. These differences, however, were not significant (p= 0.05) both for growing media in UM2 and UM3. The highest average germination (61.7%) was recorded in compost while sand and farm soil recorded values of 49.3% and 47.2% respectively. These values were not significantly different (p=0.05) (Appendix 1).

Table 6. Average germination percentage of *Tamarindus indica* in different growing media in on-farm tree nurseries

Growing medium	Agroecological zone UM2	UM3	Average germination Percentage
Compost	62	61	61.7
Farm soil	59	43	47.2
Sand	42	57	49.3
s.e.d	15.5	23.0	13.7

The slightly higher germination percentage recorded in compost growing medium could be attributed to the fact that compost had lower wet bulk density and more aeration pore volume (Table 3) that could maintain higher oxygen levels as compared to sand and farm soil. Also the compost medium had a higher level of organic matter (Table 5) that is characterized by extended moisture retention and better aeration. These results are in agreement with Ponnammal *et al.* (1993) who, while working on *Azadrachta indica,* found a mixture of sand, soil and humus (1:1:1) exhibiting higher germination percentage than either sand, red soil or black soil. Similarly, while working on *Shorea trapezifolia,* Zoysa and Ashton (1991) found light forest soil with litter to have higher germination percentage than light mineral soil, which tended to compact. Zoysa and Ashton attributed these results to the ability of the litter to retain moisture. However, Otsamo *et al.* (1996) found some species to have higher germination percentage in sand and farm soil than in compost, implying that rate of seed germination in different media could be dependent on species.

The low germination from one sand based growing medium (Kinoti) (Table 9) could be due to use of partially decomposed organic incorporation. Organic acids released during decomposition could inhibit germination of *Tamarindus indica* seedlings.

4.2.2 Effect of substrate on seedling survival

Table 7 shows the average seedling survival rate in different growing media in UM2 and UM3. Although compost had slightly higher survival rate the differences were not significant for growing media from the different agro-ecological zones; UM2 and UM3. The mean overall survival rate was 73.6%. Pair comparison using Students Newmankuels Test showed that farm soil had significantly lower survival rate than compost ($p= 0.05$) (Appendix 1).

As with germination, compost growing medium showed better results than farm soil growing medium. The low seedling survival rate recorded in farm soil could be due to their higher levels of water holding capacity that could have led to water logging. Water logging is known to hamper gaseous exchange which inhibit growth and ultimately lead to seedling mortality as the case in farm soil. The seedling survival rate in compost and sand did not differ significantly.

Table 7. Average rate of seedling survival (%) from growing media and agro-ecological zones

Growing media type	UM2	UM3	Grand average (%)	Confidence limits (P = 0.05)
Compost	94.3	93.6	94.0	86.5- 97.3
Farm soil	62.0	25.0	43.5	21.5- 68.5*
Sand	81.0	86.0	83.5	62.0- 95.2
Grand average	79.1	68.2	73.6	
Confidence limit (P= 0.05)	71.5- 93.3	47.4- 76.5		
s.e.d	16.3	24.9	15.3	

* Significantly different from compost and sand

4.2.3 Effect of farmer management practices on seedling survival

Watering regimes practiced by different tree nursery operators had high significant effect (p = 0.05) on survival rate in UM3 but was not significant in UM2 (Table 8, Table 9 and Appendix 1). This could be attributed to the lower altitude and drier conditions in UM3 nurseries that could have led to more evaporation rate as compared to tree nurseries in UM2. Insufficient moisture could have therefore led to more seedling mortality in UM3 as compared to UM2.

In addition, watering regimes significantly affected overall survival rates (p= 0.01). The study found that watering twice a day and once a day resulted in higher survival rate than irregular watering regime. Irregular watering could have resulted in extended dry period and hence unavailability of adequate water to the seedling; thereby contributing to seedling mortality. The size of containers used (10 cm by 15 cm) were holding small volumes of growing medium and hence small water volumes relative to seedling demand at irregular watering. On the other hand, frequent watering regimes (once or twice per day) provided adequate moisture to the seedlings throughout the growing period thus ensuring high rate of seedling survival.

Table 8. Effect of watering regime on seedling survival rate (%)

Watering regime	UM2	UM3	Survival rate % (p = 0.01)
Once per day	86.9	93.0	89.7
Twice per day	100.0	100.0	100.0
Irregular	65.8	39.1*	50.8*
s.e.d	23.4	17.5	17.8

* Significantly different

Shading did not influence seedlings survival rate significantly (Appendix 1) although tamarind is said to be light demanding species (Gunasena and Hughes 2000). Even though shading could lead to slow growth rate (as discussed in section 4.2.5) of *Tamarinuds indica* seedlings due to reduced photosynthesis, this could not lead to seedling mortality. The effect of pricking-out time on survival rate was also not significant (p= 0.05) (Appendix 1).

Table 9: Farmer management practices, germination percentage, sturdiness quotient, final seedling height and survival rate percentage in on-farm tree nurseries

Agro-ecological zone	Type of ving medium	Name of tree nursery	Watering Regime per day	Shading	Pricking (days after germination)	Germination percentage	Sturdiness quotient	Final seedling height (cm)	Survival rates (%)
UM2	Farm soil	Kiangondu	Irregular	✗	64	83	3.4	9.0	76
		Nyweri	Irregular	✓	24	45	3.7	8.8	85.2
		Umoja	Irregular	✓	Sowed in pots	48	4.1	9.8	24.1
	Compost	Kierera	1	✗	4	70	6.0	23.4	97.6
		Marima	1	✗	Sowed in pots	72	5.5	17.2	86.0
		Mwenda	2	✗	29	45	4.4	11.6	100
	Sand	Joyce	1	✓	33	60	3.2	9.2	88.9
		Kaburu	1	✓	15	20	3.5	10.3	75.0
		Karamani	Irregular	✗	33	45	3.6	10.7	77.8
UM3	Farm soil	Majarene	Irregular	✗	6	30	3.8	10.9	50.0
		Wendo	2	✗	29	45	3.5	11.6	100.0
		Njogune	Irregular	✗	19	57	3.7	11.3	0
	Compost	Kimene	1	✓	7	62	5.7	14.0	91.9
		Njuri	1	✓	Sowed in pots	45	4.0	12.4	96.3
		Nkubuku	1	✗	17	75	4.6	12.4	93.3
	Sand	Kinoti	2	✗	Sowed in pots	7	5.1	19.4	100
		Muthee	Irregular	✓	35	92	3.5	9.5	67.3
		Muungano	1	✓	11	72	4.6	11.9	90.7

4.2.4 Effect of growing media on seedling height in on-farm tree nurseries

Average seedling height on-farm from farm soil, sand and compost growing media in the two agro-ecological zones is shown in Table 10. Significant differences were observed between growing media types in UM2. However, there were no significant differences (p = 0.05) observed in seedling heights in UM3 between the growing media types and agro-ecological zones (Appendix 1). Significant differences in seedling height in UM2 from the different growing media could be due to the low nutrient status of sand and farm soil as compared to compost. In overall, pair comparison showed that farm soil and sand produced seedlings with significantly lower heights (p = 0.05) than compost. This could be attributed to the better combination of chemical and physical properties of the compost than farm soil and sand.

Table 10. Effect of different growing media on seedling height (cm) in Mount Kenya region

Growing medium	Agro-ecological zone			Confidence limits
	UM2	UM3	Grand average	(p= 0.05)
Compost	17.4	12.9	13.9	12.4- 17.5
Farm soil	9.2	11.3	9.6	6.4- 12.8*
Sand	10.1	13.6	12.1	9.2- 15.0*
Grand average	11.2	12.5		
Medium s.e.d	2.82	2.48	2.20	

* Different from compost at p = 0.05

As shown in Figure 3, farm soil recorded the least height in agro-ecological zones; UM2 and UM3. Superior performance of compost growing media could be due to ameliorated physical properties and ease of nutrient uptake by seedlings. This is similar to the observation by Oluwole and Okusanya (1992) and Okusanya *et al.* (1991) who found humus to significantly enhance growth compared to other growing media in *Tetracarpidium conophorum* and *Treculia africana* seedlings respectively. Compost growing medium could perform better than sand and farm soil growing media due to its lower average wet bulk density and water holding capacity (Table 3) as well as higher concentration of nitrogen and organic carbon (Table 5). The leveling of the farm soil curves in the second half of the experiment period resulting in low seedling growth could be due to exhaustion of one or more of the plant nutrients (Table 5). Such seedlings would result in slow growth later in the life of the tree. This agrees with Bana *et al*'s. (1995) finding that tall seedlings survive better and continue with superior growth when established in the field compared to short seedlings.

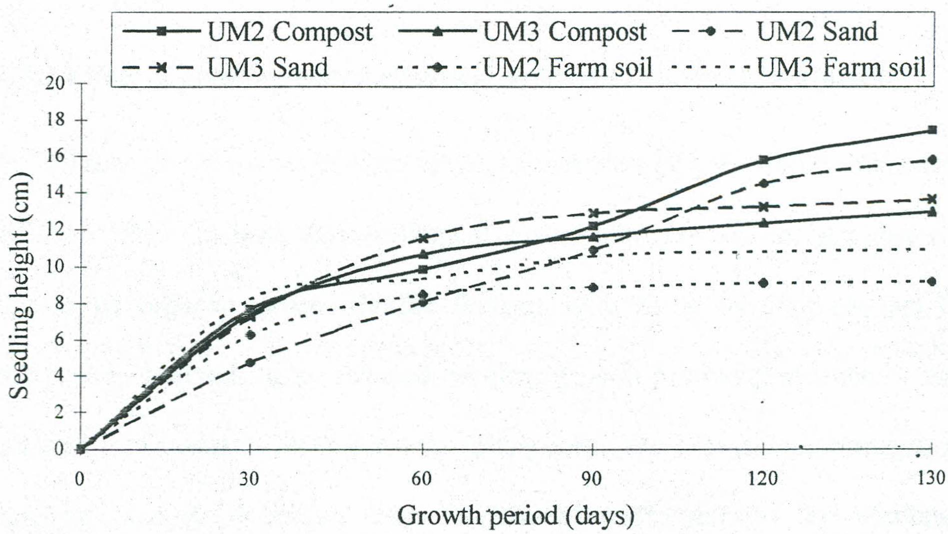

Figure 3. Seedling growth curves for farm soil, sand and compost in Mount Kenya region in UM2 and UM3 agro-ecological zones

4.2.4.1 Effect of growing media physical properties on seedling growth

The effects of growing media physical properties on seedling height were larger at initial period of growth and decreased with increasing nursery period (Table 11). Seedling height related inversely with wet bulk density and water holding capacity, and directly with aeration pore volume and total pore volume in most cases. These findings are in concordance with Bukhari's (1998) finding that high growing media bulk density and low moisture content reduced growth of *Acacia seyal* seedlings. Table 11 gives a summary of the effects of growing media physical properties on seedling height.

Table 11. Correlation (r2) value showing the effect of growing media physical properties on seedling height at different growth periods in on-farm tree nurseries

No of days of growth	Wet bulk density	Water holding capacity	Total pore volume	Aeration pore volume
30	-0.04	-0.23	0.01	0.17
60	-0.01	-0.14	0.01	0.06
90	-0.04	-0.13	0.01	0.06
130	-0.02	-0.01	0.07	0.02

4.2.4.2 Effect of growing media chemical properties on seedling growth

Table 12 shows correlation values for seedling heights with nutrient levels from UM2 and UM3. In both agro-ecological zones, nitrogen had the greatest correlation followed by organic carbon. Similar findings were made by Oluwole and Okusanya (1992) who observed higher reduced seedling growth following absence of nitrogen as compared to absence of other nutrients (phosphorus and potassium). Nitrogen is used in chlorophyll and its deficiency leads to reduced photosynthesis and seedling growth (Anoop *et al.* 1998).

Table 12. Seedling height correlation with nutrient levels in agro-ecological zone; UM2 and UM3

AEZ	pH	Ca	Mg	K	P	C	Cu	Fe	Mn	Zn	N
UM2	0.03	0	0.06	0.07	0.06	0.13	-0.01	0	-0.02	0.13	0.43
UM3	0.12	0.1	0.15	0.07	-0.00	0.18	-0.02	-0.04	-0.04	-0.08	0.35

4.2.5 Effect of farmer management techniques on seedling growth rate

The effect of tree seedling management techniques practiced by different farmers are shown in Table 13. Shading, which was practiced by 44% of the nursery operators had significant effect (P = 0.05) on seedling growth (Appendix 1). Seedlings without shade achieved significantly greater height than the shaded ones. The favourable effect without shading could be attributed to the fact that *Tamarindus indica* is a dryland species that is not tolerant to shade. This finding is in agreement with that of Gunasena and Hughes (2000) that *Tamarindus indica* is a light demanding species. Several other researchers such as Ashton and Zoysa (1989), Turner (1989), Liyanage and Jayasundera (1990), Okusanya *et al.* (1991), Liyanage and Ranasinghe (1993), Gopikumar and Bindu (1999) have found different species to respond differently to shade, concluding that response to shade is species-dependent.

Table 13. Effect of watering, shading and pricking out on Tamarindus indica seedlings' height growth (cm) in Mount Kenya region

Watering regime	Seedling height	Shading	Seedling height	Pricking (days)	Seedling height
Once	14.41	None	14.3	1- 10	15.5
Twice	15.49	Shaded	10.3	11-30	11.83
Irregular	10.44			>30	9.58
s.e.d	**3.0**		**1.86**		**2.15**

Other farmers' management techniques such as time of pricking-out and watering regime had only little effect on seedling growth rate (Table 13). 22% of the tree nursery operators planted directly into the pots while 78% sowed into nursery beds. Time of pricking-out for those who sowed in the nursery beds ranged from 3 to 64 days after germination. Seedlings pricked-out within the first ten days of germination achieved higher height than those pricked out after 30 days of germination indicating that, for

Tamarindus indica, early pricking-out could perform better than late pricking-out. Lower growth rate as a result of late pricking-out could be due to damaging or distortion of roots when pricking-out large seedlings whose root system is already well established (Quayle and Gunn 1998; ILO 1989).

Daily watering regimes (once or twice per day) resulted in greater seedling growth rate as compared to irregular regime. Daily watering could provide appropriate root environment for respiration and nutrient uptake that contributed to greater seedling growth. On the other hand, irregular watering reduced seedling height growth probably due to insufficient moisture in the growing media. Too little water resulting from irregular and longer watering intervals could reduce nutrient uptake by the seedlings. Similar observations were made by Okusanya *et al.* (1991) and Oluwole and Okusanya (1992) who found that seedlings of *Treculia africana* and *Tetracarpidium conophorum* respectively, under wet soil regime performed significantly better (<0.1%) than under either dry or waterlogged regimes. Similarly, Oleghe and Odo (1991) found seedling heights of *Faidherbia albida* and *Acacia auriculiformis* to be significantly reduced with increasing moisture stress.

The importance of nursery management on seedling growth is therefore very important. This has also been pointed out by Randall and Johnson (1998) who, while working on several tree nurseries, found nursery practice (management and growing media) to have significant impact on survival and height of douglas fir, noble fir and white pine.

4.2.6 Effect of substrate on sturdiness quotient

In the current study, the observed range of sturdiness quotients (seedling height (cm)/root collar diameter (mm)) in seedlings from on-farm tree nurseries was between 3.2 and 6.0. All tree nursery growing media used in this study produced seedling sturdiness quotient within the acceptable range. A sturdiness quotient greater than 6 has been reported as an indication of physiological imbalance resulting in tall spindly seedlings while an extremely small sturdiness quotient implies difficulty in seedling establishment (Jaenicke 1999).

As shown in Table 14, there were significant differences (p = 0.05) in seedling sturdiness quotients in UM2 but not in UM3. Also, there was a significant overall difference (p= 0.05) between the three growing media types (Appendix 1). Compost media produced seedlings with significantly higher sturdiness quotient as compared to both farm soil and sand. This could be due to the effect of organic carbon and nitrogen in the compost as discussed in section 4.1.2 and illustrated in Table 5. As with seedling heights, farm soil and sand produced seedlings with significantly lower (p= 0.05) sturdiness quotients in UM2. This could be due to the low nutrient status of sand and farm soil in UM2. Pricking-out time and watering regime did not affect sturdiness quotient significantly in both UM2 and UM3.

Table 14. Effect of growing media and agro-ecological zone on tree seedling sturdiness quotient in Mount Kenya region

Growing medium	UM2	UM3	Average
Compost	5.3	4.8	5.03
Farm soil	3.7*	3.7	3.70*
Sand	3.4*	4.4	3.92*
Average	4.16	4.28	
s.e.d	0.43	0.57	0.38

*Significantly different from compost medium (p = 0.05)

4.3 Growing media and seedling quality in a controlled experiment

Five of the on-farm tree nursery growing media mixtures from two agro-ecological zones (two from UM2 and three from UM3) and standard (ICRAF) growing media mixture were used in a controlled experiment at the ICRAF headquarters tree nursery. The physical and chemical properties are shown in Tables 3, 4 and 5.

4.3.1 Effect of growing media on germination

The observed germination percentage is within the range of 30% to 75% reported for tamarind by Gunasena and Hughes (2000). Growing media such as the standard (ICRAF), Njuri and Njaina, which had high organic matter and low bulk density, achieved higher germination percentage (Table 15). As explained earlier, such media provided good aeration and moisture that could enable high germination percentage. Use of organic incorporations in germination of tamarind is also supported by Gunasena and Hughes (2000) who suggested the use of cow dung in germination medium.

Table 15. The effect of growing media on seedling germination at the ICRAF headquarters tree nursery

Growing medium	Germination percentage
Icraf	76
Kinoti	35
Njaina	71
Njuri	72
Ntomba	37
Umoja	67

As Table 16 shows, germination percentage correlated positively with aeration porosity and total pore volume. It correlated negatively with growing media bulk density and water holding capacity. Increased bulk density reduces water-holding capacity of the growing media and its pore space (Swanson 1998; Argo 1998). The negative correlation with water holding capacity could be attributed to waterlogging which decreases oxygen necessary for germination. Similar findings were made by Zoysa and Ashton (1991) who found poor germination percentage of *Shorea trapezolia* seeds on compact mineral soil in comparison to forest topsoil. Substrate pH decreased germination slightly.

Table 16. The effect of growing media physical properties on *Tamarindus indica* seedling germination percentage

Substrate physical property	r^2 factor
Aeration pore volume	0.56
Total pore volume	0.4
Bulk density	-0.44
Water holding capacity	-0.02
Growing media pH	-0.3

4.3.2 Seedling growth performance from different growing media on-station

Growth of seedling was assessed through seedling height (SH), root collar diameter (RCD), shoot and root dry weights, Shoot/root ratio (S/R) and sturdiness quotient (SQ). The effect of the growing media physical and chemical properties on these seedling quality measures was determined and significant differences assessed.

4.3.2.1 Effect of on-station growing media on seedling heights, root collar diameter and sturdiness quotient

Seedling height growth curves from the different growing media used at the ICRAF headquarters nursery are shown in Figure 4. Generally, the seedlings from the different media had the same height growth curve pattern. However, seedlings from Njaina were taller and had greater sturdiness quotients consistently for the last half of the growth period while those from Kinoti had greatest diameter during the same period. Seedlings produced in Umoja and Ntomba had the least recorded height, root collar diameter and sturdiness quotient. This could be due to the fact that, of all growing media used on-station, Umoja had the least levels of all nutrients while Ntomba had excessive phosphorus (Table 5). Superior growth in Njaina, Njuri and kinoti over the standard ICRAF growing medium was observed at 57 days for Njaina and 99 days for both Njuri and Kinoti. This could be attributed to low phosphorus content of the ICRAF growing medium. Njaina which performed superiorly had the best range of all nutrients compared to the other growing media used at the ICRAF nursery (Table 5).

Analysis of variance showed that seedlings heights were significantly different (P = 0.05) for almost the entire experiment period, while root collar diameter and sturdiness quotient were significant at 29 days and 29 and 113 days respectively (Table 17, Appendix 2).

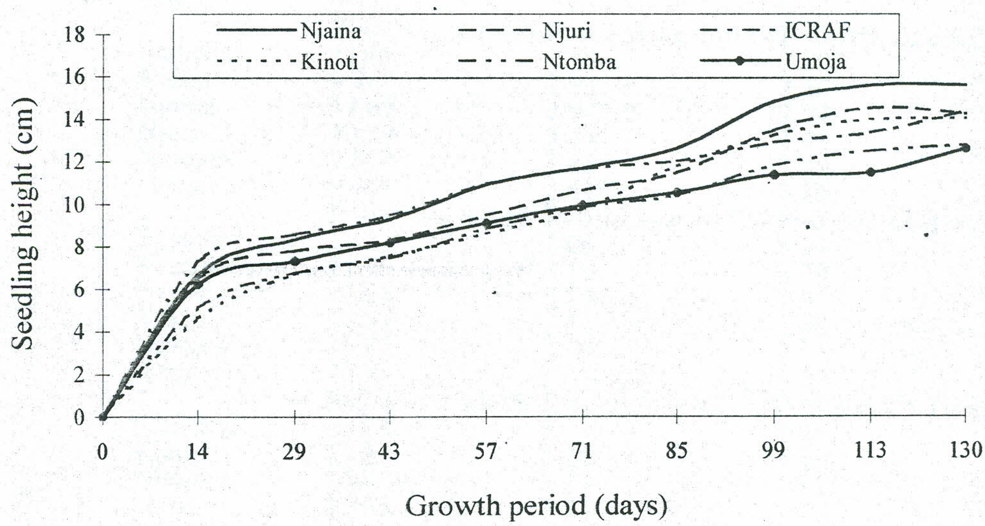

Figure 4. *Tamarindus indica* seedling height growth curves using six different growing media at ICRAF tree nursery

Table 17. Effect of growing media on seedling growth and ANOVA values at different growth periods

Growth period	Name of growing media	Seedling height (cm)	Root collar diameter	Sturdiness quotient
	Standard	8.59	1.94	4.463
	Kinoti	6.69**	2.12*	3.17
	Niaina	8.36	1.95	4.39
29	Niuri	7.80*	1.99	3.93
	Ntomba	6.77**	1.95	3.48
	Umoia	7.32**	1.83	4.04
		P=0.001.s.e.d.0.3	P=0.019.s.e.d0.061	P=0.001.s.e.d.0.16
	Standard	9.48	2.22	4.37
	Kinoti	7.55**	2.16	3.49
	Niaina	9.31	2.18	4.36
43	Niuri	8.32*	2.05	4.06
	Ntomba	7.47**	2.06	3.64
	Umoia	8.21*	2.08	3.97
		P=0.015.s.e.d.0.5	P=0.398.s.e.d0.096	P=0.086.s.e.d.0.27
	Standard	10.93	2.83	3.867
	Kinoti	8.62**	2.79	3.12
	Niaina	10.92	2.84	3.84
57	Niuri	9.47*	2.75	3.44
	Ntomba	8.83**	2.62	3.37
	Umoia	9.11*	2.63	3.47
		P=0.016.s.e.d.0.6	P=0.308.s.e.d0.114	P=0.109.s.e.d.0.25
	Standard	11.65	2.98	3.927
	Kinoti	9.76*	2.93	3.53
	Niaina	11.69	2.94	3.94
71	Niuri	10.67	2.74	3.91
	Ntomba	9.85*	2.85	3.49
	Umoia	9.96*	2.62*	3.80
		P=0.03.s.e.d.0.61	P=0.123.s.e.d0.127	P=0.202.s.e.d.0.21
	Standard	12.02	3.06	3.93
	Kinoti	11.79	3.16	3.79
	Niaina	12.61	3.14	4.01
85	Niuri	11.47	3.11	3.68
	Ntomba	10.42	2.98	3.51
	Umoia	10.55	2.95	3.57
		P=0.13.s.e.d.0.78	P=0.762.s.e.d0.162	P=0.306.s.e.d.0.23
	Standard	12.88	3.19	4.047
	Kinoti	13.23	3.26	4.13
	Niaina	14.8	3.13	4.71
99	Niuri	13.45	3.21	4.19
	Ntomba	11.8	3.15	3.75
	Umoia	11.35	3.01	3.77
		P=0.035.	P=0.893.s.e.d0.204	P=0.131.s.e.d.0.32
	Standard	13.33	3.65	3.65
	Kinoti	13.96	3.85	3.74
	Niaina	15.59*	3.60	4.32
113	Niuri	14.52	3.61	4.03
	Ntomba	12.46	3.64	3.42
	Umoia	11.47	3.22*	3.57
		P=0.024.s.e.d.0.9	P=0.201.s.e.d0.193	P=0.026.s.e.d.0.22
	Standard	14.33	3.71	3.857
	Kinoti	14.02	4.14*	3.46
	Niaina	15.57	3.80	4.09
130	Niuri	14.34	3.90	3.65
	Ntomba	12.77	3.83	3.32
	Umoia	12.59	3.57	3.52
		P=0.39.s.e.d.1.43	P=0.244.s.e.d0.189	P=0.337.s.e.d.0.34

** highly significant (p = 0.01)   *significant (p = 0.05)

Further analysis for comparison of means using Students Newman Keuls Test showed that the standard growing medium produced significantly taller seedlings than Kinoti, Umoja and Ntomba consistently up to 71 days of growth. Njuri was significantly lower than the standard from 29 days up to 57 days of growth. At the same time, Kinoti growing medium had bigger root collar diameter at 29 and 130 days of growth while Umoja produced significantly smaller diameters at 71 and 113 days (Table 17). Njaina was not different from the standard until day 113 when it produced taller seedling heights than the standard.

Sturdiness quotient, which relates seedling height to their root collar diameter, did not change widely with nursery period. Height increment was accompanied by a proportionate increase in root collar diameter. This shows that distribution of photosynthates in *Tamarindus indica* was proportionate throughout the nursery period.

4.3.2.2 Effect of growing media physical properties on seedling height, root collar diameter and sturdiness quotient

Growing media physical properties influenced seedling height, root collar diameter and sturdiness quotient as shown in Table 18. Initial growth of seedlings was influenced by aeration pore volume, total pore space and Wet bulk density. Water holding capacity of the growing media did not influence seedling growth throughout the experiment period due to adequate watering exercised daily.

Generally, the effect of physical properties on seedling growth was weakened at later stages due to the effect of nutrients that comes to play as discussed in the subsequent section. The growing media could supply enough nutrients to the seedlings at initial growth regardless of the physical properties. The effect of physical properties on seedling growth was more pronounced between the 29th –85th days. It was possible that at this growth period oxygen requirement by the roots was very high.

Table 18. Correlation values for some growing media physical properties with seedling height, root collar diameter and sturdiness quotient at different growth periods

Quality parameter	Growth (days)	Water holding capacity	Wet bulk density	Total pore volume	Aeration pore volume
SH	29	0	-0.7	0.67	0.66
	43	0	-0.76	0.76	0.77
	57	0	-0.64	0.7	0.65
	71	0	-0.62	0.66	0.61
	85	-0.01	-0.58	0.55	0.58
	99	-0.1	-0.24	0.2	0.3
	113	-0.08	-0.15	0.1	0.18
	130	-0.05	-0.4	0.38	0.46
RCD	29	0.03	0	0	0
	41	0.07	-0.65	0.78	0.54
	57	0.006	-0.64	0.64	0.53
	71	0.15	-0.16	0.31	0.09
	85	-0.03	-0.16	0.1	0.14
	99	0.18	-0.01	0.03	-0.03
	113	0.18	0	0.02	-0.02
	130	0	0.04	0	-0.09
SQ	29	0	-0.53	0.5	0.57
	43	0	-0.54	0.5	0.6
	57	0	-0.47	0.5	0.52
	71	-0.1	-0.59	0.4	0.65
	85	0	-0.7	0.7	0.69
	99	-0.2	-0.27	0.2	0.41
	113	-0.4	-0.2	0.1	0.36
	130	-0.1	-0.65	0.6	0.79

Better correlation of seedling growth with physical properties at initial growth period could be attributed to good root environment in the growing media with higher pore volume that enabled good nutrient uptake by the seedlings leading to greater growth of the shoots. On the other hand, increasing growing media wet bulk density reduces its pore volume and this could affect the ability of the roots to take up nutrients. Such stress on the seedling could lead to more allocation of photosynthetic assimilate to roots relative to shoot. Significant correlation of sturdiness quotient with aeration pore volume, total pore volume and wet bulk density observed at 130 days of growth could be due to the small sample size.

Root growth is important for nutrient uptake after cotyledon reserves are exhausted. Growing media compaction due to root growth could reduce the effect of physical properties on seedling RCD during subsequent growth periods.

Heavy growing media such as those of Kinoti, Njuri, Umoja and Ntomba produced seedlings that were significantly lower in height compared to the standard at some point during initial period of growth (Table 3). Compared to other substrates, Standard (ICRAF) and Njaina substrates had lower wet and dry bulk density and higher aeration and total pore volume. This resulted in better seedling growth. Tamarind is sensitive to low levels of oxygen. Borelli and Shirone (1988) had a similar observation using allepo pine. Similarly, Bukhari (1998) found high soil bulk density to reduce growth of *Acacia seyal* seedlings.

4.3.2.3 Effect of growing media chemical properties on seedling growth

The effect of the chemical properties on seedling growth is shown in Table 19. A positive effect on seedling growth which was found to affect seedlings up to the end of the experiment was observed with potassium, calcium, nitrogen, carbon and magnesium. Phosphorus had a negative effect on seedling growth. This effect was more significant at the initial period of growth and decreased with time, possibly because both Kinoti and Ntomba, which had the highest P levels, maintained the lowest height from germination to 71 days of growth. The P concentration of Kinoti might have reduced to favourable levels for plant growth due to uptake thus leading to accelerated growth towards the end of the study. Other researchers have observed decreased seedling biomass due to higher levels of phosphorus (Prasad and Rawat 1991; Chauhan and Sharma 1995) and attributed this to decreased use efficiency of P in the absence of N. Newton *et al* (1992a and 1992b) and Arahou *et al.*(1996) attributed lower seedling growth at higher P application to reduced colonization by mycorrhizae. On the other hand, Siqueria *et al.*(1984) as quoted by Singh *et al.*(1997), proposed that P controls root colonization through its effect on host carbon metabolism. On his part, Singh *et al* (1997) found seedling height to increase with increasing levels of phosphorus though his experimental phosphorus (P_2O_5) levels did not exceed 50 ppm. Using P levels above this rate may have resulted to declined seedling growth.

Most of the chemical properties showed significant correlation with root collar diameter between 57 and 99 days of growth. The significant effect of P on sturdiness quotient at 29, 43 and 71 days of growth was due to its effects on seedling height. The insignificant effect of phosphorus on root collar diameter agrees with the findings of Kadir *et al.*(1988) in growth of *Eucalyptus camaldulensis* and *Paraserianthes facaltaria.* Favourable response of root collar diameter to nitrogen agrees with the findings of Kannan and Paliwal (1995) who worked with *Cassia siamea* and attributed the response to better utilization of P and K in presence of adequate N levels.

Available nitrogen did not influence seedling growth in this study. However, total nitrogen had a positive direct effect on seedling height. This effect did not seem to vary with the period of growth. Similar findings of increase in seedling growth due to higher levels of nitrogen up to some point were made by Kadir *et al.* (1988), Oluwole and Okusanya (1992), Chauhan and Sharma (1995) and Singh *et al.* (1997). Nitrogen is used in chlorophyll synthesis and its deficiency leads to reduced photosynthesis and carbohydrate assimilation and thus to reduced seedling growth (Anoop *et al.* 1998).

Table 19. R2 of some chemical properties with seedling height for six different types of growing media at different growth periods

	Growth period (days)	P	Organic C	K	Total N	Ca	Mg
SH	29	-0.45	0.35	0	0.35	0.13	0.1
	43	-0.48	0.33	0	0.3	0.065	0.06
	57	-0.29	0.32	0.04	0.3	0.08	0.06
	71	-0.46	0.38	0.04	0.36	0.16	0.11
	85	-0.23	0.35	0.23	0.4	0.22	0.34
	99	-0.1	0.15	0.17	0.2	0.2	0.2
	113	0.005	0.14	0.16	0.19	0.28	0.23
	130	-0.14	0.27	0.18	0.3	0.24	0.25
RCD	29	0.08	0.10	0.39	0.14	0.30	0.43
	43	-0.12	0.36	0.39	0.35	0.06	0.23
	57	-0.23	0.55	0.24	0.59	0.38	0.53
	71	0.02	0.28	0.87	0.33	0.20	0.27
	85	-0.05	0.20	0.27	0.27	0.33	0.47
	99	0.03	0.39	0.34	0.46	0.70	0.74
	113	0.15	0.23	0.66	0.28	0.45	0.5
	130	0.14	0.02	0.30	0.05	0.21	0.3
SQ	29	-0.48	0.2	-0.06	0.13	0	0
	43	-0.52	0.2	-0.06	0.17	0.04	0
	57	-0.24	0.2	0	0.14	0.01	0
	71	-0.74	0.2	-0.14	0.2	0.06	0.04
	85	-0.25	0.4	0.24	0.38	0.15	0.26
	99	-0.16	0.1	0.1	0.09	0.07	0.08
	113	-0.25	0	0	0.05	0.06	0.04
	130	-0.42	0.2	0.02	0.2	0.05	0.05

The effects of K, Ca and Mg on seedling height increased with nursery period. Since K and Mg are used in protein synthesis, and Ca is used for cell division and growth of growing tips (Dell *et al.* 1995), their deficiency or depletion as nursery period extends could affect seedling height. Potassium is used in plants as an activator of metabolically important enzymes and catalyses reactions in carbohydrate and protein metabolism (Ogbonnaya 1994). Therefore, as observed in Umoja medium, its deficiency could reduce seedling growth.

Of all the micronutrients (zinc, copper, manganese and iron), only copper, which is used in photosynthesis (Dell *et al.* 1995), had positive correlation with seedling height that increased with nursery period. This could be because Njaina, which had superior seedling growth, had very high levels of copper compared to other substrates, but does not indicate copper deficiency in the other substrates. Fe, Mn and Zn had little effect on seedling height. Their availability from the growing media and from the large seeds of *Tamarindus indica* may have been adequate to meet the requirements of the seedlings.

4.3.3 Seedling dry weight

Dry weight measurements were taken for oven dried shoots (SDW) and roots (RDW) and were used for the determination of Shoot/root ratio (S/R).

4.3.3.1 Effect of growing media on shoot and root dry weights

Shoot and root dry mass from different growing media at the ICRAF headquarters nursery are given in Figures 5 and 6 respectively. Njuri and Njaina, which were compost media, recorded the largest shoot and root dry weight by the end of the experiment. At the same time, Umoja (100% farm soil) growing medium recorded the lowest shoot and root dry weights.

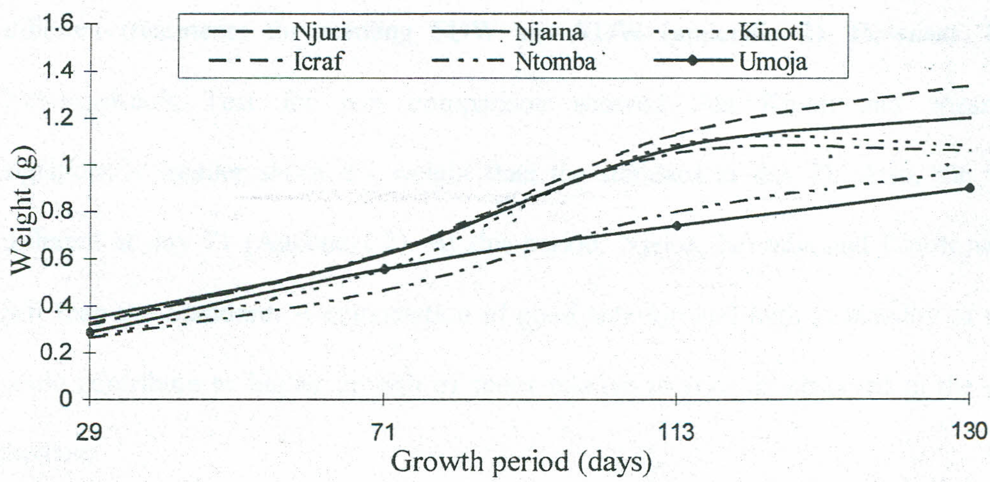

Figure 5. Shoot dry weight growth curves for different growing media at different growth period

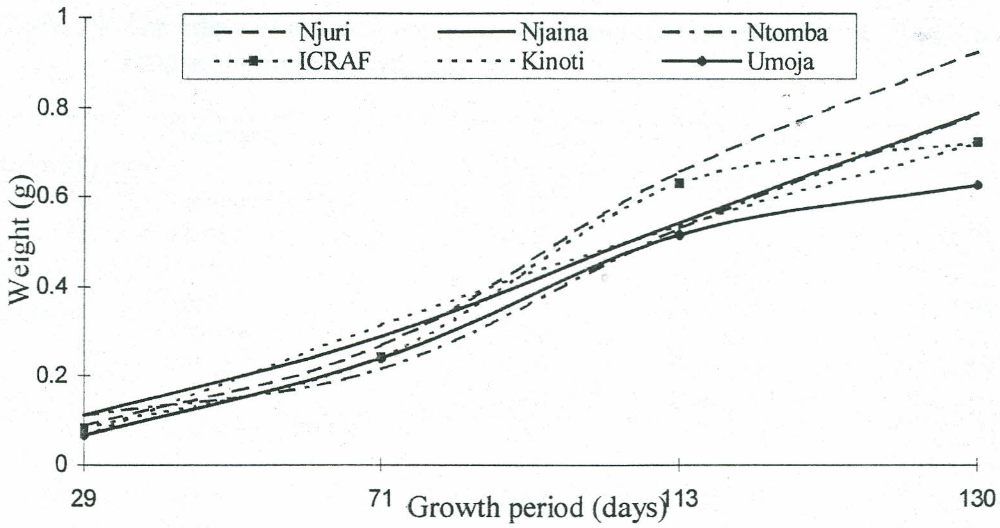

Figure 6: Root dry weight from different growing media at different growth periods

Oven dry weights for the shoots and roots and the corresponding S/R are shown in Table 20. There were no statistical differences (95% confidence level) from the different treatments for seedling SDW and RDW (appendix 2). However, Students NewmanKeuls Test for pair comparison showed that Kinoti and Ntomba had significantly smaller shoot dry weight than the standard at day 71. Also, the S/R was different at day 71 (Appendix 2). At this period, Njaina, Ntomba and Kinoti had lower S/R than the Standard. A combination of good aeration and high availability of nutrients could contribute to higher growth of shoot relative to root as observed in the standard medium.

Shoot/root ratio decreased with increasing nursery period to settle between 1: 1.28 and 1: 1.55, similar to values found by Akinnifesi *et al.* (1999) in an earlier study with *Enterolobium cyclocapum* and *Leucaena leucocephala*. Such values are generally believed to indicate healthy seedlings (Wightman 1999; Hamzah and Afendi n.d).

Table 20. The effect of growing media on shoot and root dry weights and Shoot/root ratio at different growth periods

Growth period	Treatment	Shoot dry Weight (gms)	Root dry Weight (gms)	Shoot: root ratio
29 days	Standard (ICRAF)	0.32	0.08	4
	Kinoti	0.26	0.06	4.73
	Njaina	0.35	0.11	3.17
	Njuri	0.33	0.09	3.91
	Ntomba	0.26	0.11	3.3
	Umoja	0.29	0.06	4.79
		s.e.d.0.0295	s.e.d. 0.0289	s.e.d.1.006
71 days	Standard (ICRAF)	0.62	0.24	2.591
	Kinoti	0.43*	0.27	1.687**
	Njaina	0.62	0.29	2.145*
	Njuri	0.62	0.27	2.278
	Ntomba	0.44*	0.21	2.135*
	Umoja	0.55	0.23	2.31
		s.e.d.0.0673	s.e.d. 0.026	s.e.d.0.1933
113 days	Standard (ICRAF)	1.05	0.63	1.674
	Kinoti	1.08	0.54	1.913
	Njaina	1.07	0.54	1.975
	Njuri	1.13	0.66	1.737
	Ntomba	0.72	0.51	1.423
	Umoja	0.74	0.52	1.478
		s.e.d. 0.2042	s.e.d. 0.1165	s.e.d. 0.1989
130 days	Standard (ICRAF)	1.06	0.72	1.516
	Kinoti	1.06	0.68	1.54
	Njaina	1.20	0.79	1.549
	Njuri	1.34	0.93	1.486
	Ntomba	0.97	0.79	1.286
	Umoja	0.90	0.63	1.471
		s.e.d. 0.2063	s.e.d. 0.0944	s.e.d. 0.2100

* significantly different at 95% confidence level ** highly significant

4.3.3.1.1 Effect of growing media physical properties on shoot and root dry weight

As shown in Table 21 aeration pore volume and total pore space had a positive linear relationship with seedling dry weight parameters. As discussed above, these physical properties could provide a favourable environment for nutrient uptake. Wet bulk density related inversely with SDW, RDW and S/R possibly due to higher root penetration resistance at higher bulk density as also observed by Borelli and Schirone (1988) for allepo pine (*Pinus halepensis*) and Bhukari (1998) for *Acacia seyal* seedlings. This is also in conformity with Akinnifesi *et al*'s. (1999) report that growing media bulk density of 1.4-1.8g/cm^3 decreased seedling Shoot/root ratio for *Enterolobium cyclocapum* and *Leucaena leucocephala*.

Table 21. The effect of substrate physical properties on shoot and root dry weight and Shoot/root ratio at different growth period

	Days of growth	Aeration pore volume	Total pore space	Wet bulk density	Water holding capacity
Shoot dry weight	29	0.56	0.34	-0.15	-0.1
	71	0.73	0.59	-0.50	-0.02
	113	0.18	0.25	-0.48	0.00
	130	0.06	0.03	-0.47	-0.05
Root dry weight	29	-0.02	-0.02	0.06	0.00
	71	0.15	0.05	-0.11	-0.15
	113	0.05	0.20	-0.20	0.14
	130	-0.04	-0.03	0.02	0.00
Shoot/root ratio	29	0.00	0.00	0.02	0.00
	71	0.13	0.20	-0.20	0.09
	113	0.30	0.20	-0.30	-0.10
	130	0.70	0.50	-0.70	-0.07

Water holding capacity did not influence seedling dry weight significantly. This could be due to adequate watering that was done during the nursery period. This contrasts with effect of water holding capacity observed on-farm where watering regimes varied (see Table 11).

Growing media compaction with time due to root extension and expansion may have affected the physical properties of the media thus reducing their further effect on SDW beyond day 71. The correlation may also have been weakened by the influence of growing media nutrient concentrations as discussed below.

4.3.3.1.2 The effect of growing media chemical properties on shoot and root dry weight

Table 22 shows the effect of chemical properties on shoot and root dry weights and Shoot/root ratio. The effects of organic carbon, N, Ca and Mg on SDW and RDW increased up to day 113. However, no significant differences were observed at this period of growth between the different growing media. Improved growth with nitrogen is not unusual because of its role in protein and nucleic acid synthesis, which is the core of life processes (Ogbonnaya 1994). The positive influence on SDW and RDW observed with magnesium could be attributed to the role of magnesium in production of photosynthates since it is a constituent of chlorophyll. Agboola and Kadiri (1999) found magnesium to increase dry weight of seedlings of six tropical tree species.

Table 22. Correlation values of some growing media chemical properties on shoot and root dry weight and Shoot/root ratio

	Growth period (days)	P	OC	K	N	Ca	Ma	Cu	Fe	Mn	Zn
SDW	29	-0.1	0.17	0.02	0.12	0.1	0.04	0.40	-0.09	0.10	0
	71	0.24	0.44	-0.02	0.45	0.24	0.30	0.09	0	0	-0.30
	113	0.06	0.51	0.13	0.58	0.66	0.71	0.06	-0.35	-0.36	-0.10
	130	0.02	0.2	0	0.25	0.55	0.32	0.10	-0.35	-0.19	0
RDW	29	0.02	-0.02	0.10	-0.02	0.004	-0.07	0.37	0.27	0.06	0.74
	71	0	0.03	0.10	0.05	0.05	0.22	0.11	0	-0.27	-0.16
	113	-0.08	0.67	-0.02	0.68	0.77	0.54	-0.05	-.028	-0.11	-0.17
	130	0.14	0.08	0	0.10	0.44	0.14	0.01	-0.60	-0.19	0
S/R	29	-0.10	0	-0.13	0	-0.03	0.02	0.38	-0.33	0.05	0.65
	71	-0.20	0.16	-0.16	0.10	0.02	0	0	-0.22	0.21	0
	113	-0.13	0.13	0.20	0.17	0.14	0.28	0.32	-0.06	0.15	0
	130	0.64	0.20	0	0.23	0.06	0.26	0.10	-0.04	0.01	0.40

As with SDW, potassium and phosphorus did not show significant correlation with seedling RDW. This may be attributed to higher requirement for nutrients by the seedlings at a time when nutrient deficiency was being experienced in some substrates. The effect could not be observed earlier due to adequate nutrient supply by all the growing media and low nutrient requirement by the young seedlings. More nitrogen concentration in the growing media was also observed to produce more fibrous root growth and increase RDW (Singh *et al.* 1997).

There was no significant correlation of any micronutrient and seedling dry weight. This was also not expected since micronutrients are needed in small quantities, which are usually adequately supplied by both the growing media and the big seed. Similarly, while working with different tree species, Manonmani *et al.*(1996) and Agboola (1995) found large seeds to have seedlings with better performance and attributed this to availability of greater food reserves and the presence of a large embryo.

Zinc had a significant contribution to root dry weight at day 29. On the other hand, Iron exhibited a negative correlation with root dry weight at the 130th day of growth. This could be due to the high level of iron in the Umoja growing medium, which had low seedling root dry weight due to gross deficiency in most of the important nutrients (Table 5).

From these findings, shoot dry weight and Shoot/root ratio were influenced by aeration pore volume, total pore volume and bulk density at 71 days of growth (Table 21). Growing media chemical properties such as organic carbon, magnesium, calcium and nitrogen influenced shoot dry weight significantly at 113 days of growth (Table 22). Superior shoot dry matter accumulation observed in Njuri and Njaina growing media are probably due to their particular combination of physical and chemical properties. Both media had relatively low wet bulk density and higher aeration and total pore volume as well as better nutrient concentrations. On the other hand, Ntomba and Umoja, which achieved low shoot dry weights, had particularly high wet bulk density and low aeration and total pore volume. In addition, they were found to be limited in nutrients such as magnesium, organic carbon and nitrogen (Table 5), which affected shoot dry weight (Table 22).

Chemical properties of the growing media had a greater effect on seedling root biomass than the physical properties. Njuri and Njaina, which had better nutrient levels than the other media also recorded greater root dry weights. Heavier RDW in Njuri relative to Njaina could be due to relatively higher concentrations of organic carbon, nitrogen, magnesium and calcium (Table 5) in the growing media which had significant correlations to root dry weight (Table 22).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study aimed at determining the effect of growing medium physical and chemical properties as well as farmers' management techniques on seedling growth and recommend appropriate levels for optimization of seedling quality.

The physical properties of the different growing media were found to affect seedling growth rate mostly during the initial growth period. The most important growing media physical properties that were found to have effect on growth rate were total pore volume, aeration pore volume and wet bulk density. All these properties affected seedling height up to 85 days of growth and diameter up to 71 days. On the other hand, the effect of these properties on Shoot/root ratio increased up to the end of the experiment. Water holding capacity did not influence any of the seedling quality parameters that were tested.

Substrate chemical properties influenced seedling growth during the mid and late growth phases of the seedlings in different media. Organic carbon, nitrogen and magnesium had greater effect on seedling quality parameters. Potassium effect was significant on the root collar diameter while phosphorus had effect on seedling height and hence sturdiness quotient.

The results of these experiments show that growing media chemical and physical properties affect seedling growth in various ways. Compost-based growing media produced higher germination percentage as compared to sand and farm soil-based growing media. Higher percentage of organic matter in germination media could have provided better germination environment such as moisture and aeration.

Incorporation of organic matter in the growing media improved the nutrient content of the media and resulted in higher germination percentage, better seedling survival rates, higher height and higher sturdiness quotient as compared to farm soil and sand-based growing media. Farm soil, which has little organic matter content is therefore inappropriate for good seedling production and survival. These results suggest that the use of organic matter in substrates can produce seedlings that grow significantly faster than seedlings raised from either sand or farm soil medium.

Growing media chemical properties had more effect on shoot dry weight than on root dry weight during the 29 and 71 days growth periods. At 113 days growth period, chemical properties had greater influence on root growth as compared to shoot growth.

The on-farm studies showed that daily watering improved seedling survival and height growth. Shading *Tamarindus indica* seedlings at nursery stage improved survival rate although it did not increase height. Seedlings of *Tamarindus indica* achieved better height when sowed directly in polythene bags or when pricked out within the first ten days of germination than when pricked later.

Growing media total pore volume, aeration pore volume and bulk density affected germination of *Tamarindus indica* seedlings. High aeration pore volume, high total pore volume and low density achieved higher germination than low pore volume and greater density. These physical properties also positively influenced seedling height, root collar diameter, sturdiness quotient and shoot dry matter of *Tamarindus indica* during initial growth period (0 - 85 days). After this period, the effect was not significant.

The effect of the chemical properties of the substrates on growth of *Tamarindus indica* seedlings became important from 57 days of growth period and onwards.

Chemical properties of particular significance to seedling growth included N, organic carbon, Ca, Mg and K. Significant effect of these nutrients on seedling height was observed from the 57^{th} day. However, their contribution to shoot and root dry weight became noticeable at 113 days. P concentration inhibited seedling development at high and low concentrations. Chemical properties of the growing media did not affect seedling sturdiness quotient and Shoot/root ratio significantly at any period of growth.

From the foregoing, this study concludes that physical and chemical properties of the growing media influence seedling growth and play an important role in reducing nursery period. Further, farmers' tree nursery management techniques such as watering, shading and pricking-out time influence seedling growth.

The nursery period of *Tamarindus indica* seedlings can be curtailed for more economic benefits. By using good growing media, nursery period can be reduced by up to 55 days. For example, Umoja and Ntomba growing media achieved the height achieved by Njaina at 85 days of growth 45 days later.

5.2 Recommendations

This study recommends physical properties of growing medium for *Tamarindus indica* seedlings as shown in Table 23. Since physical properties are most important at initial growth stages, the suggested levels apply for a reduced growth period of 75 days as well as for an extended period of 130 days.

As shown in Table 24, levels of nitrogen, calcium, magnesium and organic carbon for seedling growth periods of 75 and 130 days are similar. However, higher minimum level of phosphorus is recommended for growth periods beyond 75 days.

Table 23. Recommendations for physical properties of growing medium for *Tamarindus indica* seedlings

Growing media physical properties	Recommended level
Wet bulk density	1.0 – 1.2g/cm^3
Dry bulk density	0.6 – 0.8g/cm^3
Total pore space	67 – 71%
Aeration pore space	24 – 30%
Water holding capacity	41 – 43%

Table 24. Recommendations from the study for some chemical properties of growing medium for *Tamarindus indica* seedlings

Growing media chemical parameter	Recommended levels	
	75 days growing period	130 days growing period
Phosphorus (mg/kg)	18.6 – 39.5	26.4 – 127.0
Nitrogen (mg/kg)	67.4 – 186.2	67.4 – 186.2
Calcium (mg/100g)	21.2 – 37.0	21.2 – 37.0
Potassium (mg/kg)	1.26 –4.4	1.26 – 5.25
Magnesium (mg/100g)	7.0 –13.0	7.0 –13.0
Organic Carbon (g/kg)	26.4 – 54.9	26.4 – 54.9

This study recommends one watering regime daily for *Tamarindus indica* in order to achieve better seedling growth. It also recommends directly sowing seeds into the planting pots or pricking within the first ten days after germination rather than pricking-out later on. Further, shading should be avoided for Tamarind seedlings. These farmer management techniques will optimize seedling production for *Tamarindus indica* species.

There is need for further research to determine the cause of too much phosphorus concentration in a growing medium and understand ways of ameliorating its negative effect on seedling development.

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APPENDIX 1

Analyses of variance for on-farm data

Germination percentage in UM2 and UM3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Substrate	2	734.1	367.1	0.65	0.535

e.s.e 9.69 , s.e.d. 13.70, l.s.d. 29.21

Source of variation	d.f	s.s	m.s	v.r	F pr.
AEZ	1	83.1	83.1	0.15	0.707

e.s.e (UM2-8.43, UM3-7.54) , s.e.d 11.31 l.s.d 23.98

Source of variation	d.f	s.s	m.s	v.r	F pr.
Watering	2	1659.2	829.6	1.65	0.224

e.s.e (Min-15.84, Max-7.92) , s.e.d 17.71 l.s.d 37.74

Source of variation	d.f	s.s	m.s	v.r	F pr.
Pricking out time	2	601.4	300.7	0.53	0.602

e.s.e (Max-9.04, min-10.7), s.e.d 14.01 l.s.d 29.85

Survival rates in UM2 and UM3

Source of variation	d.f	s.s	m.s	v.r	F pr.
Substrate	2	5243.5	2621.8	3.76	0.049

e.s.e 10.78 , s.e.d 15.25 l.s.d 32.71

Source of variation	d.f	s.s	m.s	v.r	F pr.
AEZ	1	806.7	806.7	0.89	0.361

e.s.e (UM2-10.66, UM3-9.53) , s.e.d 14.3 l.s.d 30.47

Source of variation	d.f	s.s	m.s	v.r	F pr.
Watering	2	7612.5	3806.3	7.55	0.006

e.s.e (Min-15.84, Max-7.92) , s.e.d 17.71 l.s.d 37.74

Source of variation	d.f	s.s	m.s	v.r	F pr.
Shading	1	92.3	92.3	0.1	0.760

e.s.e (Min-15.88, Max-7.94) , s.e.d 17.75 l.s.d 38.07

Source of variation	d.f	s.s	m.s	v.r	F pr.
Pricking out time	2	377.0	189.5	0.19	0.831

e.s.e (Max-11.97, min-14.16) , s.e.d 18.54 l.s.d 39.77

Seedling height in UM2 and UM3

Source of variation	d.f	s.s	m.s	v.r	F pr.
AEZ	1	1.43	1.43	0.07	0.790

e.s.e (UM2-1.56, UM3-1.39) , s.e.d 2.09 l.s.d 4.51

Source of variation	d.f	s.s	m.s	v.r	F pr.
Substrate	2	95.39	47.7	3.28	0.073

e.s.e 1.556 , s.e.d 2.2 l.s.d 4.79

Source of variation	d.f	s.s	m.s	v.r	F pr.
Watering	2	79.8	39.9	2.60	0.115
e.s.e (Min-2.77, Max-1.384)		, s.e.d	3.09	l.s.d	6.74

Source of variation	d.f	s.s	m.s	v.r	F pr.
Shading	1	71.37	71.37	4.81	0.047
e.s.e (Min-1.455, Max-1.161)		, s.e.d	1.86	l.s.d	4.02

Source of variation	d.f	s.s	m.s	v.r	F pr.
Pricking out time	2	100.15	50.07	3.69	0.056
e.s.e (Max-1.39, min-1.646)		, s.e.d	2.16	l.s.d	4.69

Sturdiness quotient

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Growing media	2	4.6658	2.3329	3.89	0.036

e.s.e. 0.387 min.rep 0.193 max.rep, s.e.d 0.433 max-min
l.s.d 0.897 max-min

APPENDIX 2

Analyses of variance for on-station experiment

Sturdiness quotient

29 days Source of variation d.f. s.s. m.s. v.r. F pr.
farm 5 3.60805 0.72161 16.67 <.001
e.s.e. 0.1201, s.e.d. 0.1699,l.s.d 0.3785

43 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 1.5634 0.3127 2.79 0.086
e.s.e. 0.1934 s.e.d. 0.2735, l.s.d. 0.6186

57 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 1.2587 0.2517 2.51 0.109
e.s.e. 0.1827 s.e.d. 0.2584, l.s.d. 0.5845

71 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 0.64302 0.12860 1.84 0.202
e.s.e. 0.1528 s.e.d. 0.2160, l.s.d. 0.4887

85 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 0.58433 0.11687 1.41 0.306
e.s.e. 0.1660, s.e.d. 0.2347l.s.d. 0.5310

99 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 1.8181 0.3636 2.30 0.131
e.s.e. 0.2294, s.e.d. 0.3245, l.s.d. 0.7340

113 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 1.62581 0.32516 4.41 0.026
e.s.e. 0.1568s.e.d. 0.2218 l.s.d. 0.5017

130 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 1.1786 0.2357 1.32 0.337
e.s.e 0.2439 s.e.d. 0.3450, l.s.d. 0.7804

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Diameter

29 days Source of variation d.f. s.s. m.s. v.r. F pr.
farm 5 0.131778 0.026356 4.66 0.019
e.s.e. 0.0434 s.e.d. 0.0614, l.s.d. 0.1369

43 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 0.08065 0.01613 1.16 0.398
e.s.e. 0.0681 s.e.d. 0.0963, l.s.d. 0.2178

57 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 0.13781 0.02756 1.41 0.308
e.s.e. 0.0808 s.e.d. 0.1142, l.s.d. 0.2584

71 days Source of variation d.f.(m.v.) s.s. m.s. v.r. F pr.
farm 5 0.28776 0.05755 2.37 0.123

e.s.e. 0.0899, s.e.d. 0.1272, l.s.d. 0.2877

85 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	0.10132	0.02026	0.51	0.762

e.s.e. 0.1150, s.e.d. 0.1626, l.s.d. 0.3678

99 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	0.09756	0.01951	0.31	0.893

e.s.e. 0.1443,s.e.d. 0.2040, l.s.d. 0.4615

113 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	0.51627	0.10325	1.84	0.201

e.s.e. 0.1367 s.e.d. 0.1934, l.s.d. 0.4374

130 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	0.44040	0.08808	1.64	0.244

e.s.e. 0.1338, s.e.d. 0.1892, l.s.d. 0.4280

Seedling height

14 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	21.0856	4.2171	7.61	0.007

e.s.e. 0.430, s.e.d. 0.608, l.s.d. 1.402

29 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
farm	5	9.5836	1.9167	11.09	<.001

e.s.e. 0.2400, s.e.d. 0.3394, l.s.d. 0.7562

43 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	10.8742	2.1748	5.31	0.015

e.s.e. 0.369, s.e.d. 0.522, l.s.d. 1.182

57 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	15.9184	3.1837	5.16	0.016

e.s.e. 0.453, s.e.d. 0.641, l.s.d. 1.450

71 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	11.9711	2.3942	4.21	0.030

e.s.e. 0.436, s.e.d. 0.616, l.s.d. 1.394

85 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	10.9707	2.1941	2.35	0.125

e.s.e. 0.557, s.e.d. 0.788, l.s.d 1.783

99 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	22.867	4.573	3.99	0.035

e.s.e 0.618, s.e.d. 0.874, l.s.d. 1.977

113 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	32.540	6.508	4.53	0.024

e.s.e. 0.692, s.e.d. 0.978, l.s.d. 2.213

130 days

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
farm	5	18.314	3.663	1.19	0.386

e.s.e. 1.014, s.e.d. 1.434, l.s.d. 3.243

Root dry weight

	Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
27 days	root	5	0.006362	0.001272	1.01	0.459
71 days	root	5	0.012495	0.002499	2.42	0.140
113 days	root	5	0.05542	0.01108	0.54	0.739
130 days	root	5	0.16356	0.03273	2.45	0.115

Shoot dry weight

	Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
27 days	shoot	5	0.01851	0.003702	2.82	0.076
71 days	shoot	5	0.11852	0.023704	3.49	0.067
113 days	shoot	5	0.52113	0.10423	1.67	0.248
130 days	shoot	5	0.38147	0.07629	1.19	0.384

Shoot/root ratio

	Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
27 days	Shoot/root	5	6.965	1.393	0.92	0.507
71 days	Shoot/root	5	1.32121	0.26424	4.71	0.033
113 days	Shoot/root	5	0.74781	0.14956	2.52	0.118
130 days	Shoot/root	5	0.14214	0.02843	0.43	0.817