HOGESCHOOL GENT
LID VAN DE ASSOCIATIE UNIVERSITEIT GENT

Geassocieerde Faculteit Toegepaste Bio-ingenieurswetenschappen

Academiejaar 2011 - 2012

Nursery evaluation, fertilization and breeding of *Melia volkensii* in Kiambere, Kenya

Kwekerij evaluatie, bemesting en kweekprogramma van *Melia volkensii* in Kiambere, Kenya

Masterproef voorgedragen door

Pieter De Catelle

tot het bekomen van de titel en de graad van

Master in de biowetenschappen: land- en tuinbouwkunde
Afstudeerrichting tropische plantaardige productie

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Gent, mei 2012

Promotor	Copromotor	Author (Auteur)
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Woord vooraf – Foreword

Bij het begin van deze masterproef wil ik enkele mensen bedanken die er mede voor gezorgd hebben dat ik dit werk heb kunnen voltooien.

In de eerste plaats zou ik graag Better Globe Forestry (BGF) willen bedanken om mij de kans te geven om wetenschappelijk onderzoeken in het buitenland te verrichten. Dit was onmogelijk geweest zonder hun logistieke en financiële steun. Op de plantage kon ik steevast rekenen om de hulp van plantagemanager Mr. John Njeru en Mr. James Mwanzia, Musya en alle andere medewerkers.

Een speciaal woord van dank gaat ook uit naar ir. Jan Vandenabeele, Exective Director bij BGF. Zijn kennis en ervaring hebben mij veel bijgeleerd tijdens mijn verblijf in Kenia. Ook nadien, bij het schrijven van mijn masterproef, heeft zijn feedback mij goed geholpen. Mr. Jean-Mr. Paul Deprins (Managing Director) verdient ook een speciaal woord van dank: dankzij zijn hulp kon ik me voor en tijdens mijn verblijf in Kenia optimaal concentreren op mijn werk. Andere werknemers van BGF die mij rechtstreeks of onrechtstreeks geholpen hebben wil ik ook van harte bedanken.

Verder wil ik ook nog Mr. Jonathan Kituku en zijn medewerkers bedanken voor hun gastvrijheid. Dankzij hen mocht ik twee weken meewerken in hun kwekerij wat zeer belangrijk is geweest voor mijn masterproef.

Mr. Ben Chikamai, Director van het Kenya Forestry Research Institute (KEFRI) verdient ook een woord van dank. Dankzij het openstellen van de bibliotheek van KEFRI heb ik veel literatuur gevonden die van pas gekomen is bij het schrijven van mijn masterproef.

Kenya Electricity Generating Company Limited (KENGEN) wil ik ook graag bedanken voor het ter beschikking stellen van hun bungalow tijdens mijn verblijf in Kiambere.

De mensen van de VLIR-UOS (Vlaamse Interuniversitaire Raad – Universitaire Ontwikkelingssamenwerking) zou ik ook graag bedanken voor het toekennen van de reisbeurs voor studenten. Zonder deze financiële vergoeding was het heel wat moeilijk geweest om naar de tropen te gaan en terreinervaring op te doen.

De Faculteit Toegepaste Bio-ingenieurswetenschappen van de Hogeschool Gent verdient uiteraard ook een dankwoord want zij hebben mij de kans gegeven om dit buitenlands avontuur mee te maken.

De mensen die me na mijn terugkomst geholpen hebben bij het verwerken van mijn resultaten en het schrijven van mijn masterproef verdienen ook een dankwoord.

Eerst en vooral wil ik Prof. Stefaan Werbrouck en Dr. Betty Heremans bedanken omdat zij mij geholpen hebben bij het uitplaten van pathogene zaailingen, Prof. Werbrouck ook voor het meebrengen van zieke zaailingen uit Kenia en Dr. Heremans voor het identificeren van de pathogene organismen.

Mr. Peter Maene zou ik graag bedanken omdat hij mij geholpen heeft bij het bepalen van het zoutgehalte en pH van de bodemstalen.

Een woord van dank richt ik ook aan het LCA – Hogent (Labo Chemische Analyses) voor de hulp die ik gekregen heb bij het uitvoeren van de bodemanalyses.

Tot slot richt ik nog een bijzonder dankwoord aan mijn promotor Prof. Geert Baert. Hij heeft mij vanaf dag één geholpen bij het zoeken naar een gepaste stageplaats en de beursaanvraag. Tijdens het schrijven van mijn masterproef heeft hij me voortdurend opgevolgd, feedback gegeven en me bijgestaan met zijn taalkundig advies.

Abstract

This thesis gives an overview of nursery management, fertilization and a breeding programme for a tropical timber tree species in semi-arid areas. *Melia volkensii*, a tropical timber tree species from Kenya was chosen for this study. The pilot plantation of Better Globe Forestry in Kiambere, Kenya was chosen as research area.
Fungal diseases mainly caused the low germination percentage and high mortality of the seedlings in the nursery. The pathogens that infected the seeds could not be identified but following organisms were identified on the seedlings: *Fusarium sp., Alternaria sp., Trichotecium sp., Botrysphaeria sp* en *Diplodia sp.* To limit possible loss of seeds and seedlings a germination protocol was developed from seed collection until time of planting the sapling in the field. Two fertilization trials on the planted saplings were measured: the first trial was to determine the effect of different quantities (0 g - 50 g - 100 g) of fertilizer. Results show that 50 g of fertilizer has the most beneficial impact on height and stem diameter of the trees. The second trial was to determine the effect of two consecutive quantities (50 g - 100 g en 0 g - 100 g - 200 g - 300 g) of fertilizer. Results show that 100 g of fertilization applied during planting followed by 100 g 8 months after planting has the most beneficial impact of tree height and stem diameter. Soil analyses on soil samples from different altitude levels in the plantation were carried out to determine the effect of orientation of the trees on the growth parameters. The analyses showed an obvious difference in P, Mg and CEC. It's difficult to relate the results of the soil analyses to the growth of the trees. 71 potential 'plus' tree where selected during the search of breeding material in Mumoni forest. A more thorough selection resulted in 8 potential 'plus' trees that can be used for further tests. A business plan shows that the establishment of a commercial nursery requires a big investment that is almost impossible without the help of a bank or another investor. Literature shows that very little information about *M. volkensii* is available and that further research is necessary. Our investigation shows that this tree species is suitable for plantations in arid and semi-arid areas.

KEY WORDS: *Melia volkensii*, timber tree, nursery management, diseases, fertilization, breeding, business plan

Deze masterproef geeft een overzicht over het kwekerijmanagement, de bemesting en het opstellen van een kweekprogramma voor een tropische boomsoort in semi-aride gebieden. Voor deze studie werd *Melia volkensii* gekozen, een inheemse boomsoort uit Kenia. Als onderzoeksgebied werd de plantage van Better Globe Forestry in Kiambere te Kenia gekozen. Het lage kiemingspercentage en hoog sterftecijfer van de zaailingen in de kwekerij waren hoofdzakelijk te wijten aan schimmels. De pathogenen die de zaden infecteerden konden niet geïdentificeerd worden maar op de zaailingen werden volgende organismen geïdentificeerd: *Fusarium sp., Alternaria sp., Trichotecium sp., Botrysphaeria sp* en *Diplodia sp*.
Om zo weinig mogelijk zaden en zaailingen te verliezen werd een stappenplan opgesteld vanaf het verzamelen van de geschikte zaden tot het uitplanten van de zaailingen in het veld. Twee bemestingsproeven werden opgemeten op uitgeplante zaailingen in het veld: bij de eerste proef werd het effect van drie dosissen (0 g - 50 g - 100 g) getest. De resultaten tonen aan dat 50 g mest de meest gunstige impact heeft op de hoogte en stamdiameter van de bomen. Bij de tweede proef werd het effect van opeenvolgende dosissen (50 g - 100 g en 0 g - 100 g - 200 g - 300 g) bemesting getest. De resultaten tonen aan dat 100 g bemesting bij het planten van de zaailingen gevolgd door 100 g mest acht maanden na aanplanten de meest gunstige impact heeft op de hoogte en stamdiameter van de bomen. Om het effect van de oriëntatie van de bomen op de groei te bepalen werd een bodemanalyse uitgevoerd op bodemstalen van verschillende hoogteniveaus in de plantage. Dit toonde een duidelijk verschil in P, Mg en CEC. Het is moeilijk om de link te leggen tussen de resultaten van deze bodemanalyses en de groei van de bomen. De zoektocht naar geschikt kweekmateriaal voor veredeling leverde 71 potentiële 'plus' bomen op waarvan er 8 geselecteerd werden voor verdere proeven. Een businessplan toont aan dat het opstarten van een kwekerij een grote investering vergt. Zonder de hulp van banken of een andere investeerder is het onmogelijk om als arme boer een commerciële kwekerij op te starten. Literatuuronderzoek toont aan dat weinig informatie beschikbaar is over *M. volkensii* en verder onderzoek is noodzakelijk. Ons onderzoek toont wel aan dat deze boomsoort wel geschikt is voor plantages in aride en semi-aride gebieden.

KERNWOORDEN: *Melia volkensii*, boom, kwekerij management, ziekten, bemesting, veredeling, businessplan

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Introduction

Nowadays we live in a world were climate changes fast and desertification is increasing rapidly. The exponential growth of global population is also becoming a huge problem and people in developing countries suffer from food and water shortage. Planting trees can solve the problem of the global climate change and desertification without interfering with food supply: it's beneficial for the environment as trees capture carbon dioxide, which is one of the greenhouse gasses, and will decrease desertification. It's almost impossible to produce cash crops in arid and semi-arid areas because of the low and irregular rainfall but some tropical timber tree species grow excellent in these regions.

One of these species is *Melia volkensii*, also known as mukau. It's an indigenous timber tree from Kenya. *M. volkensii* is fast-growing and produces first rate and termite resistant timber in a hostile environment. It thrives well on sandy and stony soils that are common in arid and semi-arid lands and can decrease desertification in these areas.

This thesis is divided in two parts: a literature review and an experimental part. A literature study is made about *M. volkensii* but very few information is available about this species. Since germination is a bottleneck in the propagation of *M. volkensii,* part of the literature review is about germination of this species and other tropical species. Fertilization, nutrient cycles and fertilizer experiments of other tropical trees will also be discussed and a small part is dedicated to genetic improvement of the species. Finally a literature study is made about the occurrence, prevention and control of diseases in tropical tree nurseries and plantations.

The purpose of this literature review is to gather information that can be useful for the experimental part of this thesis. The background information study is also important to verify which experiments in the future can be carried out to expand the small amount of information that is available about *M. volkensii*.

When the literature assessment is done, it's time to convert al this gathered knowledge in practice and the most suitable place for this research is the pilot plantation of Better Globe Forestry (BGF) in Kiambere, Kenya. First of all an assessment was made about the plantation and the different species that are planted on site. After a follow-up of the management practices in the tree nursery it became obvious that germination was very low due to fungal diseases. After a two-week long survey in a more successful *M. volkensii* tree nursery in Kibwezi a germination protocol was developed to obtain a better germination rate. At the pilot plantation two fertilizer experiments were evaluated to determine the amount of fertilizer that is most beneficial for saplings in the field. Since a part of the plantation is located on a slope, an assessment was made to examine whether there is a relationship between tree characteristics and the nutrients in the soil. Preservation of this valuable timber tree species is very important for the future so an evaluation of potential breeding material in Mumoni Forest was carried out. Finally a case study was made about the successful nursery in Kibwezi with the emphasis on the financial side of starting a commercial *M. volkensii* nursery.

The research at the pilot plantation in Kiambere, at the nursery in Kibwezi and at Mumoni Forest will lead to improved management of the nursery and the plantation of Better Globe Forestry. It will also be beneficial for people who want to start with propagation of *M. volkensii* for their own needs or for commercial purposes.

Finally it must be mentioned that the literature review sometimes reveals contradictory information about the propagation and cultivation of *M. volkensii* in the semi-arid tropics.

I Literature Review

1 *Melia volkensii*

1.1 Introduction

Melia volkensii (Figure 1) grows naturally in the drylands of Eastern Africa, mostly in Eastern Kenya but small quantities are also found in the semi-arid zone of Ethiopia, Tanzania and Somalia (Muok et al., 2001) and are drought resistant (Juma, 2003). The Kamba is a tribe that lives in eastern Kenya, that's why the species is also called mukau, which is the Kamba name.

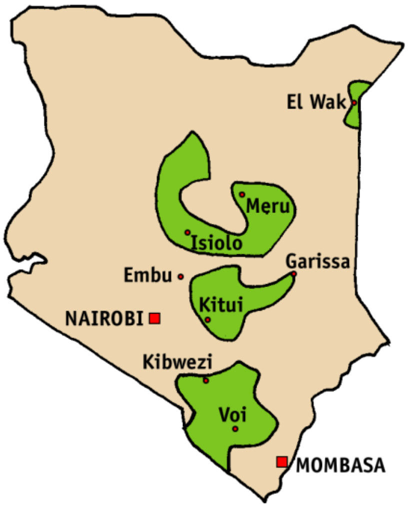

Figure 1: Distribution of M. volkensii in Kenya (Kigwa et al. 2009)

The habitat of the tree lies between 350 and 1700 metres above sea level and is characterized by dry bush land. The mean annual rainfall in these areas is 300 to 800 mm. *Melia* thrives on well-drained soils from sandy loam to sandy clay (Juma, 2003) that can be stony (Muok et al., 2001).

1.2 Morphology

M. volkensii can attain a height of 10 to 30 m and a diameter of about 50 cm. It has an open crown and the bark is grey and fairly smooth, sometimes covered with dirt of termites. The healthy leaves are pale bright green and can be up to 35 cm long. They're compound with 3 to 7 deeply lobed leaflets, which are densely hairy in the beginning of their development. The flowers of the mukau are arranged in loose inflorescences and are small, white and fragrant. The fruits are 3 to 5 cm long and have a yellowish green colour when they are ripe. Most fruits collected in the field are also covered with pale grey spots, due to the deposit of cork (Orwa et al., 2009). The fruit pulp is edible to some animals like goats (Juma, 2003). Each fruit encloses one to five seeds, which are enclosed in a rock hard shell (endocarp). This shell contains mostly one to three seeds. The seeds are oval, dark brown and have an average size of 2 cm length and 0.5 cm wideness (Muok et al., 2007). The timber has a pale reddish brown colour, resembling mahogany and is strong and durable (Jama et al., 2003). Figure 2 shows an approximately 10 years old *M. volkensii*.

Figure 2: An approximately 10 years old *M. volkensii*

1.3 Development

Germination of *M. volkensii* seeds is epigeal, where two opposite simple primary leaves are stalked and develop from the cotyledons (Milimo, 1989). The cotyledons turn green and act as the first set of leaves capable of photosynthesis before the development of the true leaves (KEFRI, 2004).

M. volkensii sheds its leaves twice a year, early in the dry season to protect the tree from dehydration. Two to three weeks before the beginning of the rainy season new leaves emerge. On cultivated lands the tree sheds its leaves normally later into the dry season.
The reproductive buds grow only at the end of branches and are in general larger than vegetative buds. Flowering and fruiting can take place two to three times a year and don't follow the seasons. On the same branch, fruits can be at very diverse stages of ripeness. The fruits are normally mature after twelve to thirteen months after the time of flowering. *M. volkensii* can already start flowering after two to three years (Orwa et al., 2009). Pollination is done by insects, especially the honeybee (*Aphis mellifera*), and it is also a self-pollinating tree (Juma, 2003). When the seeds are ripe, the fruits change colour from green to yellowish-green and the pulp becomes soft. The endocarp becomes very hard and the colour of the seed coats turns from light brown to dark brown to black (Muok et al., 2007). Seeds can have a different

colour depending on maturity; the light brown seeds are less mature than the dark brown seeds. At the age of two and a half year, *M. volkensii* can already flower and set fruits (Stewart & Blomely, 1994).

1.4 Importance

M. volkensii is one of the most valued trees in eastern Kenya. Within a period of 10 to 15 years it can provide durable construction timber of a high quality (Mulatya, 2006), which is known to be termite resistant (Blomley, 2004). Another advantage of the species is that the timber is easy to work and shape. The fruits and leaves are also used as fodder for goats, cattle and sheep during the dry season and can also be used as mulch and green leaf manure (Orwa et al., 2009). The highly scented flowers attract bees that produce good quality honey. Rural farmers have reported the use of leaf extracts to control ticks and fleas in goats (Blomley, 2004). The mukau tree has a great potential for farmers in dryland areas because of its drought tolerance, fast growing capacity and high timber value (Muok et al., 2007).

2 Seed germination

2.1 Importance

Conservation of *M. volkensii* in Kenya is mainly undertaken through intensive farm planting with assistance from tree planting projects whose major role is to distribute seedlings raised at institutional nurseries. Attempts by farmers to raise their own seedlings are still hampered by difficulties with breaking seed coat dormancy (Omondi, 2004). It is important to learn about the factors that have an influence on seed germination.

2.2 Seed storage

The aim of drying seeds is to reduce seed moisture content to manageable levels that will reduce deterioration rate. The advantages of seed drying are numerous: storage is prolonged, seeds can tolerate extreme temperatures, germination is prevented and attacks by fungi and insects are minimized. Seed drying is only applicable to orthodox seeds and drying levels vary from species to species (KEFRI, 2004).

2.2.1 Recalcitrant and orthodox seeds

A high number of tropical tree species have recalcitrant seeds or seeds sensitive to desiccation. Difficulties in seed conservation occur through desiccation intolerance. Afforestation and economic use of tropical tree species are held back due to lack of storage methods of recalcitrant seeds for long periods (Barbedo and Cicero, 2000).

Seeds can be divided into two groups, orthodox and recalcitrant, based on their response to desiccation. Seeds that can be dried to sufficiently low moisture content (generally < 7 %) to permit low temperature storage are referred as orthodox (Roberts, 1973). Those that cannot tolerate desiccation to low moisture content and remain viable for few days to weeks are referred as recalcitrant (Ellis et al., 1990). Most timber trees from tropical rain forests have recalcitrant seeds (Corbineau & Côme, 1989) characterized with rapid germination, short viability and no dormancy. Recalcitrant seeds are difficult to store because of their high seed moisture content, but they are easy to germinate if collected fresh (Kyereh et al., 1999). They do not tolerate a loss of moisture below 25 % and are called desiccation sensitive. These seeds do not undergo extensive maturation drying and are shed when their moisture content is rather high (KEFRI, 2004). It is necessary to maintain the water content of recalcitrant seeds above critical levels. This could cause seed germination or infection by micro-organisms during storage and lead to deterioration (Barbedo & Cicero, 2000). The maintenance of viability of seeds of species with recalcitrant or intermediate storage behaviour is problematic. Small improvements in the maintenance of viability could mean a significant step forward for commercial production and supply and valuable tree seeds (Vertucci and Roos, 1990). KEFRI describes orthodox seeds as seeds which are tolerant to drying to moisture content below 10 % without losing viability. The seeds in this category undergo maturation drying and are dispersed when their moisture is low about 12-10 % (2004). Orthodox seeds can be readily stored in artificial conditions and show various degrees of dormancy.

2.2.2 Seed storage potential of *Melia volkensii*

M. volkensii seeds are described as recalcitrant (Milimo, 1989), however they have recently been described as intermediate seeds (Omondi, 2004). ICRAF describes the seeds as orthodox and report that viability can be maintained for several years in hermetic storage at room temperature with 11 to 15 % moisture content. However, seed trials at the Kenya Forestry Seed Centre (KFSC), using seeds stored for tree months at -3 °C obtained a mean germination of 3 %. Other reports from the centre are that mature and properly dried nuts can be stored in airtight containers at a temperature of 3 °C for several years without damage (ICRAF, 2012). The low mean germination percentage after 3 months of storage may indicate that the seeds of *M. volkensii* are not orthodox. These different findings indicate that further research is necessary to determine whether the seeds are in fact recalcitrant, orthodox or intermediate.

Omondi (2004) has assessed the desiccation tolerance and storage potential of four tree species of economic importance in Kenya, including *M. volkensii*. The stony endocarp was removed with a knife and hammer and afterwards the seeds were pulled out. Germination tests were conducted after 3, 6 and 12 months of storage. Seeds of *M. volkensii* were sown on 1 % water-agar and then incubated in germination cabinets at 26-28 °C (Omondi, 2004).

Table 1 shows the germination percentage in relation to the drying time and moisture content. Dark brown mature seeds with 42 % initial moisture content germinated 38 %. 4 % of the seeds germinated with a moisture level of 10,3% but no seeds survived a moisture level below 10,3%. This indicates the desiccation sensitivity of the seeds. The initial viability of freshly harvested seeds attained 40-80% but due to heavy fungal infestation on the water-agar, germination was lower than 40%.

Table 1: Germination after drying dark brown mature seeds of *M. volkensii* (Omondi, 2004)

Drying time (h)	Moisture content (%)	Germination (%)
0	42	38
6	16.4	11
12	12.6	6
24	10.3	4
30	6.4	0
36	5.2	0

A drying time less than 6 hours coupled with moisture around 42 % seems optimal for the seeds. After 6 hours, the germination percentage decreases very quickly. This indicates that the moment of cracking the nuts is important for obtaining a good germination percentage at the nursery. The nuts must be cracked in the morning so that the seeds can be dried for a couple of hours and are ready to be sown in the afternoon. Further research is necessary to determine when the seeds must be planted after they are released from the stony nut.

Seeds of different maturity stages, based on colour, were also tested. Mature seeds are dark brown while the less mature seeds have a light brown colour. Figure 3 shows light brown and dark brown to black seeds of *M. volkensii*. The latter had a lower germination percentage and did not germinate at higher moisture levels. The study showed that the desiccation rate of immature seeds was higher than those of mature seeds (Omondi, 2004).

Figure 3: light brown and black *M. volkensii* seeds

2.2.3 Seed storage behaviour of two tropical tree species

Freshly harvested seeds of *Carapa procera* and *Entandrophragma angolense*, both members of *Meliaceae*, have the highest germination percentage in comparison with dried seeds. Germination percentage of the dried seeds decreases with duration of drying. The length of storage treatment and moisture content have a significant effect on seed germination. Seed storage is only possible after depulping, washing, drying and desinfecting the seeds with an insecticide to prevent formation of mould. The viability of *C. procera* seeds decreases from 85% at 0 months of storage to 75 % at 24 months of storage. The viability of *E. angolense* seeds with original moisture content decreases from 95 % after 0 months of storage to 80% after 3 months of storage (Pangou et al., 2011). This study shows that seed storage has a negative effect on germination because of a decrease in viability.

2.3 Factors affecting germination

Factors responsible for poor germination of *M. volkensii* seeds during and after storage are not well understood, but they have been attributed to both physical and physiological factors (Ellis et al., 1990).

Many factors, including dormancy, temperature light, humidity and moisture influence seed germination and seedling establishment. Obtaining high rates of seed germination is a key element of a successful reforestation programme (Moussa et al., 1998).

2.3.1 Seed dormancy

Mature seeds of most woody plants species from the temperate zones will not germinate promptly when placed under conditions that are normally regarded as suitable for germination. Such seeds are said to be dormant (Gordon, 1992). Amen (1968) claims that seed dormancy is considered as an aspect of growth cessation and describes dormancy as a state whereby seeds fail to germinate when provided with suitable germination of moisture, air and constant temperature.

Dormancy for many tree species is a partial protection mechanism to prevent the seeds from germinating under environmental conditions, which are unfavourable for the survival of the seedlings. In the arid and semi-arid tropics, seed coat dormancy in tree species is common (KEFRI, 2004).

Seed dormancy can be classified in embryo dormancy, seed coat or physical dormancy and chemical dormancy. Dormancy of *Melia sp.* seeds is known to be physical and is largely induced by mechanical, physical or chemical factors in the seed coat. Although the embryo may be capable of germination, the seed coat can inhibit water absorption, gas exchange or mechanical expansion (KEFRI, 2004).

Dormancy presents a problem in the nursery where uniform seedlings must be produced as rapidly as possible. This problem is not insolvable: dormant seeds can be induced to germinate within a reasonable time if certain predetermined conditions are satisfied (Gordon, 1992). The inhibiting factor must be removed before germination can occur (KEFRI, 2004).

2.3.2 Temperature

Most tropical seeds require a high temperature for germination that varies from 25 to 35 °C. Optimum temperature for germination varies among species. Some have a wide range while others have a very narrow range (Yirdaw & Leinonen, 2002).

Garcia & Di Stefano have tested the effect of temperature on germination of *Dalbergia retusa*, a tropical tree species. Results showed that a germination percentage of 85.6 % was obtained at 30 °C after 5 days. Lower temperatures were unfavorable for germination and resulted in a lower germination percentage. Some seeds germinated at 40 and 45 °C so this shows that this tropical species is physiologically adapted to hot areas (2000).

2.3.3 Light

Kyereh et al. (1999) tested the effect of light on germination of 17 important forest timber trees in Ghana, including *Guarea cederata*, *Entandtrophragma utile*, *Khaya anthotheca*, *Lovoa trichilioides* and *Khaya ivorensis*, which are all members of the *Meliaceae*. The effects of light (30 % irradiance) versus dark (0 % irradiance) and neutral shade (5 % irradiance) on germination of tree species in shade houses were examined. Results showed that there was no significant difference in germination percentage between the light and dark treatment of the five *Meliaceae* species. Of the remaining non-*Meliaceae* species, only those with the three smallest seeds showed a significant difference in germination percentage between light and dark.

2.3.4 Moisture

Moist is essential for germination but water excess is most often damaging for the germinating seeds. Abundant water can replace the air in the soil and can cause soil compaction that restricts respiration. Another result of water excess is the growth of fungal diseases such as damping off, which is a major problem in *M. volkensii* nurseries. Water management is important during germination since the seeds are sensitive to desiccation. Good drainage of the growing medium is important since only moisture close to the seeds and seedlings is absorbed during germination. Regularly watering of the sowing bed is necessary to avoid desiccation but coarse-grained material such as coarse sand is an effective measure to help drainage of the sowing bed (Schmidt, 2000).

2.4 Germination study on *Meliaceae* species

Effect of desiccation and temperature on germination

Pritchard et al. (2004) tested the effect of desiccation and temperature on seed germination of 9 tropical African dryland trees, including *Khaya senegalensis* and *Trichilia emetica*, both members of the *Meliaceae*. Seeds of these species were sown at a temperture range from 11 to 36 °C. The germination rates of both species are given in table 2, based on a figure presented by Pritchard et al. (2004).

Table 2: Effect of temperature on seed germination of *K. senegalensis* and *T. emetica*

Germination rate (%)		
Temperature (°C)	K. senegalensis	T. emetica
11	0	0
16	4	4
21	6	7
26	12	9
31	15	15
36	17	15

The data from table 2 show that there is an approximately linear increase in seed germination rate with increasing temperature in the range between 11 and 36 °C for both species. Temperatures highes than 36 °C are not presented in this study.

3 Fertilization of tropical trees

3.1 Introduction

As the cover of natural forests in the tropics has declined over the last decades and the demand for wood products continues to grow, tree plantations have become increasingly important (Zeugin et al., 2010). Many of the tropical plantations are monocultures of fast growing species such as teak and *Eucalyptus*. This has been seen as a problem for nutrient availability in long term (Aweto, 2001). An understanding of the comparative nutritional requirements of important timber species is fundamental in the development of sustainable systems for the production of wood from plantations on many infertile, highly weathered soils in tropics with high rainfall (Webb et al., 2000). In areas where evapotranspiration exceeds the average yearly rainfall, anti-erosion measures are indispensable. These measures are important for maintaining soil fertility and to conserve the topsoil from being washed away (Vandenabeele, 2009b). Improvement of soil fertility in semi-arid lands is necessary as nutrients are washed away by soil erosion. This extra cost makes the use of fertilizers unaffordable for many farmers and compost manure is a cheaper alternative in these areas (Better Globe, 2009). The use of fertilizer is expensive and it should only be applied if there is an economical benefit (West, 2006). Int his chapter fertilization studies of other tropical tree species will be discussed since very little to no information is available concerning fertilization of *M. volkensii*.

3.2 Nutritional elements

3.2.1 The necessity of nutritional elements

A nutritional element is considered to be essential in case of these four criteria: the presence of the element is necessary for the lifecycle of the plant, even in minimal quantities; the absence of the element causes first of all a growth inhibition followed by a stagnation in growth and finally an appearance of visual deficiencies; the element must be part of an indispensable component of the plant such as an enzyme, metabolite or DNA string; the element cannot be replaced by another element (Baert, 2009). It is important to ensure that essential nutritional elements are available when they are required or health and growth rate of the trees will suffer (West, 2006). Fertilizers that combine nitrogen, phosphorus and potassium are routinely required to maintain agricultural activity (Wright et al., 2011).

3.2.2 Nitrogen and phosphorus

Graciano et al. (2006) report that nitrogen and phosphorus are the nutrients that frequently limit tree growth.

Nitrogen

Nutrient shortage in short and long term must be minimized but the losses can be made up by fertilization (West, 2006). Primarily, nitrogen affects the metabolism of proteins so a deficit has a negative influence on the modification of carbohydrates into proteins. A nitrogen deficiency results in a decrease of chloroplast formation, which is reflected primarily in the leaves. Nitrogen is then carried away to other sinks from older leaves to other sinks. This clarifies the mobility of nitrogen as nutritional element (Baert, 2009). Nitrogen is the nutrient required in the largest quantities by arable crops and is the most difficult nutrient to manage due to the complex physical, biological and chemical transformations (Fowler, 2003). It can be taken up as cation or as anion, respectively as NH_4^+ and NO_3^- (Switzer & Nelson, 1972). In forest ecosystems, the dominance of N is less pronounced in comparison with agricultural crops but still present. A steady supply of nitrogen is essential to a balanced nutrition and to tree vitality. Compared with other nutrients, nitrogen inside trees is present mainly in the leaves while little is transported to the wood (Arnold & van Diest, 1991).

Phosphorus

Phosphorus has been identified as one of the most widespread and severe limitations of tree growth on reforestation sites in the tropics but there is still little published information on the response of tropical plantation timber species to P fertilizers (Webb et al., 2000). With the *Eucalyptus* tree the demand for P is high during the first year of growth. In later stages the demand decreases due to internal recycling (Fernandez et al., 2000). In 2005, Graciano et al. already showed that fertilization with P increased growth of young *E. grandis* plants more than fertilization with N, even in soils that are relatively poor in N and where N is limiting.

Webb et al. (2000) tested the growth response of four tropical plantation timber species to increasing phosphorus supplementation. One of these four species was *C. odorata*, a genus that belongs to the family of the *Meliaceae* such as *M. volkensii*. Growth response was determined 4 and 9 months after the fertilizer treatment. *C. odorata* showed a significant increase in both height and volume index with four increasing rates of P applications (0, 60, 150 and 300 g P per tree) at most ages. The phosphorus was supplied as triple super phosphate; 21 % P and 15 % Ca. Results also indicated that volume index was much more responsive to increasing P supply than height. Even though this experiment was conducted in a humid tropical area with a mean annual rainfall of 3600 mm it shows that phosphorus is an important nutrient in wood producing tree species.

Nutrient use efficiency

Zeugin et al. (2010) tested the effect of tree diversity on nutrient use efficiency, a helpful measure to determine the nutrient demand. Nutrient use efficiency is defined as the productivity of a tree species on site and is the amount of biomass produced per unit of a certain macro- or micronutient. Six tree species were used in the study and the design included monocultures, three-species mixture and six-species mixture. Table 3 gives an overview of the effect of species richness on nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE). The results show that there was not an increasing relationship between tree diversity and NUE and PUE. The study also indicated that the largest fraction of fresh biomass was produced in the stem of all tree species without any influence of the species richness. *M. volkensii* was not included in this experiment but the results of this study indicate that nutrient use efficiency in monocultures of this species is not less in comparison with plantations where more species are combined. Further research is needed to investigate the effect of *M. volkensii* in monoculture on nutrient use effeciency.

Table 3: Effect of species richness on nitrogen (NUE) and phosphorus use efficiency (PUE) (Zeugin et al., 2010)

Species richness	NUE (kg dry matter/kg N)	PUE (kg dry matter/kg P)
1	171	870
3	170	710
6	167	881

3.2.3 Potassium

Potassium is taken up as a cation (K^+) and is important for osmotic functions, metabolism and electrical charges. Due to its high concentrations, potassium contributes to the osmotic potential in living cells and is essential for opening and closing the stomata. Potassium is also important for the metabolism since it is a component of over 50 enzymes such as nitrate reductase. Its positive charges neutralize the charge of several anions in the plant so the pH remains sufficient for optimal activity of enzymes. Lack of potassium can lead to withering of plants, less stable tissue and necrosis of leaf edges (Baert, 2009). K addition for established trees is important since this nutrient is relatively immobile in soils (Gillman & Rosen, 2000).

Laclau et al. (2008) tested the effect of K-additions on leaf life span, leaf production and tree growth in *Eucalyptus grandis*. Two K treatments were tested during the study: a control treatment with no K addition and and a treatment with 116 kg K/ha applied as KCl. 3 equally divided amounts of KCl were applied 0, 6 and 12 months after planing. Results show that fertilization of K leads to an increase in tree height of 3.7 m at 36 months. Table 4 gives an overview of the influence of fertilization with K on the accumulation on above-ground biomass. Addition with K also leads to a larger above-ground biomass of 118% 12 months after planting in comparison with the control treatment. The same trend is visible 24 and 36 months after planting.

Table 4: Influence of K fertilization on the accumulation of above-ground biomass (Laclau et al., 2008)

	Control treatment	**116 kg KCl/ha**
Biomass (g/m²) 12 months after planting		
Leaf	97	212
Branch	209	362
Stem	109	324
Total above-ground	412	898
Biomass (g/m²) 24 months after planting		
Leaf	292	528
Branch	610	808
Stem	1118	2763
Total above-ground	2049	4099
Biomass (g/m²) 36 months after planting		
Leaf	215	518
Branch	627	1330
Stem	2359	5602
Total above-ground	3265	7450

K fertilization also has a significant influence on leaf mortality: in the control treatment about 50 % of the leaves were shed between 50 and 100 days after emergence whereas about 25 % of the leaves were shed every 50 days between 50 and 250 days after emergence in the fertilizer treatment.

Fertilization with K causes a significant reduction in the root/shoot ratio which means that additional K reduces allocation to the seedling roots and stimulated the above ground growth. Availability of K can have a large effect on forest seedling growth. Further investigation is necessary to improve the understanding of K-limitation (Santiago et al. 2012).

3.3 Different growth stages of trees

Tree crops differ from annual crops in the numerous stages of growth in a life cycle which Yost and Ares (2007) describe as nursery, establishment, fast-growth and maturity stage. In order to determine nutrient requirements, it is important to know the growth stage of the tree during its life cycle. Some of these stages such as fast-growth and maturity can extend for several years. The four stages each have a specific process of nutrient absorption and internal and external cycling that determine the requirement for nutrients. Nutrient management should definitely take these differences in nutrient uptake into account.

In the nursery stage, seeds are germinated and grown up to individual seedlings under controlled conditions to ensure high survival. In the establishment stage, seedlings are placed in their final location and growth is highly dependent on soil properties. The seedlings must develop an extensive root system for nutrient and water uptake, resistance to unfavourable conditions and structural support. During the stage of fast-growth, the above ground plant biomass accumulates at an exponential rate generating a high demand for nutrients (Yost & Ares, 2007). One of the reasons of inefficient nutrient uptake is the interaction between soil and fertilizer so that large quantities of applied fertilizer are unavailable or leached by the time the fast growing stage starts. During this phase of growth, it seems complicated to satisfy the demand in nutrients of the trees (Hunter & Smith, 1996). When the trees have reached maturity, the increase of biomass is relatively small compared with the fast-growth stage. Therefore nutrient management should take these differences in developing nutrient management for tree crops into account (Yost & Ares, 2007).

The first few years of growth of the plantation trees are critical for nutrient supply. During this stage the canopy and root system enlarge which requires an increase in nutrients. The right amount of fertilizer at the right time is necessary to provide enough nutrients for the trees (West, 2006).

3.4 Sustainability of forest management practices

Roughly three quarters of the planted forests have production as their most important purpose, so removal of wood for timber is necessary. The reported wood removals since 2005 amounted approximately 3,4 billion cubic metres every year. Illegal removal of wood is not recorded so the real quantity of wood removal is much higher. These large quantities of wood removal indicate the importance of forest resources to the economy and local communities (FAO, 2010). An understanding of the nutritional requirements of important timber species is fundamental in the development of sustainable systems for the production of wood from plantations on many infertile, highly weathered soils in the tropics (Webb et al., 2000).

3.4.1 Nutrient management

Attanandana et al. (s.d.) developed a framework to support nutrient management decisions for crops that also could be used for tree crops. This framework was designed to match a typical sequence in decision-making in four steps and can be a valuable instrument. The first step is the diagnosis whether or not there's a nutrient management problem. Secondly is the determination of what is required to remedy the deficiency. The third step is an economic analysis to determine if the predicted solution is likely to be economically valid. Al this information can be communicated to the manager of the plantation.

3.4.2 Nutrient losses in forests

Eucalyptus is a widely planted genus in tropical regions but the sustainability of those plantations is of concern since they are usually established on low-fertility soils and large nutrient exports occur every 6-7 years with biomass removal (Laclau, 2005). In future *Melia volkensii* plantations, the large nutrient exports will also occur when the trees are being cut down for timber.

Sustainability of forestry practices is influenced by several factors that should be taken into account in long-term: quality of the forest is one of these factors and very important in influencing the sustainability of forest management. For *Pinus sylvestris* potential N losses in poor quality stands are significantly lower than those of high quality forest stands. Potential nutrient P and K losses are similar in high- and low-production forests. A second important factor on sustainability is the tree removal procedure: stem removal or removal of the whole tree. The latter results in significant higher potential nutrient losses against stem removal where nutrients in leaves, twigs and branches can be recycled. Intense thinning is a third essential factor of sustainability. Too higher thinning intensities in *P. sylvestris* stands (more than 30% of the basal area) can cause severe reduction in tree density and growth increments of remnant trees do not compensate for this reduction (Blanco et al., 2005).

3.5 Adequate fertilizer use

Artificial forests are increasing and account for approximately 7 % or 264 million hectares of the total forest area. Between 2000 and 2010, the area of planted forest trees increased by approximately 5 million hectares per year (FAO, 2010). Tropical plantation forests provide an increasing share of the global wood supply and competition with other land uses in the future will require sustained yields to fulfil demand (Laclau et al. 2010). Nowadays, forestry is practiced on lands susceptible to nutrient deficiency so fertilizer use is an important part of forest managing (Hunter and Smith, 1996).

3.5.1 Eutrophication

Strict limitation of fertilizer application instead of an overload of fertilization is becoming essential for economic and environmental reasons (Laclau et al., 2010). Excessive inputs of fertilizer in agricultural crops are likely to lead to eutrophication of surface waters (Domagalski et al., 2007). Eutrophication is a natural process where lake productivity increases, nutrients are enriched and lake aging occurs. The role of phosphorus in eutrophication is determinative as it's the most limiting nutrient in most freshwater lakes and streams. This means that the amount of phosphorus in a lake limits aquatic plant and algal productivity; less phosphorus means less growth of aquatic plants and algae. Minimum amounts of phosphorus can cause enormous increases in growth (Addy and Green, 1996).

The highest possible nutrient scenarios should not be the ultimate goal of applying fertilizers. The highest nutrient efficiency occurs when limited amounts of fertilizer are applied on soils that show nutrient deficiency. Inadequate fertilizer use also occurs in agriculture when an insufficient quantity of nutrients is applied to meet the needs of the crops. Soil productivity will steadily decrease as crop production continues to be increasingly dependent on the nutrient reserves from the soil (Mikkelsen, 2005).

3.5.2 Alternatives of chemical fertilizers

Commercial fertilizers are expensive and beyond the means of many smallholders so organic approaches to N management are important, those based on N_2-fixing legumes in particular (Smithson and Giller, 2002). Green manure can also be used in tropical forest plantantions. A green manure crop is a non-commercial crop grown during autumn and winter and during this time it accumulates N from soil reserves and atmosphere through N fixation. After incorporation into the soil, subsequent crops can benefit from this accumulated N. The release of N from the green manure and the N demand of the subsequent crop determine the N benefit. The environmental and agronomic benefits of green manures depend on climate, soil type, crop species and other factors. All these factors affect the ability of a certain green manure to grow and accumulate N (Fowler, 2003).

3.5.3 Mycorrhizal association in tree species

Some forest species form arbuscular mycorrhizas but some other types of mycorrhiza such as ectomycorrhiza (ECM) are important for forest production. Inoculation with ECM can benefit timber production at two phases: in the nursery and after outplanting the saplings. Research showed that ectomycorrhizal inoculation of seedlings causes great response under the most extreme conditions such as drought and presence of pathogens and illustrated the ameliorative effect of ECM fungi (Smith & Read, 2008).

Melia volkensii

The role of mycorrhiza in growing *M. volkensii*, has numerous benefits: it increases the surface area of roots for absorption of nutrients and water, phosphorus uptake, drought resistance, control of root pathogens, reserve nutrients and help nitrogen fixation of rhizobium (Harley and Smith quoted by Juma, 2003).

Acacia trotilis

Munro et al. (1999) demonstrated that a low-cost method of mycorrhizal inoculation improves growth of *A. tortilis* seedlings in the nursery. Treatments compared the growth of pre-germinated *A. tortilis* seedlings in either sterilized (killed inoculum was applied) or unsterilized (killed inoculum or living inoculum was applied) nursery soil. Polyethylene tubes were half-filled with sterilized or unsterilized soil, mycorrhizal root inoculum and soil inoculum. Seedlings that received living mycorrhizal inoculum were also inoculated with a dosage of *Rhizobium* mixed culture at time of planting, and this was repeated two weeks later. Four weeks after planting and receiving living or killed inoculum the first treatment effects became clear: the seedlings that received the living inoculum were significantly taller than the control group. The overall conclusion was that inoculation resulted in taller, heavier plants and a faster growth rate over the experiment in comparison with the control treatments. This shows that simple pot cultures of mixed mycorrhizal inoculum can be used to improve plant quality in the nursery.

There was also a siginificant difference between the two types of soil used as growing medium: sterilized and unsterilized soil. Table 5 shows the effect of equally treated *A. tortilis* seedlings in sterile and unsterile soil. After 15 weeks there is only a difference in root/shoot ratio but no difference in height and root collar diameter.

Table 5: Effects of inoculation with mixed mycorrhizal inocula and Rhizobium on the growth of *A. tortilis* in sterile and unsterile soil (Munro et al., 1999)

Growth of *A. tortilis*	**Nursery treatment**	
	Sterile soil & killed inoculum	**Unsterile soil & killed inoculum**
After 15 weeks		
Height (mm)	64.2	64.8
Root collar diameter (mm)	2.82	2.42
Shoot dry mass (g)	0.125	0.124
Root dry mass (g)	0.125	0.080
Root/shoot ratio	1.055	0.641
After 24 weeks		
Height (mm)	65.2	79.9
Root collar diameter (mm)	2.91	2.71
Shoot dry mass (g)	0.117	0.190
Root dry mass (g)	0.132	0.128
Root/shoot ratio	1.183	0.781

The data from table 5 show that there is a significant effect between the use of sterilized and unsterilized soil. After 24 weeks the seedlings in unsterilized are higher and have a higher dry root mass. Munro et al. suggest that soil sterilization has a negative impact on mycorrhizal infection and seedling growth without inoculation (1999).

3.6 Slow release fertilizer

3.6.1 Nursery experiments

Cedrela odorata

Cost-effective slow release forms of N and K are a necessity in forestry. Types of fertilizer that give a long lasting response from an early single application are an example of sustainable forestry management (Hunter & Smith, 1996). Baker et al. (1999) determined the optimal rate of slow released fertilizer (Nitrophoska, Macrocote, Osmocote and Nutricote) for maximum growth of *C. odorata* in a forest nursery. The elemental composition of these slow release fertilizers is given in table 6.

Table 6: Elemental composition of the different types of slow release fertilizer (Baker et al., 1999)

Element	Nitrophoska [1]	Macrocote [2] 4 to 5 month formulation	Macrocote 9 month formulation	Osmocote [3] 4 to 5 month formulation	Osmocote 5 to 6 month formulation	Osmocote 9 month formulation	Nutricote [4] 4 to 5 month formulation	Nutricote 9 month formulation	Micromax [3] Micro Nutrients
	%	%	%	%	%	%	%	%	%
N	15.0	15.0	12.0	18.0	17.0	17.0	13.3	13.3	
P	3.9	4.0	4.6	4.8	4.4	1.6	5.8	5.8	
K	12.4	8.0	10.0	9.1	10.0	8.7	9.7	9.7	
S	7.0	4.3	5.17	4.0	4.1	4.5	0.5	0.5	15.0
Ca	3.4			0.96	0.2		5.5	5.5	5.5
Mg	1.2	0.75	0.75						3.3
Mo									0.005
Fe	0.1	0.20	0.20						12.0
Cu		0.03	0.03						0.5
Zn	0.02	0.03	0.03						1.0
Mn	0.10	0.09	0.09						2.5
B	0.03								0.10

The four types of slow release fertilizer were tested in six rates of application (1 g, 2 g, 4 g, 6 g and 8 g per L medium). Additional to the slow release fertilizer, 0,5 g Micromax and 0,25 g of $FeSO_4.7H_20$ were added per L medium. Micromax is also a slow release fertilizer containing necessary trace elements to ensure optimal plant growth (Everris International B.V., 2011). The graphic in figure 4 shows the effect of the four fertilizers and amount of application on dry matter production of *C. odorata* seedlings after 15 weeks in the nursery.

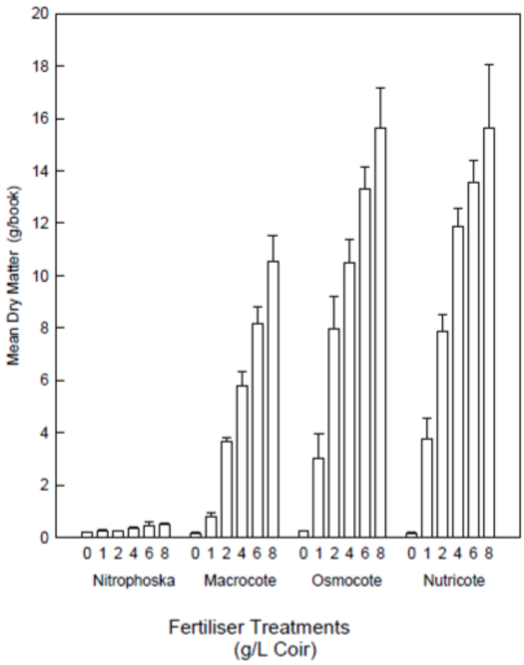

Figure 4: The effect of different slow release fertilizers and amounts of application on dry matter production of *Cedrela odorata* seedlings after 15 weeks in the nursery (Baker et al, 1999)

Shoot growth increases with increasing application of each of the slow release fertilizers and was significantly affected by both the fertilizer type and rate. The effect of Nitrophoska addition on dry matter production is very low in comparison with the three other fertilizers. The effect of Osmocote and Nutricote fertilization on dry matter production is very high while the effect of Macrocote on dry matter production was high but less than Osmocote and Nutricote. The increase on dry matter production from no added fertilizer to 8 g per L after 15 weeks was also remarkable: the response of Nitrophoska, Macrocote, Osmocote and Nutricote was respectively 3, 65, 69 and 97 times higher. This experiment shows that all four types of slow release fertilizer have a positive effect on dry matter production of *C. odorata*. It also shows that there is a big difference between the four types of slow release fertilizer. The consideration was made that further experiments must be established to determine the minimum rate required to achieve maximum growth in the nursery (Baker et al., 1999).

Gmelina arborea

Reddell et al. (1999) tested the effects of five rates of nursery-applied, slow release fertilizer on growth of clonal white teak (*G. arborea*). This was investigated during the first 14 months following planting out.

A mixture of 2 Nutricote slow release fertilizers was mixed with the potting medium. Nutricote Blue and Nutricote Black both have a release time of respectively 4 to 5 and 6 to 9 months at 25 °C. The five rates used were 0, 2, 10, 15 and 20 g fertilizer per L medium. Root cuttings of a single clone were set to each treatment. The root cuttings were planted in the field six weeks after planting. At the end of these six weeks, the fertilizer had no effect on height and survival rate of the cuttings. Six months after planting there were significant increases in height with increasing rates of fertilizer. Trees were 60 % taller at a rate of 20 g fertilizer per L coir, but near maximal response was already achieved at 10 g per L.

The conclusion of this study was that addition of slow release fertilizers into the nursery medium improved growth of *G. arborea* during the first 14 months of establishment in the field, which is known as the most critical period. The remarkable increasing tree growth in the field was probably the result of the location of the slow release fertilizer, namely the immediate proximity of the roots. Two cumulative effects of the fertilizer placement are likely to explain the growth responses that were achieved: immediate and continuous access to nutrients within the root zone and a greater competiviness through the higher growth rates. Very remarkable was the high effectiveness of the slow release fertilizer in *Gmelina* in comparison with field-applied fertilizer, which was reported to be low effective. It's probably that suckering vegetation and leaching beyond the root zone capture a significant amount of field-applied fertilizer. The use of slow release fertilizer is also beneficial for economic reasons: lower overall fertilizer costs, lower labour costs and earlier canopy closure (Reddell et al., 1999).

The research of Reddell et al. (1999) and Baker et al. (1999) indicatie that the use of slow-release fertilizer in *M. volkensii* nurseries should definitely be considered.

3.6.2 Cost of slow release fertilizer

Nutricote Black and Blue are both available in bags of 25 kg with a cost price of respectively 160.60 Australian Dollar (AUD) (EUR 117.25) and AUD 155.27 (EUR 113.36) (SureGro, 2012). Reddell et al. (1999) reported that 10 g of the 50:50 (w/w) mixture Nutricote Black and Blue per L potting medium achieved near maximal response in *Gmelina arborea*. The assumption is made that the same quantities can be used for seedlings of other tropical tree species such as *Melia volkensii.* From a 25 kg Nutricote Black bag, 5000 portions of 5 g are available as for a bag of Nutricote Blue. This gives 5000 portions of 10 g Nutricote mixture. This means that 5000 portions of mixture have a cost price of EUR 230.61 or EUR 0.0461 per seedling (KES 5.5394). Assuming that spacing between the planted seedlings in the field is 3m x 3m, one seedling occupies 9 m^2. This means that a hectare can accommodate 1111 seedlings. At 10 g of slow release fertilizer mixture, 4,5 hectares can be planted with a cost price of EUR 230.61 for fertilization. With a spacing of 4m x 4m, 8 hectares can be planted with the same cost price of fertilization.

4 Tree improvement

4.1 Introduction

Timber species from the *Meliaceae* are very important for the forest industry of many counties. The continuous exploitation of natural forest stands has seriously reduced stocks of the timber species. Usually the best trees are cut down during exploitation so the number of superior genotypes is decreasing. The result is a consequent decrease of the gene pool of the exploited timber tree species, a process called genetic erosion. Mature trees of good form with superior wood quality that can be used for seed production and breeding remain only in isolated and places hard to access. The selection of these trees with superior genotype or so-called 'plus' trees creates a need for more knowledge of the reproductive biology of the trees (Styles, 1972). The goal of *M. volkensii* improvement programmes is to found new plantations that have trees of better quality in comparison to their predecessors in important economic traits. The fast growing character of *M. volkensii* is the most important one (Kariuki et al., s.d.), while stem form, branching habit and resistance to fungal diseases also has to be considered. The growth of these trees is even faster on plantantations than in the wild so that domestication of this species could mean a great potential increase. The biggest obstacle to the successful domestication of *M. volkensii* is the source of good germplasm because most superior trees have been cut down by local people (Muchiri & Mulatya, 2004).

4.2 *Meliaceae*

The *Meliaceae* are an important genus of woody plants and include more than 1400 species in 52 genera and the genus *Melia* includes 15 species and has 28 chromosomes. Within the family there's a big variation in chromosome numbers and it has a large number of polyploid species. This variation can be explained to loss of chromosomes or hybridisations and species with differing chromosome numbers can be found in several genera (Finkeldey & Hattemer, 2007).

The best known of al timber producing trees of the *Meliaceae* is the true mahogany, produced by the genus *Swietenia*. In the late 60s, accessible supplies of marketable trees were exhausted and only trees of poor form were remaining over large areas in Central and Southern America. Because of this, two species of *S. mahogany* were crossed and raised in plantations in several parts of the world to produce timber of outstanding quality. In this hybrid species, the best characteristics of both parents were combined: a faster growth rate of one parent and a denser wood of the other. It showed also a greater resistance to mahogany cancer (Styles, 1972).

Pollen distribution in an artificial clonal seed orchard of *Tectona grandis* is very restricted. This could mean that the gene flow in natural populations may be more efficient (Finkeldey & Hattemer, 2007).

4.3 Flower biology

Individual trees of *Meliaceae* can have male and female flowers or only one type of both and are either monoecious or dioecious. Very rarely, some species have functional hermaphrodite flowers and may be accompanied by male flowers. Trees belonging to genera *Melia* and *Azadirachta* carrying these flowers are called polygamous. In this case, great care will be necessary for the selection of the correct type of flower for pollination experiments (Styles, 1972).

4.4 Breeding

The purpose of breeding is to make use of genetic differences between individuals to increase yield. The success of tree plantations depends on the choice of suitable reproductive material such as seedlings from the nursery or collected seeds. Conventional breeding selection of trees is always based on the observation of phenotypic traits. Genetic markers are very important tools for genetic research of many organisms including tropical timber tree species. They are applied in breeding programmes for preservation of genetic resources (Finkeldey & Hattemer, 2007).

4.4.1 Seed source

The seed source can be a tree or a group of trees, which carries the fruits. Not every tree is suitable for forestry, so a good selection of the mother plant must be made. An appropriate seed source has to ensure genetic variation and quality. The genetic characteristics of the seed trees are expected to be transmitted to the offspring, so the selection of the tree seed source is based on this assumption. The fruits should be selected to criteria such as age, health, growth performance and size of the source. A safe judgement on health and performance of the source can be made by the age of the seed source. The state of health can be used as an identification of adaptability and resistance under a given environment. A big size of the source can provide a high number of genotypes and thus guarantee genetic variation. Isolated trees are not suitable for seed collection even if they carry numerous flowers and fruits. These trees can have the risk of being self-pollinated, which often results in a high percentage of hollow seeds, low germination rate and inferior health to the offspring (Omondi et al., 2004).

4.4.2 Collection of breeding material

Selection of plus material is from different provenances is the first step in a tree breeding programme (Bedell, 2006). During the collection of material for provenance trials, some guidelines must be applied: a minimum number of trees is necessary for the harvest of seeds. Seed harvest from closely related trees should be avoided so a certain distance between seed trees must be kept. The forest where the seeds for plantation establishment are harvested are often dependent for the performance of the tropical trees in the artificial plantations. If forest stands are artificially established by sowing or planting the choice of the provenances must be considered. One of the most important criteria to select *M. volkensii* provenances is the availability of reproductive material and this holds for many tropical tree species. An indispensable step in breeding programmes are the field trials where trees of different populations can be selected for the plantation. The most simple case of selection of plus trees is the immediate use of the seeds in the plantation nursery. The genotypes of these seeds are not the same as the genotype of the seed parent since the pollen contribution of unselected trees with the parent. (Finkeldey & Hattemer, 2007).

4.4.3 Field trials

The breeder is free to choose a mating systems depending on his purposes and several are available. In each mating system the breeder will combine traits of two different genotypes into a new individual by mating (Bedell, 2006).

The basis of breeding is the selection of single genotypes and the offspring of this genotype. The most frequent trial for this purpose in forestry is known as the half-sib progeny trial where progenies from single seed trees are compared. The selection of seed trees for tree breeding is based on the performance of the offspring. During the field trials, several traits are measured that characterize tree growth: plant height, stem diameter at breast height, stem volume and plant health, stem straightness and branching habit. There characteristics are influenced by genetic and environmental factors. The most important tests to investigate genetic components of economic important characteristics are the progeny tests where the traits of the offspring are observed. (Finkeldey & Hattemer, 2007).

Bedell reports that seed collection for provenance testing is done by collecting seeds from different populations covering the entire distribution range of the species. Depending upon the purpose of the test two methods can be followed: the seeds from all trees of one population are mixed together or the seeds from the best trees of one population are mixed together. The first test is used when genotypic variation in the distribution range of the species must be evaluated and the second test is used for plus tree selection and breeding (2006).

4.4.4 Genetic variation of *Melia volkensii*

Odee et al. (2006) investigated the genetic structure of nine *M. volkensii* populations from the Coastal and Eastern region of Kenya. Information of genetic variation can help in making choices on preservation of the genetic resources of *M. volkensii*. Conclusion of the study was that levels of genetic diversity ranged from 0,0663 to 0,1372 with a mean value of 0,0946. The genetic diversity of populations in the eastern region was almost double as high as the one of the populations in the coastal region. The suggestion was made that further research is necessary throughout the natural distribution of this timber tree species. This is important to fix the existing gene pool to speed up the conservation, improvement and sustainable utilization.

A larger genetic variation in the eastern regions could mean that genetic erosion in the past was higher than in the coastal regions. This could also mean that more genetic material is available is eastern regions, which is advantageous for the development of a potential breeding programme. Bedell (2006) says that mating between trees from populations with small genetic variation should be avoided since this increases the change of inbreeding and homozygosity.

5 Diseases in tree nurseries and plantations

5.1 Introduction

Within nurseries, diseases are an important limiting factor in the production of tree seedlings in all stages of tree development (James, 2006). Seeds, seedlings in the nursery and older trees can be attacked by fungal pathogens in various ways. Tropical forest plantations are often dominated by one tree species and provide a very large amount of biomass suitable for the host. Combined with the lack of diversity this can result in a population explosion of the pathogen that uses the trees as host (FAO, 2001).

5.2 Diseases of *Melia volkensii*

The last years there have been several reports of disease symptoms caused by fungal pathogens that affect growth and development of *M. volkensii*. Stem cancer and dieback disease affect saplings and mature trees of *M. volkensii*, sometimes causing the death of trees. Observations of the integrated pest management team of KEFRI show an increase in a variety of disease symptoms between 2000 and 2005 from 18 % to 35 %. Susceptibility to disease attacks of seedlings in the nursery is high and a fifth of the seedlings do not survive the first year of growth. Seeds, leaves, stems, roots and branches were equally affected by different fungal diseases (Njuguna, 2010). No further details about this trial are available.

5.2.1 Diseases affecting seeds, seedlings and trees

A range of diseases affects seeds, seedlings and mature trees: several species of *Fusarium*, *Botryosphaeriaceae*, *Aspergillus*, *Rhizopus* and *Penicillium* cause pre- and post-germination damping-off . Laemmlen (2001) defines damping-off as disintegration of stem and root tissue below the soil line. Germination potential of the seeds is limited by damping-off before emergence while damping-off after germination kills seedlings (Njuguna, 2010). Pre-emergence damping-off kills seeds or seedlings before they emerge from the growing medium while post-emergence damping-off causes rot to the seedling stem. 80% loss of the seeds sown can be reached (Sutherland, 1991) and this can even go up to 100% loss. Humid conditions are perfect for reproduction and spreading of fungi that cause damping-off (NAERLS, 1999). *Phomopsis* spp. is known to cause damping-off before and after germination in many plant species. Seed-borne pathogens are some *Fusarium* species and *Neofusicoccum parvum* and *Lasiodiplodia theobromae*, both genera of Botryosphaeriaceae. *Aspergillus*, *Rhizopus* and *Penicillium* are not seed-borne and are thus surface contaminants (Njuguna, 2010).

Rhizoctonia solani generally attacks tree seedlings near the surface of the soil and causes red to brown coloured stem lesions. Damping-off caused by *Pythium* spp. that survives as oospores in the soil usually begins as root rot. This pathogen attacks root hairs and tips and causes thus deterioration of the root system (Laemmlen, 2001).

Root collar rots, leaf blight, chlorosis, wilt, yellowing and powdery mildews are most common with young seedlings. The root collar rot on young sapling is caused by a combination of *Fusarium* spp. and *Botryosphaeria* spp. Stem, branches, twigs and shoots of mature trees are susceptible to stem cancers and dieback disease. The stem cancer causes stem deformation and internal rotting of the wood resulting in decreased value of the timber (Njuguna, 2010).

Njuguna et al. (2004) carried out a survey on *Melia* diseases in the nursery, on-farm and on-station trials and plantation between May 2003 and April 2004. Following disease symptoms were recorderd in the nursery: wilting, leaf necrosis and root collar rots or damping-off. *Fusarium* was the main cause of these disease symptoms. The symptoms on-farm and on-land were wilting, severe chlorosis, weak seedlings, powdery mildews, root collar rots, stem breakages, diebacks and gummosis. Gummosis is the production of a yellowish brown resin. Figure 5 shows a detail of the stem of a diseased *M. volkensii*. The infection was probably initiated due to thinning without the proper hygenic measures (Vandenabeele, 13 August 2010 – personal communication).

Figure 5: Details of a Melia volkensii stem with gummosis at Mukuyu farm in Kibwezi, Kenya (September 2010)

Laboratory research showed that four major groups of fungi were isolated from the diseased materials. The disease symptoms of these four groups of fungi are given in table 7.

Table 7: Disease symptoms and their corresponding pathogens (Njuguna et al., 2004)

Plant part	**Symptoms**	**Pathogen**
Stem	Root collar rots and wilting	*Fusarium sp.*
	Stem cancer	*Botryosphaeria sp.*
	Powdery mildew	Unidentified mildew fungus
Leaves and shoots	Blights	*Colletotrichum* and *Alternaria*
Branches and tips	Dieback	*Phomopsis sp.*

The four major groups of fungi causing disease symptoms are *Fusarium, Botryosphaeria, Colletotrichum* and *Phomopsis.* An unidentified mildew caused powdery mildew on the stem and *Alternaria* together with *Colletotrichum* also caused blights on leaves and shoots (Njuguna et al., 2004).

5.2.2 Stem cancer and dieback disease

Four agroforestry tree species (*Grevilea robusta*, *Senna siamea*, *Azadirachta indica* and *Melia volkensii*) are known to be susceptible for five fungal species that cause cancer and dieback symptoms in semi arid lands of Kenya and *M. volkensii* is the only native species of these four. The five fungal species are *Neofusicoccum parvum, Lasiodiplodia theobromae, Diplodia seriata*, *Botryosphaeria sp*. and *Phomopsis sp.* and are genera of the order *Botryosphaeriaceae*. *N. parvum* and *L. theobromae* showed early development of cancer in inoculated seedlings, with *N. parvum* the most aggressive pathogen on the tree species. Figure 6 shows a healthy (left) and diseased (right) *M. volkensii* tree planted at the same time.

Figure 6: A healthy and diseased Melia volkensii tree at Mukuyu farm owned by Jan Vandeabeele in Kibwezi, Kenya in August 2010

Inoculation with *D. seriata* and *Botryosphaeria sp.* showed a slower cancer development in seedlings. *D. seriata* was the least virulent while the other two pathogens showed moderate virulence (Njuguna, 2011).

M. volkensii showed a late response to inoculation of the five pathogens and showed lowest mortality since it was least susceptible of all four tree species. *Phomopsis sp.* does not cause symptoms on *M. volkensii* seedlings but it can be a weak pathogen on the species since it kills seedlings of *Azadirachta indica.* The reason for this lower susceptibility can be explained by an active defence mechanism also known as wound healing. *M. volkensii* showed highest wound healing incidences of all four tree species and is thus better adapted to environmental conditions in semi arid lands (Njuguna, 2011).

5.3 Managing diseases

5.3.1 Prevention

Disease prevention is a tactical management use to reduce the probability of the incidence of a disease or to create an environment that is not hospitable for the development of the disease (FAO, 2001). Disease prevention in forest nurseries is the best way to control fungi since the pathogens can spread rapidly and cause a lot of damage in a very short period. Successful control of diseases in the nursery includes the reduction of pathogen inoculum in the areas where seedlings are produced (James, 2006).

The seeds and seedling stage are the best stages for disease control in tree species since this is difficult when the trees have passed the seedlings stage (Njuguna, 2010). The use of pathogen-free seed is essential for seedling production within the nursery. Treatment with running water helps to reduce pathogen contamination of the seed coats and chemical treatments may be necessary if high levels of fungi are present (James, 2006). The use of systemic fungicides and maintenance of seedling hygiene at nursery stage is the important to avoid damping-off (Njuguna, 2010).

Once the seedling stem of a tree species becomes woody, incidences of post-germination damping-off decrease. The disease is thus favoured by management practices and environmental factors that inhibit woody stem development. One of these management practices is reputedly nitrogen fertilization of germinants and seedlings that make them succulent and more susceptible for damping-off (Sutherland, 1991). Restricted nitrogen fertilizer use during certain growth stages is a way to reduce mortality from disease. Young seedlings that are susceptible to damping-off should not be fertilized with nitrogen (James, 2006). Sowing of stratified seeds that germinate quickly and covering the seeds with a non-compacting material such as sand to make germination easier are two cultural practices that can contain mortality from damping-off (Sutherland, 1991).

5.3.2 Suppression

Direct disease control or suppression is a tactic against the disease and can be biological, mechanical or chemical (FAO, 2001). Chemical disease control should be used as a last resort and is specific to a particular group of fungi. An accurate diagnosis of the disease is thus essential (James, 2006). Fungicidal control of seeds is not an adequate method to fight damping-off since phytotoxicity kills more seeds and germinants as they protect from damping-off. The continuous use of fungicides used in seeds results often in pathogens that show resistance. Effective fungicides against damping-off should be used in rotation (Sutherland, 1991).

5.3.3 Pesticide use in *Melia volkensii* cultivation

Diseases of *M. volkensii* can be controlled using commercial fungicides that are commonly available. Tentative results from tests where pesticides such as benlate and lindane are used show progressive recovery in some diseases trees (Njuguna et al., 2004).

5.3.3.1 Lindane

Lindane is an organochloride molecule that is an insecticide and belongs to the GABA antagonists. These molecules interfere with the GABA-A receptors so that the inhibitory activity of the neurotransmitter GABA decreases. This leads to too much excitation of the postsynaptic membrane and causes the death of the insect. Lindane is a nerve poison and is active as contact and stomach insecticide. It interferes with the chloride channel of the postsynaptic membrane. In tropical countries, lindane is a popular insecticide used in agriculture and against disease vectors (Haesaert, 2009). However this molecule is forbidden because of its high toxicity and persistence.

5.3.3.2 Carbendazim

Bavistin is a broad-spectrum and systemic fungicide that is used for the control of fungal diseases in various crops. The active constituent is carbendazim and is a member of the benzimidazole group of fungicides (BASF, 2001). Members of the benzimidazole group interfere during the mitosis through forming a complex with β-tubuline proteins. Fungicides from the benimidazole group also interfere with other processes that require β-tubuline activity such as cell wall formation or cellular transport. Carbendazim is very persistent in the leaves, in the soil and has a half-life of 2 to 6 months. It's a systemic fungicide and works both preventive and curative: it's preventive in low doses and in higher doses it stops further development of the mycelium and sporulation. Carbendazim is effective against Ascomycetes but not against Oomycetes (Haesaert, 2009). Figure 7 shows the chemical formula of carbendazim.

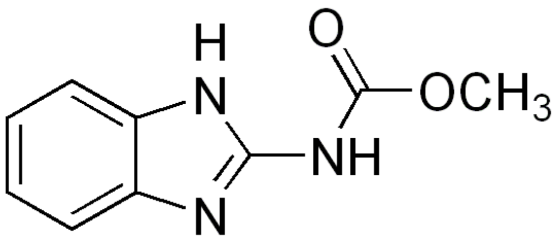

Figure 7: Chemical formula of carbendazim (Haesaert, 2009)

5.3.3.3 Benlate

The active constituent of benlate is benomyl and is a member of the benzimidazole group of fungicides (BASF, 2001). In plant cells, benomyl is converted to carbendazim. Benomyl is effective against a large number of Ascomycetes, a limited number of Basidiomycetes but not against Oomycetes (Haesaert, 2009).

II Experimental part

6 Better Globe Forestry Limited

6.1 Introduction

Better Globe Forestry Ltd. (BGF) is part of the Better Globe Group, which is settled in Norway. The Better Globe Group is doing business in Africa and they present themselves as a group of companies presenting a very powerful concept to fight poverty, improve the environment and make this world a better place to live for this and future generations. They concentrate on three different areas: children education, micro financing for agriculture and forestry. Since 2004, forestry is managed in Kenya by BGF through creating a pilot plantation in Katithini at Lake Kiambere. By hiring people to work at the plantation, BGF provides the local population with jobs so they can become self-sustainable. The company has an agreement with Kibwezi Mukuyu Farm for test and training purposes.

In 2008, BGF and the Kenya Forestry Research Institute (KEFRI) signed a Memorandum Of Understanding (MOU) in the area of cooperation in developing industrialized planting of *Melia volkensii* and *Jatropha curcas* in Kenya. From this time on, BGF has the full support KEFRI's knowledge and facilities. KEFRI was established in 1986 to carry out research in forestry and allied natural resources. The institute has a role to play in influencing policies on forest resource management (KEFRI). BGF also signed an MOU with the Kenya Forest Service (KFS). Since the beginning of 2009 BGF has launched Miti, the first tree business magazine for East-Africa.

6.2 Pilot plantation at Lake Kiambere in Kiambere

6.2.1 Site description

The pilot plantation of BGF is situated at Lake Kiambere. The Tana and Athi Rivers Development Authority (TARDA) owns the land. Lake Kiambere is one of the five artificial lakes in the area and is created by damming the Tana River for generating electricity. The Kenya Electricity Generating Company (KENGEN) generates the electricity and is the leading electricity generation company in Kenya. Figure 8 showes 2-year-old *M. volkensii* trees and gives an impression of the plantation at Lake Kiambere in september 2010.

Figure 8: Impression of the pilot plantation at Lake Kiambere, September 2010

Kiambere is a village in Mwingi district and is located 130 kilometres northeast of the capital Nairobi (Figure 9) with an elevation of 700 to 800 masl.

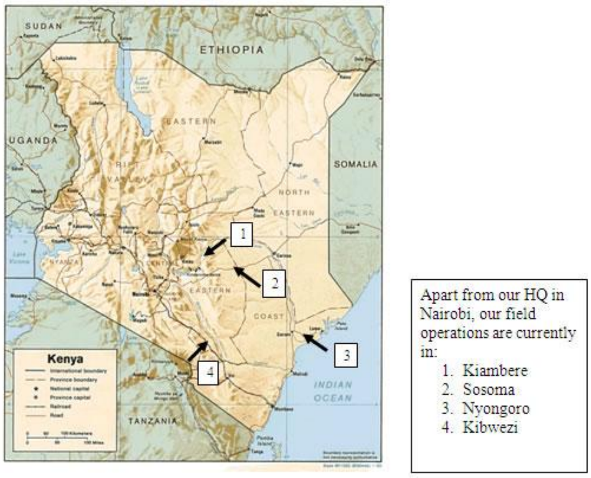

Figure 9: Pilot plantation at Kiambere indicated with arrow number 1 (source: BGF)

The agro-climatic zone map of Kenya developed by Braun (1980) divides the country in 7 agro-climatic zones from humid to very arid based on the average annual rainfall (r) and average potential evaporation (E_0). These agro-climatic zones are presented in table 8.

Table 8: Agro-climatic zones in Kenya (Braun, 1980)

Zone	Classification	r: Average annual rainfall (mm)	E_0: Average annual potential evaporation (mm)	Vegetation	Potential for plant growing assuming that soil conditions are not limiting
l	humid	1100-2700	1200-2000	moist forest	very high
ll	sub-humid	1000-1600	1300-2100	moist and dry forest	high
lll	semi-humid	800-1400	1450-2200	dry forest and moist woodland	high to medium
lV	semi-humid to semi-arid	600-1100	1550-2200	dry woodland and bushland	medium
V	semi-arid	450-900	1650-2300	bushland	medium to low
Vl	arid	300-550	1900-2400	bushland and scrubland	low
Vll	very arid	150-350	2100-2500	desert scrub	very low

In the humid (l) and sub-humid tropics (ll) of Kenya average annual rainfall normally exceeds average annual evaporation and the potential for plant growing is high. In the semi-humid, semi-humid to semi-arid, semi-arid, arid and very arid tropics average annual transpiration exceeds average annual rainfall. The potential for growing plants in the arid (Vl) and very arid (Vll) tropics is low to very low and not suited for agriculture. In the remaining agro-climatic zones (lll, lV, V) the potential for growing plants is medium. The pilot plantation of BGF is located in the semi-arid agro-climatic zone where average annual potential evaporation exceeds average annual rainfall. The main vegetation in these semi-arid regions is bushland and the potential for plant growing is medium to low (Braun, 1980).

6.2.2 Importance of the pilot plantation

The Tana River, which originates from the slopes of Mount Kenya, and its tributaries find their way to the lowlands through densely populated areas, carrying plenty of soil from erosion (BGF, 2012a).

Aware of their illegal status as unlawful resident, the farmers never invested in anti-erosion measures and soil fertility management, as they knew they could be evicted every day (Vandenabeele, 2009). After a major rain shower, thousands of tonnes of soil are washed into the lake due to strong soil erosion. This process is disastrous because it fills up the dam, reducing the lifetime for the power generation facility and reducing the capacity for provision of affordable electricity. Planting trees and blocking erosion gullies with thousands of check dams can stop erosion on the lakesides completely (BGF, 2012a). Soil conservation is truly important but rainfall is equally important as soil quality (Vandenabeele, 2009).

Poverty is widespread in the area, with over 65 % of the population living below the absolute poverty line, defined at an income of 1 USD per day (Vandenabeele, 2009). BGF provides work for 20 to 80 people, depending on the work, which depends on the season. Land preparation, tree planting and plantation maintenance are the most extensive tasks. Guarding the plantation day and night is also very important to prevent theft from the store and trees or to avoid tree damage by goats or other livestock. BGF is the biggest employer in the area and payment of the salaries is an important injection of cash into the local economy (BGF, 2012a).

6.2.3 Management

Since the foundation in 2006 of the plantation in Katithini, *Jatropha curcas*, *Azadirachta indica* (neem) and *Melia volkensii* have been planted. The pilot plantation covers an area of about 100 hectares and is the beginning of a planned 5.000 hectares plantation.
J. curcas covers approximately 54 hectares of the plantation while *A. indica* and *M. volkensii* each cover about 24 and 20 hectares respectively (Table 9).

Table 9: Different blocks of the pilot plantation in September 2010 (Nowak, 2010)

Block	**Spacing (m)**	**Seedlings**	**Area (ha)**
J. curcas 1	1.5x3.5	5,550	2.91
J. curcas 2	2x3.5	38,948	27.26
J. curcas 3	2.5x3.5	24,273	21.23
A. indica 1	4x4	14,665	23.46
M. volkensii 1	4x4	2,517	4.03
A. indica & *M. volkensii*	4x4	4,749	7.67
J. curcas trials	various	3,168	1.94
M. volkensii trials	4x4	4,937	7.90
TOTAL		98,807	96.40

Shortly, *Acacia senegal* has also been planted. Trials on germination and cultivation have shown that *M. volkensii*, planted for its superior mahogany-type timber, is the most successful of the different species. It can be planted year-round, provided it receives adequate care and irrigation. After 18 months, the seedlings attain a height of 3 metres, demonstrating its excellent growth. The seeds of *J. curcas* are used to produce bio fuel but it's not easy to sell them at a good price. Also, the tree is affected by a lot of pests and diseases. *A. indica* is used to produce oil, which is used in biological pesticides and has medicinal properties. Nowadays, the plantation is still populated with all these species, but in the future only new blocks of *M. volkensii* and *Acacia senegal* will be planted. *A. senegal* produces valuable gum arabic, a stabilizing agent that has many industrial applications in food, beverage and printing industry. *M. volkensii* and *A. senegal* are both extremely drought resistant and thus adapted to the hot and semi-arid environment with irregular rainfall (BGF, 2012b). Figure 10 shows a view of the pilot plantation at the Kiambere dam.

Figure 10: Satellite view of the pilot plantation of BGF (source: Google Earth)

7 Identification of organisms causing high mortality on *Melia volkensii* seedlings

7.1 Problem

Farmers in the arid and semi-arid lands of Kenya have reported incidences of *M. volkensii* disease attack in the nurseries. At the Kiambere site of Better Globe Forestry, these attacks mainly cause high mortality after germination and are responsible for very low germination rate. A nursery in Kibwezi suffered from the same problems, but disease attacks on the seeds was also determined. It is important to know whether these disease organisms are seed and/or soil borne to develop an appropriate decontamination protocol. This study was only carried out to identify the organisms causing a high mortality rate of the seeds and the seedlings from the Kiambere site.

7.2 Material and methods

The first step in this study was the search for affected seedlings in the greenhouses of the nursery. Symptoms were described and photographs were taken from affected seedlings. Figure 11 and 12 show pictures from affected roots of *M. volkensii* seedlings.

Figure 11: affected root of *M. volkensii* after germination

Figure 12: diseased and health *M. volkensii* seedling

Eight infected seedlings were sampled for analysis in the laboratory of the University College in Ghent where pathogens were cultured and identified using standard procedures.
The affected seedlings were cultured on two different types of agar: PDA or potato dextrose agar and phyto agar. For laboratory use, 39 g potato dextrose agar is suspended in 1 l of purified water. After that the solution is heated with frequent agitation and boiled for one minute to dissolve the medium. The final step is to autoclave at 121 °C during 15 minutes. The same procedure is required for phyto agar, but only 5 g of agar is suspended per litre of purified water. When the agar is cooled down the 45-50 °C, 15 to 20 ml of agar must be poured is a sterile petri dish. The affected seedlings can be placed in the petri dishes when the agar is solidified. After several weeks the organisms were identified in the laboratory.
The affected seeds were collected from the propagator and put away in an airtight bag. The seeds were examined for pathogens three days after collection at the laboratory of KEFRI in Nairobi. Figure 13 shows a picture of affected *M. volkensii* seeds that produce mycelium.

Figure 13: Infection of *M. volkensii* seeds in a nursery in Kibwezi

7.3 Results

Identification of organisms causing infected seedlings showed following results: the seedlings had traces of *Fusarium* sp., *Alternaria* sp., *Trichotecium* sp., *Botrysphaeria* sp. and *Diplodia* sp. Not all species are pathogens (Heremans, 29th of February, 2012 - personal communication).

Identification of organisms causing infected seeds was not possible. According to the KEFRI researchers too much time had passed between the sampling of the rotten seeds and possible identification of pathogens.

7.3.1 *Fusarium* sp.

Fusarium is a genus from the phylum *Ascomycota* and includes several important species that are pathogenic for plants: *F. graminearum* is one of the most common fungus species in cereals and maize and causes root rot. This species can cause severe economic damage and can produce mycotoxines that are toxic for humans and animals. Other species are *F. solani*, *F. oxysporum*, *F. poae* and *F. chlamydosporum*. Suppression against *Fusarium* can be chemical with a select number of triazoles such as metconazole, tebuconazole and prothioconazole. Crop rotation, removal of crops residues and the use of resistant varieties are measures to protect the plants from *Fusarium* infection (Haesaert, 2010). Further investigation of the infected *M. volkensii* seedlings is necessary to identify the correct *Fusarium* species.

7.3.2 *Alternaria* sp.

Alternaria is a genus from the phylum *Ascomycota* and includes pathogenic species such as *A. solani* and *A. brassicae*. *Alternaria* sp. causes brown dead portions of leaves on *Jatropha curcas*. This fungus causes defoliation of the plants because infected leaves are shed prematurely (Otieno and Mwangi, 2009). Figure 14 shows the disease cycle of *Alternaria* sp.: the spores are spread by wind and fall on the leaves of the plants where they cause black spots. These infected plants produce infected seed or infect other healthy seedlings causing spots on seedlings leaves. The spots turn dark brown and spores are ready to be spread again by wind. Azoxystrobine, prochloraz and boscalid can be used for chemical suppression against *Alternaria* (Haesaert, 2010).

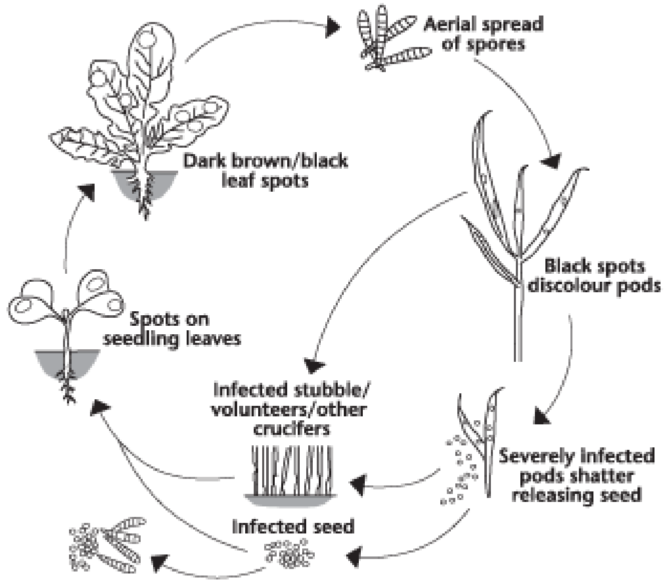

Figure 14: Disease cycle of *Alternaria* sp. (Haesaert, 2010)

7.3.3 *Trichothecium* sp.

There are no reports about *Trichothecium* sp. contamination on *M. volkensii* in Kenya. Nowak reports however an appearance of the fungi on *J. curcas* on the same plantation in Kiambere, Kenya (2010). Freeman and Morrison demonstrated that trichothecin, a substance isolated from *Trichothecium roseum*, has antifungal properties and is responsible for the antagonism exhibited by this fungi towards other fungi (1948).

7.4 Discussion

Fusarium sp., *Alternaria* sp., *Trichotecium* sp., *Botrysphaeria* sp. and *Diplodia* sp. are found on the infected seedlings. It’s not certain which of these organisms cause diseases on the seedlings. *F. graminearum* is a pathogen that causes root rot but is mainly a problem in cereals and maize so it cannot be said if the seedlings are infected with this fungus. The presence of *Fusarium* in *Melia* nurseries and farmland causing root collar rot and wilting is already reported by Njuguna et al. (2004). Njuguna also reports that some *Fusarium* species are seed-borne: this can explain the presence of *Fusarium* on the infected seedlings (2010). Further research is necessary to determine if the *Fusarium* species is in fact a seed-borne pathogen and how it can be treated.

The effect of *Alternaria* on the seedlings is not clear. Njuguna et al. report that *Alternaria* causes blight on leaves and shoots on *M. volkensii* farmland (2004). Nowak (2010) reports that *Alternaria* causes leaf spots and produces mycotoxines on *Jatropha curcas. M. volkensii* and *J. Curcas* are both present on the pilot plantation in Kiambere and can explain the presence of *Alternaria* on the seedlings.

Diplodia seriata and *Botryosphaeria* sp. inoculation shows a moderate development of cancer in seedlings with *D. seriata* the least virulent (Njuguna, 2011). Njuguna et al. also report that stem cancer on *M. volkensii* is caused by *Botryosphaeria* (2004). These studies show that *D. seriata* and *Botryosphaeria* sp. cause cancer on seedlings of *M. volkensii.* Further research can reveal how *D. seriata* and *Botryosphaeria* sp. can be treated to avoid cancer development.

Nowak suggests that *Trichothecium* sp. can be used as a biological product to control *Fusarium* sp. as this is a fungus that is very common in the area. Since this fungus with antifungal components is already present in the ecosystem it can be used effectively to control possible *Fusarium* sp. attacks (2010). Further investigation is necessary to improve disease control in the nursery and to prevent mortality.

8 Germination protocol for a successful *Melia volkensii* propagation

8.1 Problem

Farmers in the arid and semi-arid lands of Kenya report a low germination rate of *M. volkensii* seeds in the nursery. Diseases can cause this high mortality, but fruit and seed treatment, propagation management and treatment of the seedlings after germination are also very important. A study was carried out to develop a proper germination protocol to obtain maximum germination in the nursery.

8.2 Material and methods

To establish correct germination rate in the nursery of Better Globe Forestry in Kiambere, the number of seedlings out of 1 kg of *M. volkensii* was determined. One kg of *M. volkensii* fruits contains 40 to 50 fruits. Each fruit contains 1 nut, thus 40 to 50 nuts in 1 kg of fruits. As a nut contains an average of 1.44 seeds, one kg of fruits contains approximately 57 to 72 seeds. The seed losses through pre-sowing treatments cracking and slitting are respectively estimated at 20 to 25 % and 5 to 10 %. So after these seed treatments, 38 to 51 seeds are remaining. The average germination percentage in the nursery after planting is reported to be less than 10 %. This means that one kg of *M. volkensii* fruits produces less than 3 to 5 seedlings and the actual germination rate is somewhere around 5 %. As the fruits are bought per kg, it's very important to increase germination percentage through more careful pre-sowing treatment to obtain an economically successful nursery.

The first step in this study was to make an evaluation of the current propagation method at the Kiambere site of Better Globe Forestry. This evaluation was made during three weeks of co-operation in the nursery of BGF and exposed the bottlenecks of the propagation method. After this evaluation, a second evaluation of the propagation method was made in a *M. volkensii* nursery at Kibwezi, where germination percentages of 50 % and higher were achieved. The results of these two studies formed the base form the development of a proper protocol for a successful propagation of *M. volkensii* seedlings.

8.3 Results

The evaluation resulted in a protocol involving from fruit selection up to the planting of the saplings in the field. The protocol consists of four parts: a pre-sowing treatment, a sowing treatment, a post-sowing treatment and a post-germination treatment, where suitable treatments are presented per stage.

8.3.1 Pre-sowing treatment

Most important treatments before sowing are the selection of mature fruits and prevention of seed damage. A good germination can only be achieved with mature seeds. Seed damage is common with *M. Volkensii* seeds during cracking the nuts and breaking dormancy of the seeds. An experienced employee who handles the seed extractor can prevent the damage during nut cracking. Removal of the seeds can only happen after a few hours to prevent breaking of the seeds. Experienced employees must also do breaking dormancy by nipping and slitting without damaging the embryo. Table 10 shows the pre-sowing treatment of the *M. volkensii* propagation protocol.

Table 10: Pre-sowing treatment for M. volkensii propagation

PRE-SOWING TREATMENT	
Materials	Net, mortar and pestle, cloth, seed extractor, razorblades, fresh water.
STAGE	TREATMENT
Fruit collection	- Select mature (yellow to green with brown grey spots) fruits - Spread a net under the tree and hand pick the fruits or shake the branches of the tree
Fruit treatment	- Depulp with a mortar and pestle
Nut treatment	- Spread the wet nuts on a cloth in the sun, do not use plastic or synthetic material - Dry the wet nuts for several hours to a day - Crack the nuts with the seed extractor - Do not remove the seed immediately from the nut to avoid seed damage - Remove the seed from the nut after a few hours
Seed treatment	- Separate the brown from the black seeds - Dry the brown seeds for four days - Dry the black seeds for seven days - Place the seeds in the shade during the hottest period of the day - After drying carefully nip the top of the seeds with a razorblade without damaging the embryo - Soak the seeds overnight in fresh water - Slit the seeds once with a razorblade without damaging the embryo

8.3.2 Sowing treatment

The climate of propagators is an ideal environment for diseases because of high relative humidity and temperatures. Disease attack in propagators is known to be very high in *M. volkensii* nurseries so proper measures must be taken: disinfection of the soil, propagator and sowing medium with pesticides is necessary to prevent insect and fungal attack. Table 11 shows the sowing treatment of the *M. volkensii* propagation protocol.

Table 11: Sowing treatment for M. volkensii propagation

SOWING TREATMENT	
Materials	Watering can, fresh water, insecticide, propagator, sand and coarse sand.
STAGE	TREATMENT
Propagator treatment	- Disinfect the soil with an insecticide - Place the propagator on the soil - Disinfect the propagator with a fungicide - Treat the sowing medium (sand) with a fungicide and mix it with the medium - Put the sand in the propagator
Sowing	- Shape shallow grooves into the medium - Sow the seeds into the grooves - Cover the seeds with a thin layer of coarse and sterilized sand - Water till the sand is moist - Close the propagator

8.3.3 Post-sowing treatment

Propagators must kept closed as much as possible since germinating seeds are sensitive for sudden changes in temperature. Wind direction must also be taken into account so that wind can't penetrate into to propagator. Table 12 shows the post-sowing treatment of the *M. volkensii* propagation protocol.

Table 12: Post-sowing treatment for M. volkensii propagation

POST-SOWING TREATMENT	
STAGE	TREATMENT
Propagator treatment	- Keep the propagator closed as much as possible - Check the propagator every day and water it briefly if the sand is hard and dry - If necessary remove rotten seeds or fungus

8.3.4 Post-germination treatment

The seedlings are transferred from the propagator to poly bags filled with top soil and must be handled with care since to roots are sensitive. They are placed in an environment where wind is the most dangerous enemy; wind can cause breaking of the stem and evaporation of water. Watering the seedlings and protection from wind until lignification of the stem is thus necessary. Table 13 shows the post-germination treatment of the *M. volkensii* propagation protocol.

Table 13: Post-germination treatment for M. volkensii propagation

POST-GERMINATION TREATMENT	
Materials	Fresh water, watering can, mosquito nets, poly bags, top soil, rope.
Preparations	- Fill the poly bags with top soil
STAGE	TREATMENT
Germination	- Seedling are ready for transfer when they are green and erected
Seedling transfer	- Carefully remove the seedlings from the sand by picking them around the roots - Place the seedlings is a reservoir filled with water to avoid desiccation - Put the seedlings in poly bags filled with sterilized top soil
Protected seedling treatment	- Put the seedlings in a sterilized, shaded and wind protected environment (an setting covered with wind breakers such as mosquito nets) - Water the seedlings daily - Refill the top of the poly bags with top soil so that water doesn’t accumulate at the top
Unprotected seedling treatment	- When the stems of the seedlings are hardened (after two weeks) place them into the sun - Arrange the seedlings in a blocks of 10 by 100 - Arrange the weakest seedlings in the centre of the block - Water the seedlings daily - Refill the top of the poly bags with top soil so that water doesn’t accumulate at the top - Saplings are ready to be planted when the stem is lignified

8.4 Discussion

A proper protocol for propagation of *M. volkensii* will contribute to a more successful germination percentage in any nursery. Mortality of seeds and seedlings can be caused by many factors that are sometimes hard to control. Collecting mature fruits, breaking dormancy and preventing seed damage by working with experienced employees are the most important factors during the pre-sowing treatment to achieve higher rates of germination. Omondi et al. report that an important step during the production of good-quality seedlings is to collect fruits of good quality of a mature mother plant. The best period to collect the fruit is from April till August (2004). Dormancy prevents the seeds from germinating and several scarification protocols have been described. The protocol that has so far produced the best germination rates involves breaking of the top of the seed, soaking the seed in water overnight and longitudinal slitting of the seed. With this method a germination rate of more than 60 % is possible (Milimo, 1989) and Kyalo (2006) reports that a germination rate of 80 % can be achieved within 5 to 7 days. In the past, nurseries had a lot of trouble in seed extraction because of the stony nut. The only option back then was to crack the nut with a sharp knife and a hammer. But this technique often led to seed damage and sometimes injuries to the operator. In the 1990s, a more efficient extraction device was developed by KEFRI and the Japan International Cooperation Agency (JICA) and is called the *Melia volkensii* seed extractor (Lugadiru, 2006). Vandenabeele (2012) reports that seed losses in the nursery nowadays are less than in 2010 and that germination percentage is increased up to 50 %.

Disinfection of environment where seeds are sown is the key factor during the sowing-treatment to prevent seed losses. Kyalo reports that seeds must be sowed in a sterilised medium in the germination chambers where the temperature must be kept between 30 and 38 °C. He also recommends that the ambient humidity must be maintained high by covering the germination chambers with polyethylene sheets (2006).

Observations have showed that the seedlings should be pricked out immediately after emergence. To avoid loss of seedlings after transplanting, the soil that is used for potting must be well drained. Proper water management is essential to avoid water logging. The seedlings should be sprayed regularly with a plant fungicide to avoid losses through fungi, which is very common with *M. volkensii* (Kyalo, 2006). When lignification of the seedling stem starts they must be watered once every week until planting time (Juma, 2003).

This germination protocol can result in a higher germination percentage so that farmers in the arid and semi-arid lands of Kenya will stop using stem or root cuttings to raise trees on their farm that will compete with their cash crops. There is a difference in root architecture between 16 months old *M. volkensii* trees raised from cuttings and seedlings: cuttings from stem and root tissue rooted more shallowly and had a greater competitivity index (CI) than transplanted seedlings. These results suggest that trees raised from cuttings will interfere with crop yield in agroforestry systems since they root more shallowly. The use of seedlings to raise *M. volkensii* trees on farm will have a less negative impact on the yield of cash crops (Mulatya et al., 2002).

9 Impact of fertilization on *Melia volkensii*

9.1 Purpose

The goal of this study was to determine the effect of different quantities of fertilizer on the growth parameters of *M. volkensii* in the second year of growth and to determine the optimum quantity of fertilizer. This study is the follow-up on the fertilization study of Silke Nowak in 2009 (Nowak, 2010)

9.2 Material and methods

To determine the effect of the different quantities, two trials were measured. Mavuno fertilizer was used in both trials. This local fertilizer contains 10 % ammoniacal N, 26 % available P_2O_5, 10 % K_2O, 10 % CaO, 4 % MgO, 4 % S and the meso- and micro elements B, Mn, Cu, Mo and Zn.

9.2.1 Fertilizer trial 1

The first trail measured was to determine the effect of different quantities (0 g - 50 g - 100 g) Mavuno fertilizer on one-year-old *M. volkensii* trees planted in July 2009. Every treatment was repeated 4 times and the quantities of fertilizer were added near the seedling. The trees in this trial were planted in 12 blocks of 49 trees (7 by 7) each, so the growth parameters of 588 trees were measured. Figure 15 and 16 show the layout of the fertilization trial.

1 (0 g)	2 (100 g)	3 (50 g)	4 (100 g)
5 (50 g)	6 (0 g)	7 (0 g)	8 (100 g)
9 (50 g)	10 (0 g)	11 (100 g)	12 (50 g)

Figure 15: Orientation and numeration of the blocks and quantities of fertilizer in one block

1	2	3	4	5	6	7
14	13	12	11	10	9	8
15	16	17	18	19	20	21
28	27	26	25	24	23	22
29	30	31	32	33	34	35
42	41	40	39	38	37	36
43	44	45	46	47	48	49

Figure 16: Numeration of the plants in one block

From every tree, the total height was measured from the soil level up to the apical growing point. The stem diameter was measured with a calliper 150 cm above soil level (diameter breast height: DBH). During these measurements, a clear difference was visible between the leaf densities of the tree, so a leaf score was also given (Figure 17). This leaf score is a number from 1 to 4:
1: no to very few leaves
2: few to average number of leaves
3: average number of leaves
4: a lot of leaves.

Figure 17: Leave score of the *M. volkensii* fertilization trial, from 1 to 4

Dead trees and trees with a height below DBH are not included to calculate average values of the growth parameters. The results of this fertilizer experiment were statistically tested with the statistical program SAS. A One Way Anova was used to test the results and the output is added in Appendix I.

9.2.2 Fertilizer trial 2

The second trial that was measured, planted in October 2009, was executed in two phases: the first phase was a dosage of Mavuno fertilizer in October 2009 of two quantities: 50 g and 100 g (Treatment 1). Blocks 1, 2, 5, 6, 9, 10, 13 and 14 received a dosage of 100 g while the other blocks received a dosage of 50 g. After this treatment, no measurements were carried out to determine the effect of these quantities. The second phase was a dosage of Mavuno fertilizer in June 2010 of four quantities: 0 g, 100 g, 200 g, and 300 g (Treatment 2). Each treatment was repeated 4 times and the quantities of fertilizer were added in a circle around the seedling. There are thus 8 different fertilizer quantities applied in this trial: 50 g - 0 g; 50 g - 100 g; 50 g - 200 g; 50 g - 300 g and 100 g - 0 g; 100 g - 100 g; 100 g - 200 g; 100 g - 300 g.

The trees in this trial were planted in 16 blocks of 24 trees (4 by 6) each, so the growth parameters of 384 trees were measured. Figures 18 and 19 show the layout of the fertilization trial. This trial can reveal a possible fertilization protocol during the first two years of growth and whether the first dosage of Mavuno influences the second.

From every tree DBH and total height was measured from the soil level up to the apical growing point. Dead trees and trees with a height below DBH are not included to calculate average values of the growth parameters.

100 g		50 g	
1 (0 g)	2 (200 g)	3 (100 g)	4 (100 g)
5 (300 g)	6 (300 g)	7 (0 g)	8 (0 g)
9 (200 g)	10 (0 g)	11 (300 g)	12 (200 g)
13 (100 g)	14 (200 g)	15 (300 g)	16 (100 g)

Figure 18: Orientation and numeration of the blocks and quantities of fertilizer per block

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

Figure 19: Numeration of the plants in one block

The two dosages of fertilization make it impossible to draw conclusions based on a One Way Anova since the first treatment can influence the second. The layout of this fertilization trial has also a problem and figure 9 clarifies this: the number of trees fertilized with 50 g - 100 g is not the same as the number of trees fertilized with 100 g - 100 g. The same problem was recorded for trees fertilized with 50 g - 200 g and 100 g - 200 g.

To solve this problem the median of tree height and stem diameter of the control treatments (0 g of treatment 2) was measured. These medians, shown in table 14, are equalized to 100% and the growth parameters of the other trees are converted to the 100% of the medians.

Table 14: Medians of the growth parameters of the control treatment per dosage of treatment 1

	Treatment 2	
	0 g	
	Treatment 1	
	50 g	100 g
Height (cm)	240	246
DBH (cm)	1,6	1,9

The results of this fertilizer experiment were statistically tested with a Two Way Anova to investigate whether treatment 1, treatment 2 or interaction between these two has a significant effect on tree height and DBH. If there is interaction, a Tukey-Kramer test will show the differences between the fertilizer treatment. The output is added in Appendix II.

The blocks of this fertilizer trial are oriented on a slope which means that trees are planted on different altitude levels. The influence of the orientation of the blocks will be discussed in chapter 10: growth comparison of *M. volkensii* on different altitude levels.

9.3 Results

9.3.1 Fertilizer trial 1

The average height, stem diameter and leave score of the trees of the first trial are shown in figures 20, 21 and 22.

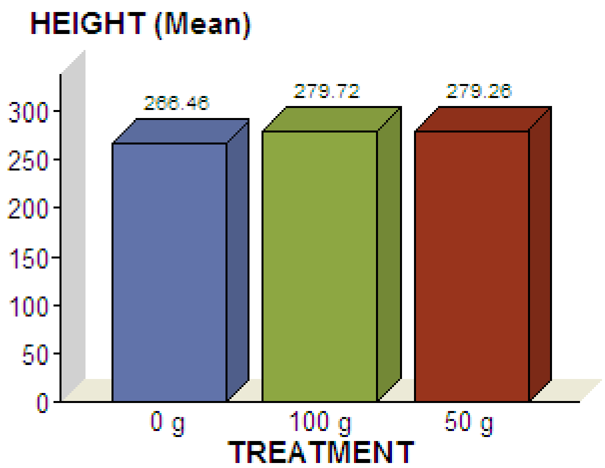

Figure 20: Average height of *M. volkensii* trees per treatment

The average heights of the trees of the 0 g, 50 g and 100 g treatments are respectively are 266.46, 279.26 and 279.72 cm.

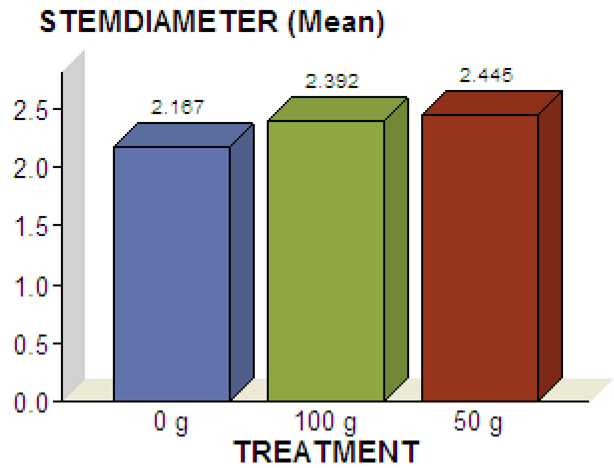

Figure 21: Average stem diameter of *M. volkensii* trees per treatment

The average stem diameter of the trees of the 0 g, 50 g and 100 g treatment are respectively 2.167, 2.445 and 2.392 cm.

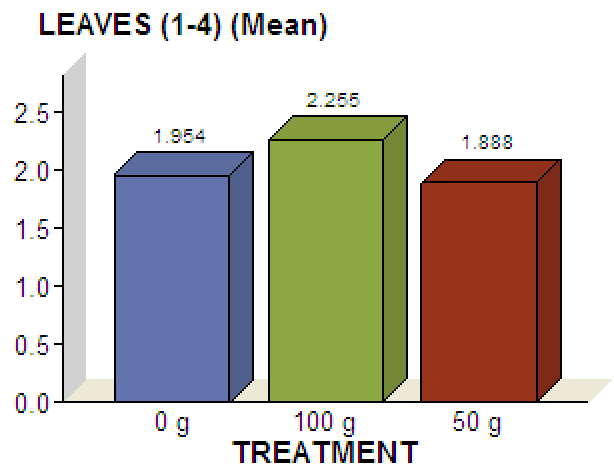

Figure 22: Average leaf score of *M. volkensii* trees per treatment

The average leaf scores of the trees of the 0 g, 50 g and 100 g treatment are respectively 1.954, 1.888 and 2.255.

The results show that the different quantities of fertilization still have an impact on the growth parameters of *M. volkensii*. The height, DBH and leave scores show a significant difference per treatment with a P value of respectively < 0,01 %, < 0,01 % and 0,04 % with a probability of 95 %. Important to notice is the effect of fertilization on the height of the trees during the second year of growth: in 2009 there was no significant effect of different quantities of fertilization on the height of the trees (Nowak, 2010). The results of 2010 show there is an effect of the different quantities during the second year of growth. Height and DHB differ significantly between the 0 g treatment and the 50 g and 100 g treatments. There was no significant difference between the 50 g and 100 g treatments, which show optimal conditions, with a small benefit for 50 g. Leave scores differ significantly between the 100 g treatment and the 0 g and 50 g treatments. There was no significant difference between the 0 g and 50 g treatment. 100 g seems the most optimal quantity for leave score, 50 g the least.

9.3.2 Fertilizer trial 2

The results show that the interaction between treatment 1 and 2 has a significant effect on tree height and DBH. There is no significant difference in height and DBH between treatment 50 g - 0 g and 100 g - 0 g. There is no significant difference of the growth parameters between treatment 50 g - 300 g and between treatment 100 g - 300 g. There is also no significant difference between these 4 treatments.

Results show that the 100 g - 100 g treatment produces the highest and widest trees, followed by the 100 g - 200 g treatment. The influence of the fertilizer treatments on height and DBH are shown in figures 23 and 24.

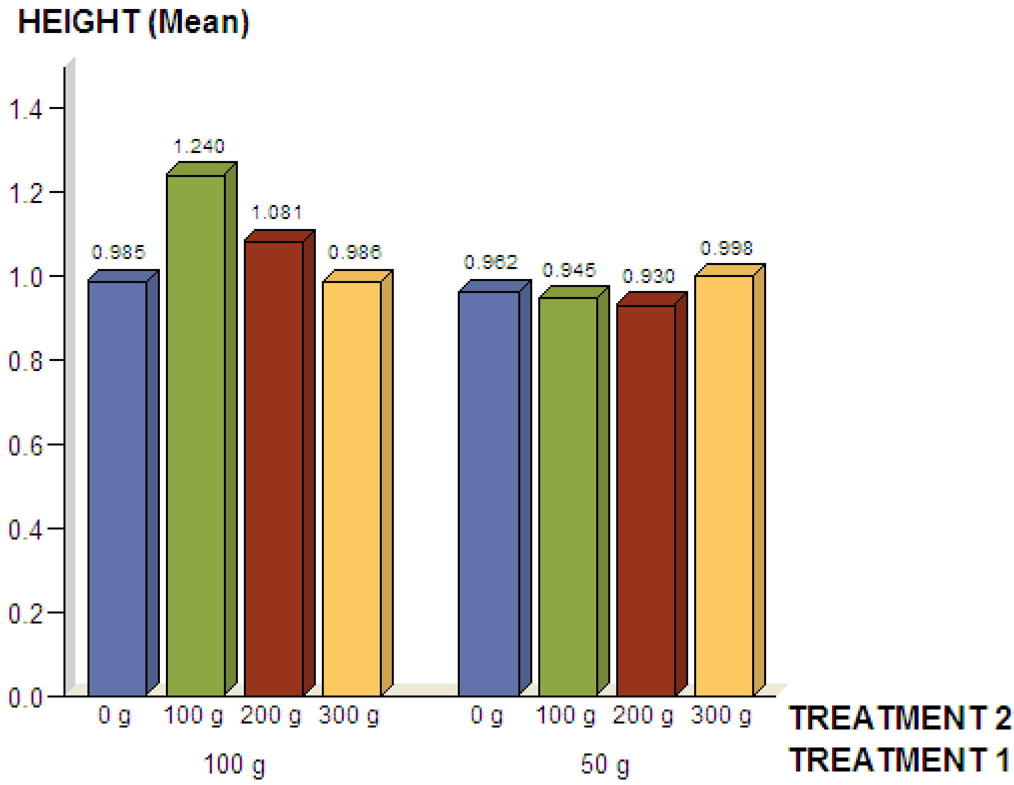

Figure 23: Effect of fertilizer treatment 1 and 2 on tree height of *M. volkensii*

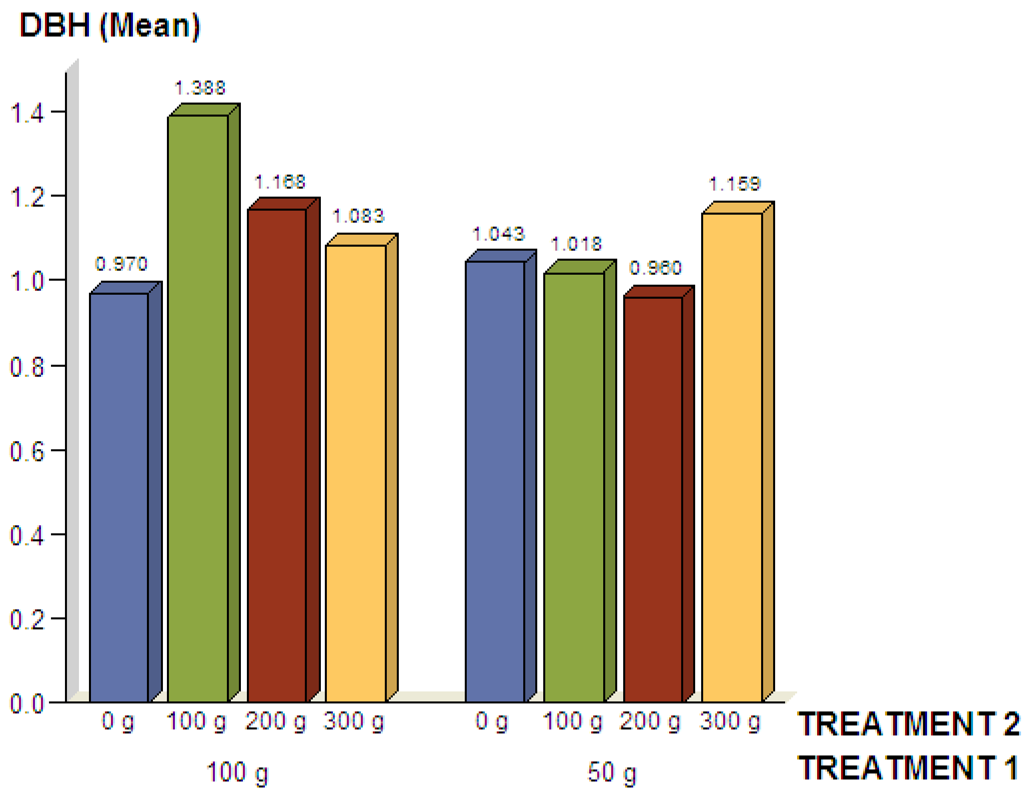

Figure 24: Effect of fertilizer treatment 1 and 2 on DBH of *M. volkensii*

9.4 Discussion and conclusion

9.4.1 Fertilizer trial 1

The results of 2010 show thus that different quantities of fertilizer have a significant impact on the growth parameters of *M. volkensii*. The results of this trial in 2009 showed that fertilization had an influence on a number of growth parameters of *M. volkensii*. The health of fertilized seedlings was significantly better compared to seedlings that didn't receive fertilizer. Seedlings fertilized with 50 g and 100 g showed no significant difference in stem diameter, leading to the assumption that 50 g is the most beneficial amount. The Mavuno fertilizer improved the growth of cambium, which is responsible for the increase of the stem diameter (Nowak, 2010). The results of 2010 show that 50 g of Mavuno still produces trees with the widest stem diameter. 100 g of fertilizer leads to a small decrease in stem diameter.

In 2009, an increasing tree height was achieved when fertilizer quantity increased from 0 g to 50 g. 100 g of Mavuno gave a decrease in tree height but was still better than 0 g of fertilizer (Nowak, 2010). The results of 2010 show that 50 g of fertilizer still has the most beneficial impact of height of the trees. 100 g of fertilizer also leads to a small decrease in tree height.

100 g of Mavuno fertilizer seems to have the most beneficial impact on the leaves, while 50 g has the least beneficial impact. Overall, 50 g seems the most beneficial treatment except for the leaves. The consideration has to be made whether the additional 50 g is worth the extra cost. The more leaves, the more photosynthesis a tree is able to do. A lot of leaves is optimal for photosynthesis but it seems that the least beneficial treatment for the leaves produces the highest and widest trees. A possible explanation can be that trees fertilized with 50 g of Mavuno are better protection against dehydration and shed their leaves immediately when they experience heat stress. At the beginning of the rainy season, new leaves can grow resulting in stronger trees. This is only a hypothesis and height and stem diameter are the two most important growth parameters for trees planted for timber production.

50 and 100 g of Mavuno fertilizer seem to have the most beneficial impact on height and stem diameter, with a small benefit for 50 g. This shows that 50 g of fertilizer applied during the first year of growth is the optimal amount for tree height and stem diameter.

9.4.2 Fertilizer trial 2

Trees fertilized with 50 g - 0 g, 100 g - 0 g, 50 g - 300 g and 100 g - 300 g have almost the same effect on tree height and stem diameter. This means that a second application of 300 g of fertilizer is economically not profitable and treatments with 300 g of fertilizer must no longer be applied in the future.

The 50 g -200 g treatment produces the least high and wide trees so this fertilizer treatment also must no longer be applied in the future.

The highest and widest trees received 100 g - 100 g followed by trees received 100 g - 200 g. The best fertilizer programme for young *M. volkensii* trees in the field is 100 g of Mavuno during the first year of growth and 100 g during the second year of growth. Further experiments are necessary to investigate long term effects of fertilizer on growth parameters of *M. volkensii*.

10 Growth comparison of *Melia volkensii* trees on different altitude levels in the plantation

10.1 Purpose

The growth of *M. volkensii* trees of the same origin is not homogenous on the pilot plantation in Kiambere. The purpose of this study is to examine if trees planted on different altitude levels in the plantation show a difference in tree height, stem diameter and growth of leaves.

10.2 Material and methods

Examination site for this study is the trial fertilized with 0 g - 100 g - 200 g - 300 g Mavuno fertilizer. Two samples were taken from the trial: a sample from block M4 and a sample from M13 (Figure 25). These soil samples are respectively taken at the highest and lowest point on the plantation and have received the same amount of fertilizer in June 2010. Following tree characteristics were measured: height, diameter breast height (DBH) and leave score. The height of the trees was estimated since there was no material available to measure trees. The DBH was measured at a height of 150 cm. A leave score was given between 1 and 4. A One Way Anova was used to determine if there's a significant difference in tree characteristics between the trees of block M4 and M13. Trees lower than 150 cm are not included. The SAS output is added in Appendix III.

	slope				top
slope	M1 (0 g)	M2 (200 g)	M3 (100 g)	M4 (100 g)	slope
	M5 (300 g)	M6 (300 g)	M7 (0 g)	M8 (0 g)	
	M9 (200 g)	M10 (0 g)	M11 (300 g)	M12 (200 g)	
	M13 (100 g)	M14 (200 g)	M15 (300 g)	M16 (100 g)	
valley		slope			

Figure 25: Orientation of blocks M4 and M13 on the trial site

In addition, soil analyses will reveal whether the nutritional elements in the soil, pH, CEC and EC of the soil are influenced by the orientation of the blocks. A pit of 15 cm depth was dug in each plot and a topsoil sample was taken.

10.2.1 N and P

The chemical analysis of the soil sample was carried out in the LCA – University College of Ghent (Laboratory for Chemical Analyses). Total amount of N was determined with the Dumas method with Variomax. Available P was measured with the Bray 2 method.

10.2.2 CEC and exchangeable cationes

CEC and exchangeable cationes Ca, Mg, K, Na were determined with an extraction with ammonium acetate buffer (1M, pH 7) and percolation.

10.2.3 pH

The pH gives an indication about the nature of the salts that are present in the soil (Baert, 2010).
The pH of the soil samples was measured in the laboratory of food industry at the University College of Ghent. After adding 25 g of KCl (1M) to 10 g of soil sample, the suspension is shaken for 30 minutes. The pH was measured with a pH electrode.

10.2.4 Electrical conductivity (EC)

Measuring the EC gives information about the total amount of soluble salts in the soil. The international parameter for salinity of soils is the EC measured in a saturation extract (ECe). The preparation of this extract takes a lot of time and is very subjective so the EC is measured in an aqueous soil extract and converted in ECe (Baert, 2010). The EC of the soil samples was measured in the laboratory of food industry at the University College of Ghent. A suspension of 10 g soil sample and 20 g distilled water was made; thereafter the EC was measured with an EC electrode.

10.3 Results

10.3.1 Growth parameters of *M. volkensii*

The results of the height, DBH and leave score are presented in figures 26, 27 and 28. The results of the One Way Anova show that there is a significant difference in height, DBH and leave score between both blocks.

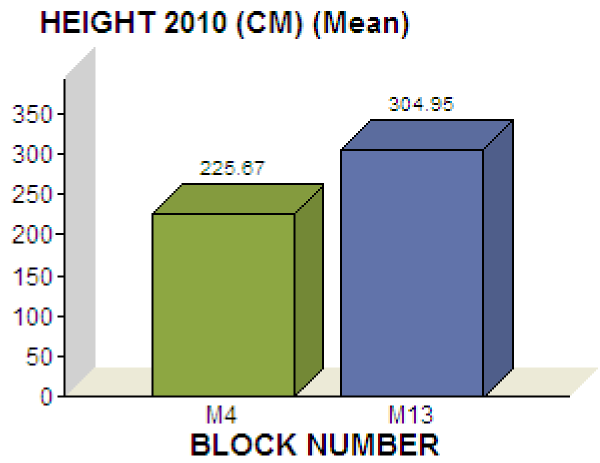

Figure 26: Average height of the *M. volkensii* trees

The average height of the trees in M4 and M13 is respectively 225.67 and 304.95 cm which means that trees of block M13 are 26 % higher than those of block M4.

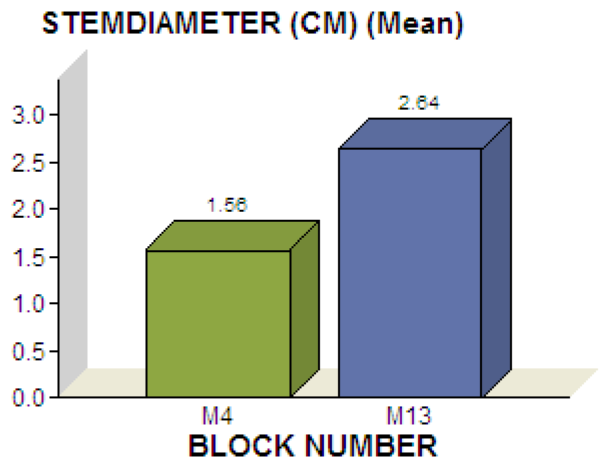

Figure 27: Average DBH of the *M. volkensii* trees

The average DBH of the trees in M4 and M13 is respectively 1.56 and 2.64 cm which means that trees of block M13 are 41 % wider than those of block M4.

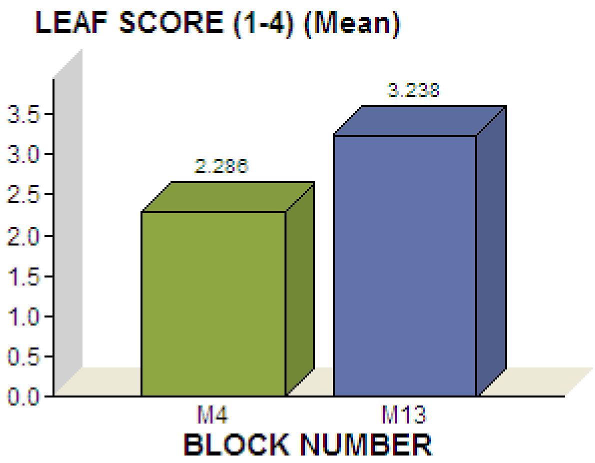

Figure 28: Average leave score of the *M. volkensii* trees

The average leave score of the trees in M4, M10 and M13 is respectively 2.286 and 3.238 which means that the average leave score of the trees of block M13 is 29 % higher than block M4.

10.3.2 Chemical soil analysis

The results of the soil analysis are presented in table 15.

Table 15: Results of the chemical analysis of the topsoil samples

	C (%)	N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	CEC (meq/100 g)	pH	EC (μS/cm)
Topsoil sample M4	0.402	0.045	106	167	1290	296	23.1	7.9	5.53	63.8
Topsoil sample M13	0.402	0.051	45.7	178	899	256	22.2	8.7	5.38	103.9

The chemical analysis of the topsoil samples show that the amounts of C, N, K and Na are approximately the same in both samples. The amount of P in block M4 (106 ppm) is more than the double amount of P in block M13 (45.7 ppm). The amount of Ca in sample M13 (889 ppm) but is approximately 30 % lower than in sample M13 (1290 ppm). The amount of Mg in sample M4 (296 ppm) is slightly higher than is sample M13 (256 ppm). The acidity, with a pH value of 5.53 for sample M4 and 5.38 for sample M13, is approximately equal in both soil samples. There's also a small difference in CEC values between both samples with a value of 7.9 and 8.7 meq/100 g for samples M4 and M13. The lowest EC is measured in block M4 and has a value of 63.8 µS/cm while the highest EC with a value of 103.9 µS/cm is measured in block M13.

10.4 Discussion

There is an significant difference in average tree height, average DBH and average leave score between the investigated blocks: trees of block M13 are the highest, have the widest DBH and have the highest leave score. The amounts of C, N, K and Na of the blocks are approximately equal so it's likely that these elements are not responsible for the difference in three heights.

The amounts of P, Ca and Mg are the lowest in block M13: this could mean that a higher concentration of one or more of these elements can cause a lesser tree growth and smaller DBH. This may be the case in block M4 where concentration of P is the highest and were average tree height is the lowest and average DBH is the smallest. The amount of Ca in block M13 is lower than in block M4: this can also cause the higher average tree height and bigger BDH of the trees in block M13. This is just a hypothesis and it's very difficult to determine if the results of the soil analysis can be related to the growth parameters of the trees.

The results of the EC indicate that the salinity effects on the young trees are negligible (Baert, 2010). There is only a small difference in pH between the soil samples; this could mean that the acidity of the soil in not influenced by the orientation of the blocks on the slope.

Other factors can also cause the difference between the trees of the measured blocks: fertilizer or organic matter run off can influence the tree characteristics in these blocks. Block M13 can receive fertilizer and organic matter of upper, adjacent plots while M4 can lose fertilizer and organic matter.

The difference between the trees of the blocks is probably due to the different amount of fertilizer applied in October 2009 when the trees of block M13 received 100 g fertilizer and the trees of block M4 only 50 g. It's only possible to draw conclusions when trees are fertilized with the same amount of fertilizer. Further research is necessary to determine the effect of different altitude levels in a plantation on equally treated trees.

11 Evaluation of *Melia volkensii* plus trees around Mumoni Forest

11.1 Purpose

Some natural tree populations have good plus trees that are comparable or better than trees on farm, even without management, and represent good gene pools for the species. (Kariuki et al., s.d.). Nowadays, *M. volkensii* trees are heavily overexploited in the arid and semi-arid lands leading to erosion of the species' genetic variability. A survey was carried out to identify and select superior *M. volkensii* trees or ‘plus’ trees around Mumoni forest: potential ‘plus’ trees were evaluated on farmland and in natural populations. In the future, the seeds of these selected trees can be used to cultivate trees of good genetic quality so the genetic material of these superior trees can be preserved.

11.2 Material and methods

The first two activities in search of potential plus trees are carrying out a survey to identify potential areas and making a selection of candidate trees from these areas (Kariuki et al., s.d.). Mumoni forest was chosen as survey site to look for superior trees. A previous survey to confirm availability of *M. volkensii* indicated that a lot of trees of good quality were present in this area.

The following two activities during the selection of potential plus trees are making a comparative assessment of the selected trees and describing characterization of the site (Kariuki et al., s.d.). An evaluation sheet was developed to collect data from the trees and the site. The evaluation form is added in Appendix IV.

During the four-day lasting survey, tree and site characteristics were recorded in the evaluation form. The age of the trees was estimated with help of local farmers who lived for decades in the area and a specialist who worked with *M. volkensii* trees for many years. The DBH (diameter breast height) or stem diameter at 150 cm height was measured using diameter tape. The total and bole height of the trees couldn't be measured exactly because there was no hypsometer available, but a good estimation of both parameters was made. Branching habit, presence of flowers, fruits and leaves and canopy characteristics were also noted. Tree geographical data such as altitude, longitude and latitude were collected using GPS, which is useful in the future when the trees are chosen for an actual breeding programme. All selected trees were given a number and four photographs were taken: one of the entire tree and its environment, two of the bole and one of a special characteristic (stem close-up, damage or canopy).

After the survey, a more thorough selection of the chosen 'plus' trees was made to separate the superior trees from the other trees. This selection process was based on three steps: the first step was a selection based on the estimated age of the tree. Trees with an estimated age older than 20 years were automatically removed from the potential breeding list. Most farmers in the region cut down their *M. volkensii* trees once they've reached this age. Farmers in the area report that after 20 years the quality of the wood deteriorates due to ring crack in the middle of the stem (Figure 29). This ring crack reduces the yield of available timber so the farmers earn less money.

Figure 29: The remains of a 20-year-old *M. volkensii* suffering from ring crack

After this first selection, the estimated bole height and DBH were used to make a second selection. Trees with an estimated bole height higher than 5 m, a DBH wider than 28 cm and a straight bole were selected. These trees were chosen because they can produce a lot of good quality timber. The final step in the selection process was an elimination based on the photographs made on site.

11.3 Results

11.3.1 Selection of plus trees

After the survey, 71 trees of good form were located and identified. A good breeding programme acquires only the most superior trees, so a selection of these 71 trees was made. Five of the 71 trees were estimated 20 years or older, so they were eliminated from the potential breeding list. One of these trees was already cut down during the survey. The second selection step excluded another 28 trees from the potential breeding list, remaining 38 potential plus trees. After the final elimination, 8 of the 71 selected trees or 11.27 % was still remaining. The trees selected for a further breeding programme are presented in table 16. The photographs of the trees are presented in figures 30 to 36. A clear photograph of tree number 40 was not available.

Table 16: Potential plus trees selected around Mumooni forest

Tree number	Estimated age (years)	DBH (cm)	Estimated bole height (m)	Estimated height (m)
20	17	35	7.0	14
22	14	29	7.0	15
32	12	27	6.5	12
37	13	26	7.0	14
40	14	28	10.0	15
49	15	33	6.0	13
59	13	26	5.5	12
60	10	23	5.0	11

Figure 30: Tree number 20

Figure 31: Tree number 22

Figure 32: Tree number 32

Figure 33: Tree number 37

Figure 34: Tree number 49

Figure 35: Tree number 59

Figure 36: Tree number 60

Al these eight trees were found on-farm and not in natural populations: trees number 20 and 22 are situated on a farmland where maize and peas are grown. The owner of the trees sells the fruits and wants to cut down the trees before the age of 20 years. The straight, thick and long bole of both trees are ideal for further breeding of the species. At first sight, tree number 22 didn't qualify for a breeding program because its crooked position probably due to wind or wrong method of planting. Further examination made clear that the characteristics, the straight bole and its length, of this tree are perfect for a further breeding programme. Tree number 32 is located in a secondary bush where other trees are planted like mangos. The owner of this *M. volkensii* wants to cut down the tree and sell the timber when financial difficulties should occur. A farmland with maize, green grams and beans is the habitat of the numbers 37 and 40 but both trees are on different sites and have different owners. In the future, they want to cut down the tree for selling the timber. Most crucial in their selection was the length of the straight bole, which is respectively estimated at 7 and 10 m. Tree number 49 is situated on a farmland and is surrounded by mangos, peas, maize and other *M. volkensii* trees. Production of timber is also the reason why the owner keeps these trees. Trees 59 and 60 were eliminated during the first two selection steps, but were eventually selected based on the photographs. Both trees have a long and straight stem, which is ideal for a timber producing species. The former is situated in secondary bush while the latter on a farmland with maize. Like all previous trees, the owners want to cut down the trees and sell the timber.

11.3.2 Genetic improvement

Kariuki et al. (s.d.) have divided the genetic improvement of *M. volkensii* in 4 specific objectives: the first objective is selection of 'plus' trees in natural and on-farm populations. The survey carried out in Mumoni forest is thus part of a larger purpose and a selection was made based on only the estimated tree age, stem height and stem diameter at breast height. Other traits must also be used during the selection of possible 'plus' trees.

According to Kariuki et al. following traits are the most important: stem form, growth and vigour, disease resistance, spiral grain tendency, branching habit and crown diameter and volume. Following 3 objectives are activities that must be carried out in the future: propagation and conservation of the selected trees, seed collection for half-sib progeny tests and the assessment of potential tissue culture use for propagation of high value plus trees (s.d.).

11.3.3 Ring crack

The circle shaped crack in the stem of the older *M. volkensii* trees is a phenomenon also known as ring crack or heart crack and the cause of this symptom is not always clear. It is possible that multiple causes could affect the tree leading to this phenomenon: a disturbance of the growth rate due to physiological drought or significant damage such as sudden branch mortality, severe pruning or root rot (Peyman, 23rd of November, 2011 - personnel communication). The ring crack could also be due to damage such as fire in an early growth stage (Beeckman, 13th of November, 2011 - personnel communication). Trees generate an active response on injuries and form a reaction zone against the expansion of these injuries. When a tree is actually injured the cambium releases special cells that form a barrier. This barrier separates the wood present at the moment of the injury from the later developed wood and is the final defence mechanism of the tree. This barrier can form a closed circle and is mechanical weaker than the surrounding wood so sometimes ring cracks occur along the barrier zone (Agentschap voor Natuur en Bos, 2008).

11.4 Discussion

After the survey in and around the Mumoni forest, 71 potential ‘plus’ trees were selected. After a more thorough selection based on tree characteristics (bole height and DBH) and photographs, 63 trees were eliminated from the potential breeding list. This means 8 trees or 11,28 % of the selected trees are chosen for a potential breeding programme. These selected trees are found on farmland and not in natural stands. This supports the theory of Kariuki et al.: on farm *M. volkensii* trees in Mbeere are of good form and vigour. This could be attributed to the presence of other timber tree species like *Grevillea* and *Eucalyptus* leading to lower levels of genetic erosion of the species on farmland. Other sources of available income can also be a possible explanation for the higher genetic diversity on farm (s.d.). Trees older than 20 years are mostly cut down by the owner for timber.

The selection based on estimated age, stem height and stem diameter is not perfect: direct comparison of growth traits such as height and diameter may not be used as a criterion due to possible differences in ages (Kariuki et al., s.d.). The selection of these possible plus trees is only the first step in genetic improvement of *M. volkensii*. Bedell reports that the selection of desirable genotypes is problematic since the heritability is less than 100 % and the effect of dominant alleles. The number of selected trees should be high to avoid inbreeding and maintain heterozygosity (2006).

Kariuki et al. (s.d.) report also that the best genetic material has already been cut down but some trees of superior quality in wild populations and natural parks may still contain adequate gene pools for improvement of the species.

Further surveys around Mumoni forest and other areas are necessary to document traits of other potential plus trees on farmland, natural populations and natural parks. Bedell (2006) reports that if a systematic survey is carried out for selection of plus trees, differences in easily recognisable traits can be documented.

12 Case study: A guideline for a successful *Melia volkensii* nursery

12.1 Problem

M. volkensii can become one of the most important and profitable trees in the arid and semi-arid lands of East-Africa. Commercial nurseries and plantations of this tree can provide work for a lot of people as the trees are beneficial for the poor soil and in long term the nursery can become very lucrative.

Most people in the arid and semi-arid lands are very poor and haven't got proper education. The unemployment percentage is very high in most areas, sometimes up to 65% or more (Deprins, 2009) and people who are employed don't make a lot of money. For example, the estimates of an average annual income per annum per person in the Ukambani districts are 13,964 Kenyan Shillings per person, which is less than the absolute poverty line (Wekesa, 2009).

A small scale nursery can easily provide employment for 3 to 5 people, but even with the proper knowledge of the ecology of *M. volkensii,* it's almost impossible to start propagating and planting *M. volkensii* without any knowledge of the financial side of this business.

12.2 Material and Methods

This case study is based on a successful *M. volkensii* nursery in Kibwezi, Kenya managed by a man named Jonathan Kituku. He started his nursery in 2005 and is now the most successful grower in the area. Moreover, he trains other farmers who want to start propagating *M. volkensii* seedlings by themselves.

During a period of two weeks, Kituku and his employees have been questionned, followed and assisted to obtain maximal information about the installation and management of the nursery. The most important part during this two weeks was to gain Kituku's confidence to question him about his financial input for the foundation of his nursery, as well as the payment of his employees and other supplies such as tools, fuel, water, etc. Co-operating in the nursery during these two weeks also gave a good outline regarding management and labour in a successful nursery.

Al these elements were combined in a simple business plan that can be a very helpful tool for people in the arid and semi-arid lands of East-Africa who want to crawl their way out of poverty by planting *M. volkensii*. It provides the beginning entrepreneur with essential management and financial information.

12.3 Results

The results of two weeks in Kibwezi are presented in following topics, which form the base of a solid business plan: mission statement, target, product, market, human resources, starter formalities and financial plan.

12.3.1 Mission Statement

The main goal of a commercial nursery is to provide the local people with an income by selling seedlings.

12.3.2 Target

To describe the exact target of a commercial nursery, it's necessary to take the SMART principle (Specific, Measurable, Attainable, Realistic, Time) into account. With this principle it's possible to test if the commercial nursery has a chance to succeed in its goals.

12.3.2.1 Specific

A commercial nursery aims at making profit by selling seedlings to local farmers. This means profit in short term for the owner and his workmen in the nursery but also in long term for the local farmers. Each year they can buy some seedlings and after a period of ten to fifteen years they can sell the wood for timber, if they take good care of the trees.

12.3.2.2 Measurable

During the process of propagation, the owner and the workmen have to pay attention because problems can occur. The most troubling problem is the loss of seeds and seedlings due to management issues. As soon as a problem has been determined, the nursery management can adjust this to prevent further problems in the future.

12.3.2.3 Attainable

It's only possible to take good care of the customers if you take good care of your workmen so a good working environment is essential. Therefore, it's necessary to choose employees who can be trusted, are motivated to work and eager to learn.

12.3.2.4 Realistic

To test the feasibility of the commercial nursery, it’s necessary to present a business plan. This financial plan is a study of all the possible costs and incomes of the project and must show that the nursery can be profitable with a small margin of profit. In the future profit can rise with an increasing customers base and increasing production.

12.3.2.5 Time

The propagation of *M. volkensii* seedlings is time-related, so it's important to know when it's best to start with the production of the first seedlings. According to the successful grower in Kibwezi, Kenya, the best period to produce the seedlings is from May until October. So at the beginning of May, all required resources have to be in place. To prevent loss during the first year of production, it's necessary that the nursery can produce seedlings when the growing season starts.

12.3.3 Product

12.3.3.1 SWOT analysis

The SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) indicates the benefits and disadvantages of the beginning nursery. If this analysis is taken into account, it's possible to optimise the project by strengthening the benefits and improving the disadvantages.

12.3.3.2 Strengths

The following questions can help to determine the strengths of the nursery: what are we good in and what is our major strength? The major strength of a *M. volkensii* nursery in arid and semi-arid tropics is without doubt the production of tree seedlings that can grow in this dry environment, which is hostile for most food crops and tree species. Another strength is the resistance of *M. volkensii* against insects, particularly termites.

12.3.3.3 Weaknesses

Propagation of seedlings has also its difficulties: the major problems are the germination percentage of the seeds and the presence of good quality seed. The presence of fungal and bacterial diseases is a major constraint in *M. volkensii* nurseries. Other factors such as temperature, humidity, water management, wind and other natural influences determine whether the seeds germinate or not. The relative high price of the seedlings can also be a problem for the farmers.

12.3.3.4 Opportunities

Primarily, a study must be made of the environment where the nursery will be build. Because natural influences are difficult to control, a setting with optimal environmental factors for the seedlings is essential for the nursery. Since nature and environment are hard to control, management is very important in a nursery. Secondly, commercial *M. volkensii* nurseries are rarely seen today so it can be a targetable part of a market.

12.3.3.5 Threats

The major threat, mentioned earlier, is the low germination rate of the seeds in the green houses, which can cause a major setback during the first years of production. A second threat

is the period between November and April, when the propagation of *Melia* is less or not productive due to weather conditions.
A second major threat is the diseases occurring during propagation of the trees. The planted seeds in the green houses and the seedlings in the nursery are very susceptible to infection of fungal diseases that can cause a high mortality rate.

12.3.4 Market

12.3.4.1 Market Research

It's important to do a market research before the start of a commercial nursery. First of all this includes a survey whether a commercial tree nursery is already in place. If so, price and quality of the product will determine which nursery will be most successful. Secondly a survey must be carried out with the local people. It's essential to know whether farmers are interested in buying seedlings. Another important factor is the presence of *M. volkensii* seed sources in the area. If not, transportation costs will be high and can become a constraint for an efficient nursery.

12.3.4.2 Costumer

The costumers of a *M. volkensii* nursery in arid and semi-arid lands are mostly poor farmers so it's necessary to adapt the prices of the seedlings to these people. In some cases, the price of a seedling can be adjusted to the level of poorness, but this can be risky: when other costumers become aware of this price difference, it's possible they will buy seedlings from another nursery or demand lower prices for themselves.

12.3.4.3 Value of the Product

A *M. volkensii* seedling has a multiple value: during its growing process, the seedling will capture carbon dioxide, which has a negative effect on global warming, through photosynthesis. *M. volkensii* is a good grower in arid and semi-arid lands, so farmers can plant the seedlings in fields where other crops can't survive. After 10 to 15 years they can sell the wood, which can be used as termite resistant timber. According to a successful *M.* grower in Kibwezi, Kenya, the value of 40 cm thick *Melia* tree is estimated at 5,000 to 6,000 Kenyan Shillings (36 to 43 EUR) per piece, while processing them into timber with a chainsaw would push the value up to 12,000 to 14,000 Kenyan shillings (87 to 102 EUR) for an average tree (Vandenabeele, 2009). The leaves of the tree can be used as fodder while the fruits can be used as an insecticide.

12.3.4.4 Geographical Area

In general, the optimal area for *M. volkensii* is arid and semi-arid land, which covers about 80 % of Kenya's land surface. These are lands characterized as hot and dry and daytime

temperatures up to 40 °C. The rainfall is very unpredictable and mean annual rainfall varies from 150 to 750 mm.
More specific it's important to take other *Melia* nurseries into account in the possible area where the nursery will be built.

12.3.4.5 Competition and Marketing Strategy

Since commercial *M. volkensii* nurseries are still rare in Kenya, competition in the same region will probably be negligible. However Vandenabeele (2012) reports that competition between nurseries already exists in Kibwezi. The price of a single seedling is usually low, between 40 and 50 Kenyan shillings, which is high for the average farmer whom is willing to pay only around 20 Kenyan shillings without a problem. The best way to deal with competition is to produce seedlings of excellent quality in the most efficient way.

12.3.5 Human Resource Management

The employees in the nursery can be divided in two groups: permanent employees and temporary employees. The latter group consists of seed collectors and a carpenter. Seed collectors climb in *M. volkensii* trees to collect the fruit, which contains the seeds needed for propagation. A carpenter constructs the greenhouses where the seeds are being planted.
The permanent employees are responsible for depulping the fruits, cracking the nuts, slitting and sowing the seeds and other tasks such as taking care of the water management and cooking. Two to three permanent employees plus manager are more than enough in a beginning nursery. The manager of a nursery must learn about the biology and physiology of *M. volkensii* and seek help with a manager of a successful nursery. Nowadays, seminars are being held and training is being given by some of these successful managers.

12.3.6 Starters formalities

The most important formality is the contract with the water company if natural water supply is insufficient. The contract includes the installation of the tap and a price per m³ used water. A second formality is the license application for the nursery, which is not mandatory. But with this license the customers are sure that good-quality seedlings are produced in the nursery.

12.3.7 Micro financing

One of the Millennium goals, formed by the United Nation in 2000, is to ban poverty in the world. Micro financing is one of the remedies that can achieve this goal but it's not a panacea against poverty. The United Nation defines micro financing and a micro credit as follows: 'micro financing includes loans, savings, insurances and other financial products established on people with a low income. A micro credit is a small amount of money loaned to a client by a bank of other institution' (CeFiP, 2007).

12.3.8 Financial Plan

This is the most important section of the business plan because it gives an indication of how successful the nursery can become. This financial plan is different from a normal financial plan where the goal is to apply for credit with a bank. In this case, all investments are made without credit but with capital of the founders of the nursery. The goal of this financial plan is to give an overview of all costs and revenues for beginning entrepreneurs who are interested in establishing a commercial nursery.

12.3.8.1 Investment Plan

The investment plan gives an overview of all investments necessary to start with the nursery. These investments are made before the first customer actually buys a seedling and are divided in formation expenses, tangible assets, supplies and cash. The overview of all these investments is presented in table 17 and. A more detailed overview is added in appendix V. These investments are necessary for a nursery that can produce a few thousand seedlings during the first year with an increasing capacity during the next year. Small-scale nurseries require less investments.

Table 17: Investment plan

Total formation expenses	2,500.00 KES
Total tangible assets	147,640.00 KES
Total supplies	24,100.00 KES
Total cash	5,000.00 KES
TOTAL INVESTMENT PLAN	179,240.00 KES

12.3.8.2 Opening Balance

The opening balance gives an overview of the investments necessary for the nursery such as fixed assets (formations expenses and tangible assets) and current assets (supplies and cash) and how they're financed (equities or foreign debt) at the beginning of year 1 of the nursery (Table 18). In this case, all investments are financed with equities and nothing with foreign debt. A more detailed overview is added in appendix VI.

Table 18: Opening balance

ASSETS		LIABILITIES	
Fixed Assets		**Equity**	
Formation Expenses	2,500,00 KES	**Capital**	100,000.00 KES
Tangible Assets	147,640.00 KES		
Current Assets			
Supplies	24,100.00 KES	**Foreign Debt**	79,240.00 KES
Cash	5,000.00 KES		
TOTAL ASSETS	179,240.00 KES	**TOTAL LIABILITIES**	179,240.00 KES

12.3.8.3 Cost Evaluation

The cost evaluation is an overview of all costs such as costs of material consumption, staffing costs, costs of capital goods, land costs and costs of services and deliveries. The costs of the first 3 years since the start-up are calculated in table 19. The costs of capital goods are calculated with the linear depreciation method, which are attached in appendix VII. The cottage, motorcycle, water tank, watering cans and machetes are debited during a period of ten years while the greenhouses are debited during a period of seven years.

Table 19: Cost evaluation

	season 1	season 2	season 3
Costs of Material Consumption	58,300,00 KES	66,150,00 KES	77,025.00 KES
Staffing Costs	80,400.00 KES	87.240,00 KES	96,369.00 KES
Costs of Capital Goods	14,507.14 KES	14,507.14 KES	14,507.14 KES
Capital costs	15,848.00 KES	-	-
Land Costs	4,000.00 KES	4,000.00 KES	4,000.00 KES
Costs of Services and Deliveries	17,140.00 KES	9,325.00 KES	10,273.75 KES
Total Cost Evaluation	174,347.14 KES	181,222.14 KES	202,174.89 KES

12.3.8.4 Revenue Evaluation

The revenue evaluation gives an overview of the number of sold seedlings and the incomes, which come with this sale (Table 20). In this case, the price of a seedling is 50 Kenyan Shillings and the amount of produced and sold seedlings are 3,500 pieces during the first season: a total revenue of 175,000 KES is thus estimated. The total number of produced seedlings in the second and third season is estimated at 4,500 and 6,000 but these are just target numbers. The acquired knowledge and know-how during these following seasons will increase the number of produced seedlings whereby the total revenues will also increase.

Table 20: Revenue evaluation

Product	Price per seedling	Number of seedlings season 1	Number of seedlings season 2	Number of seedlings season 3
Melia volkensii seedling	50.00 KES	3500	4500	6000
TOTAL REVENUES		175,000.00 KES	225,000.00 KES	300,000.00 KES

12.3.8.5 Result Evaluation

The result evaluation is the difference between the operation income and the operational costs is presented in table 21.

Table 21: Result evaluation

	season 1	season 2	season 3
Operational Income	175,000.00 KES	225,000.00 KES	300,000.00 KES
Operational Costs	174,347.14 KES	181,222.14 KES	202,174.89 KES
Operational Result	652.86 KES	43,777.86 KES	97,825.11 KES
TOTAL RESULT	652.86 KES	43,777.86 KES	97,825.11 KES

12.4 Discussion

The total investment reveals that there's a necessity of 179,240.00 KES to start a commercial nursery that can produce a few thousand seedling during the first year. Most farmers in arid and semi-arid lands of Kenya do not have this amount of money, so the support of a wealthy person or micro-credit is thus essential. The cost evaluation is estimated at 174,347.14, 181,222.14 and 202,174.89 KES the first 3 seasons of the nursery: major costs are the purchase of the seeds and labour costs. The result evaluation is estimated at 652.86 KES the first season of production. This is very low, but the result evaluation of season 2 and 3 show that profit will increase every season. A higher number of produced seedlings is the most important reason of this increase. This model shows that poor people can crawl their way out of poverty will some financial help and knowledge how to manage a successful *M. volkensii* nursery.

The Kenyan wood industry has mainly depended on short-rotation industrial plantations planted by the Kenya Forest Service (KFS). One of the measures undertaken to enhance sustainable forest management in Kenya is the use of sustainable harvesting levels and monitoring forest planting programmes (Wasike, 2010). The development of sustainable forests for wood production will require a lot of good quality seedlings that can be produced by potential commercial nurseries. This means also there always will be a market for timber tree seedlings.

Tree cultivation is being firmly established as an investment project with returns in long-term. The National Forestry Authority (NFA) of Uganda encourages people to invest in tree farming. Over the years, the NFA has received complaints about seedlings of bad quality. Seedling quality is thus very important for tree farmers to maximize returns. (Watasa, 2009). Poles of *Eucalyptus grandis* used for construction are one of the most traded tree products in Western Kenya (Cheboiwo, 2009) and at the age of 10 years, a eucalyptus tree can fetch an average price of 6,000 Kenyan Shillings (Watasa, 2009). This shows that tree nurseries can become very profitable in arid and semi-arid lands were trees such as *M. volkensii* could be cultivated.

General conclusion

The potential for growing plant in the semi-arid areas where the pilot plantation of Better Globe Forestry (BGF) is situated is medium to low but ideal for planting *Melia volkensii* trees.

Following organisms were identified on diseased *M. volkensii* seedlings at the BGF nursery in Kiambere: *Fusarium* sp., *Alternaria* sp., *Trichotecium* sp., *Botrysphaeria* sp. and *Diplodia* sp. It’s not clear which *Fusarium* species causes the infection on the seedlings. Previous studies show that some *Fusarium* species are seed-borne but further research is necessary which species causes the infection. *Alternaria* produces leaf spots and produces mycotoxines on *J. curcas* and *M. volkensii*. The presence of this fungus on the diseased seedlings can be explained since *J. curcas* and *M. volkensii* are both planted on the pilot plantation. *Diplodia seriata* and *Botryosphaeria* sp. are known to induce cancer development in seedlings and further research is necessary to determine how these diseases can be prevented and treated. The presence of *Trichothecium* sp. on the infected seedling can be explained by *J. curcas* trees that are planted in the pilot plantation. Previous reports showed that *Trichothecium* sp. were isolated from this tree species. Further research is needed to test the antifungal properties of trichothecin, a substance isolated from *Trichothecium roseum*.

The development of the propagation protocol showed that propagation of *M. volkensii* can be divided in a pre-sowing, sowing, pre-germination and post-germination treatment. During the pre-sowing treatment it’s important to collect mature fruits, break dormancy and prevent seed damage. Sterilization with insecticides and fungicides is essential when the seeds are being sowed. When the seeds are germinated the seedlings must be pricked out of the propagator after emergence from the substrate. Water management is important to avoid water logging that causes loss of seedlings after transplanting.

The first fertilizer trial shows that 50 and 100 g of Mavuno seem to have the most beneficial impact on height and stem diameter, with a small benefit for 50 g. The second trial shows that the best fertilizer programme for young *M. volkensii* trees in the field is a dosage of 100 g of Mavuno during the first year of growth and a dosage of 100 g during the second year of growth. Further experiments are necessary to investigate long term effects of fertilizer on growth parameters of *M. volkensii*.

Trees planted on different altitude levels in the plantation show a difference in tree height, stem diameter and growth of leaves. It’s very difficult to explain these differences based on the soils analyses. The difference between the trees of the blocks is probably due to the

different amount of fertilizer applied in October 2009. Further research is necessary to determine the effect of different altitude levels in a plantation on equally treated trees.
The survey in an around Mumoni Forest resulted in 8 potential plus trees that can be used for a breeding programme. This selection was based on tree height, stem diameter, estimated age and photographs. Provenance trials need to determine which of these trees are suitable for an actual breeding programme. Further surveys must be carried out to identify more potential breeding material.

The foundation of a commercial tree nursery that can produce a few thousand seedlings during the first year is estimated at 179,240.00 Kenyan Shillings. Micro-financing or financial help of a wealthy person can help farmers to found their own commercial tree nursery. Producing timber tree seedlings can become a very lucrative business since the demand for timber is very high in Africa.

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Appendixes

Appendix I: SAS output One Way Anova fertilizer trial 1

One-Way Analysis of Variance

Results: HEIGHT

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
TREATMENT	3	0 g 100 g 50 g

Number of Observations Read	519
Number of Observations Used	519

One-Way Analysis of Variance

Results

Dependent Variable: HEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	19670.9638	9835.4819	7.88	0.0004
Error	516	643653.7799	1247.3910		
Corrected Total	518	663324.7437			

R-Square	Coeff Var	Root MSE	HEIGHT Mean
0.029655	12.83884	35.31842	275.0906

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREATMENT	2	19670.96383	9835.48191	7.88	0.0004

One-Way Analysis of Variance

Results: STEMDIAMETER

Dependent Variable: STEMDIAMETER

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	7.6395312	3.8197656	9.33	0.0001
Error	516	211.1899871	0.4092829		
Corrected Total	518	218.8295183			

R-Square	Coeff Var	Root MSE	STEMDIAMETER Mean
0.034911	27.40664	0.639752	2.334297

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREATMENT	2	7.63953120	3.81976560	9.33	0.0001

One-Way Analysis of Variance

Results: LEAVES (1-4)

The ANOVA Procedure

Dependent Variable: LEAVES (1-4)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	12.9136109	6.4568055	7.96	0.0004
Error	516	418.7087398	0.8114510		
Corrected Total	518	431.6223507			

R-Square	Coeff Var	Root MSE	LEAVES (1-4) Mean
0.029919	44.44089	0.900806	2.026975

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREATMENT	2	12.91361092	6.45680546	7.96	0.0004

Appendix II: SAS output Two Way Anova fertilizer trial 2

Linear Models

The GLM Procedure: HEIGHT

Class Level Information		
Class	Levels	Values
TREATMENT 1	2	100 g 50 g
TREATMENT 2	4	0 g 100 g 200 g 300 g

Number of Observations Read	347
Number of Observations Used	347

Generated by the SAS System (Local, XP_PRO) on 04mei2012 at 11:44 AM

Dependent Variable: HEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2.01519018	0.28788431	8.94	<.0001
Error	339	10.91482757	0.03219713		
Corrected Total	346	12.93001775			

R-Square	Coeff Var	Root MSE	HEIGHT Mean
0.155854	17.79799	0.179436	1.008179

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREATMENT 1	1	0.74458136	0.74458136	23.13	<.0001
TREATMENT 2	3	0.23881487	0.07960496	2.47	0.0616
TREATMENT*TREATMENT	3	1.03179395	0.34393132	10.68	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREATMENT 1	1	0.96374891	0.96374891	29.93	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREATMENT 2	3	0.56947298	0.18982433	5.90	0.0006
TREATMENT*TREATMENT	3	1.03179395	0.34393132	10.68	<.0001

Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

TREATMENT 1	TREATMENT 2	HEIGHT LSMEAN	LSMEAN Number
100 g	0 g	0.98540281	1
100 g	100 g	1.23964383	2
100 g	200 g	1.08101045	3
100 g	300 g	0.98572278	4
50 g	0 g	0.96202652	5
50 g	100 g	0.94521858	6
50 g	200 g	0.92973485	7
50 g	300 g	0.99820076	8

Least Squares Means for effect TREATMENT*TREATMENT
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: HEIGHT

i/j	1	2	3	4	5	6	7	8
1		<.0001	0.1063	1.0000	0.9987	0.9493	0.9350	1.0000
2	<.0001		0.0102	<.0001	<.0001	<.0001	<.0001	<.0001
3	0.1063	0.0102		0.1260	0.0146	0.0005	0.0145	0.2453
4	1.0000	<.0001	0.1260		0.9988	0.9527	0.9370	1.0000
5	0.9987	<.0001	0.0146	0.9988		0.9998	0.9972	0.9813
6	0.9493	<.0001	0.0005	0.9527	0.9998		1.0000	0.8110
7	0.9350	<.0001	0.0145	0.9370	0.9972	1.0000		0.8274
8	1.0000	<.0001	0.2453	1.0000	0.9813	0.8110	0.8274	

The GLM Procedure: DBH

Class Level Information		
Class	**Levels**	**Values**
TREATMENT 1	2	100 g 50 g
TREATMENT 2	4	0 g 100 g 200 g 300 g

Number of Observations Read	347
Number of Observations Used	347

Generated by the SAS System (Local, XP_PRO) on 04mei2012 at 11:51 AM

Dependent Variable: DBH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3.91906929	0.55986704	4.04	0.0003
Error	339	46.99274333	0.13862166		
Corrected Total	346	50.91181262			

R-Square	Coeff Var	Root MSE	DBH Mean
0.076978	34.16722	0.372319	1.089697

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREATMENT 1	1	0.44510171	0.44510171	3.21	0.0740
TREATMENT 2	3	0.86209288	0.28736429	2.07	0.1035
TREATMENT*TREATMENT	3	2.61187470	0.87062490	6.28	0.0004

Source	DF	Type III SS	Mean Square	F Value	Pr > F

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREATMENT 1	1	0.85196021	0.85196021	6.15	0.0137
TREATMENT 2	3	1.54714855	0.51571618	3.72	0.0117
TREATMENT*TREATMENT	3	2.61187470	0.87062490	6.28	0.0004

Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

TREATMENT 1	TREATMENT 2	DBH LSMEAN	LSMEAN Number
100 g	0 g	0.97009569	1
100 g	100 g	1.38847118	2
100 g	200 g	1.16766917	3
100 g	300 g	1.08344031	4
50 g	0 g	1.04261364	5
50 g	100 g	1.01844262	6
50 g	200 g	0.96022727	7
50 g	300 g	1.15909091	8

Least Squares Means for effect TREATMENT*TREATMENT
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: DBH

i/j	1	2	3	4	5	6	7	8
1		0.0008	0.1093	0.8558	0.9847	0.9980	1.0000	0.2541
2	0.0008		0.2528	0.0496	0.0121	0.0026	0.0047	0.2842
3	0.1093	0.2528		0.9450	0.6571	0.3031	0.3080	1.0000
4	0.8558	0.0496	0.9450		0.9996	0.9889	0.9154	0.9823

Least Squares Means for effect TREATMENT*TREATMENT
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: DBH

i/j	1	2	3	4	5	6	7	8
5	0.9847	0.0121	0.6571	0.9996		1.0000	0.9902	0.8243
6	0.9980	0.0026	0.3031	0.9889	1.0000		0.9985	0.5450
7	1.0000	0.0047	0.3080	0.9154	0.9902	0.9985		0.4528
8	0.2541	0.2842	1.0000	0.9823	0.8243	0.5450	0.4528	

Appendix III: SAS output One Way Anova growth comparison of *Melia volkensii* of different altitude levels

One-Way Analysis of Variance

Results: HEIGHT 2010 (CM)

The ANOVA Procedure

Class Level Information

Class	Levels	Values
BLOCK NUMBER	2	M13 M4

Number of Observations Read	42
Number of Observations Used	42

Dependent Variable: HEIGHT 2010 (CM) HEIGHT 2010 (CM)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	66005.3571	66005.3571	26.95	<.0001
Error	40	97975.6190	2449.3905		
Corrected Total	41	163980.9762			

R-Square	Coeff Var	Root MSE	HEIGHT 2010 (CM) Mean
0.402518	18.65418	49.49132	265.3095

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK NUMBER	1	66005.35714	66005.35714	26.95	<.0001

Generated by the SAS System (Local, XP_PRO) on 21mei2012 at 9:39 AM

One-Way Analysis of Variance

Results: STEMDIAMETER (CM)

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
BLOCK NUMBER	2	M13 M4

Number of Observations Read	42
Number of Observations Used	42

The ANOVA Procedure

Dependent Variable: STEMDIAMETER (CM)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	12.16095238	12.16095238	43.51	<.0001
Error	40	11.17904762	0.27947619		
Corrected Total	41	23.34000000			

R-Square	Coeff Var	Root MSE	STEMDIAMETER (CM) Mean
0.521035	25.17405	0.528655	2.100000

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK NUMBER	1	12.16095238	12.16095238	43.51	<.0001

Generated by the SAS System (Local, XP_PRO) on 21mei2012 at 9:42 AM

One-Way Analysis of Variance

Results: LEAF SCORE (1-4)

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
BLOCK NUMBER	2	M13 M4

Number of Observations Read	42
Number of Observations Used	42

Dependent Variable: LEAF SCORE (1-4)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	9.52380952	9.52380952	13.56	0.0007
Error	40	28.09523810	0.70238095		
Corrected Total	41	37.61904762			

R-Square	Coeff Var	Root MSE	LEAF SCORE (1-4) Mean
0.253165	30.34434	0.838082	2.761905

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK NUMBER	1	9.52380952	9.52380952	13.56	0.0007

Generated by the SAS System (Local, XP_PRO) on 21mei2012 at 9:42 AM

Appendix VI : Evaluation sheet of potential Melia volkensii plus trees

		description by:
Tree number:		
Date:		
Location:		**Remarks:**
district, division, location		
sublocation, village		
altitude		
latitude		
longitude		
Owner		
name		
contact/address		
previous treatment of tree		
ideas about tree		
Tree characteristics:		
estimated age		
total height (m)		
diameter at 1.5m (cm)		
tree form (class 4-6)		
bole length (m)		
branch diameter (cm)		
bark colour		
wood (straight, spiral grain)		
leaves (presence, colour)		
flowers (presence)		
fruits (presence, colour)		
canopy max diameter (m)		
canopy min diameter (m)		
tree shape		
Climate:		
mean annual rainfall		
length of dry season		
mean annual temperature		

Soil characteristics:		
surface texture		
subsurface texture		
colour		
salinity		
pH		

Site description:

field/fallow/secundary bush

crop history

slope/orientation

class 6: straight and lightly branched

class 5: straight and moderately brached

class 4: slightly bent and heavily branched

Appendix V: Overview of the investment plan

1. Formation Expenses		
Licenses	License	2,500.00 KES
Total formation expenses		2,500.00 KES
2. Tangible Assets		
Land and buildings	Land	35,000.00 KES
	Cottage	3,800.00 KES
	Poles	4,000.00 KES
	Roof	1,800.00 KES
	Fence	8,800.00 KES
	Timber	14,560.00 KES
	Polyethylene	6,500.00 KES
	Nails	680.00 KES
	Water tank	20,000.00 KES
Material	2 Watering cans	1,000.00 KES
	3 Machetes	1,500.00 KES
Transport	Motorcycle	50,000.00 KES
Total tangible assets		147,640.00 KES
3. Supplies		
Material nursery	Razor Bladers	3,000.00 KES
	Rope	1,200.00 KES
	10 Mosquito nets	1,000.00 KES
	Polybags	12,500.00 KES
Pesticides	Bavistin	3,500.00 KES
	Polytrin	2,000.00 KES
Cleaning products	Omo	800.00 KES
	Sponges	100.00 KES
Total supplies		24,100.00 KES
4. Cash		

Total cash		5,000.00 KES
5. Total Investment Plan		
Total formation expenses		2,500.00 KES
Total tangible assets		147,640.00 KES
Total supplies		24,100.00 KES
Total cash		5,000.00 KES
TOTAL INVESTMENT PLAN		179,240.00 KES

Appendix VI: Overview of the opening balance

ASSETS		LIABILITIES	
Fixed Assets		**Equity**	
1. Formation Expenses		**1. Capital**	
License	2,500,00 KES		100,000.00 KES
2. Tangible Assets			
Land	35,000.00 KES		
Buildings	18,400.00 KES		
Motorcycle	50,000.00 KES		
Greenhouses	21,740.00 KES		
Water Tank	20,000.00 KES		
Watering Cans & Machetes	2,500.00 KES		
Total Tangible Assets	147,640.00 KES		
Current Assets		**Foreign Debt**	
3. Supplies			
Material nursery	17,700.00 KES	Micro credit	79,240.00 KES
Pesticides	5,500.00 KES		
Cleaning products	900.00 KES		
Total Current Assets	24,100.00 KES		
4. Cash			
	5,000.00 KES		
TOTAL ASSETS	179,240.00 KES	**TOTAL**	179,240.00 KES

Appendix VII: Costs of capital goods

1. Costs of Material Consumption		season 1	season 2	season 3
Fuel Motorcycle		22,500.00 KES	24,750.00 KES	27,225.00 KES
Transport	Sand	7,800.00 KES	7,800.00 KES	7,800.00 KES
	Seed	21,600.00 KES	25,920.00 KES	32,400.00 KES
Seed	Seed per season	6,400.00 KES	7,680.00 KES	9,600.00 KES
Total Costs of Material Consumption		58,300,00 KES	66,150,00 KES	77,025.00 KES
2. Staffing Costs		season 1	season 2	season 3
Labour Share in Entreprise Income	Manager	20,000.00 KES	22,000.00 KES	24,200.00 KES
Permanent Employees	Permanent Employee 1	17,500.00 KES	19,250.00 KES	21,175.00 KES
	Permanent Employee 2	17,500.00 KES	19,250.00 KES	21,175.00 KES
	Permanent Employee 3	17,500.00 KES	19,250.00 KES	21,175.00 KES
Temporary Employees	Seed Collectors	6,400.00 KES	7,040.00 KES	7,744.00 KES
	Carpenter	1,500.00 KES	450.00 KES	900.00 KES
Total Labor Costs		80,400.00 KES	87.240,00 KES	96,369.00 KES
3. Costs of Capital Goods		season 1	season 2	season 3
Cottage		1,850.00 KES	1,850.00 KES	1,850.00 KES
Motorcycle		7,250.00 KES	7,250.00 KES	7,250.00 KES
Greenhouses		2,827.14 KES	2,827.14 KES	2,827.14 KES
Water tank		2,350.00 KES	2,350.00 KES	2,350,00 KES
Watering cans & Machetes		230.00 KES	230.00 KES	230.00 KES
Total Costs of Capital Goods		14,507.14 KES	14,507.14 KES	14,507.14 KES
4. Capital costs		season 1	season 2	season 3
Interest micro credit		15,848.00 KES		
Total capital costs		15,848.00 KES		
5. Land Costs		season 1	season 2	season 3
Lease		4,000.00 KES	4,000.00 KES	4,000.00 KES
Total Land Costs		4,000.00 KES	4,000.00 KES	4,000.00 KES
6. Costs of Services and Deliveries		season 1	season 2	season 3

Cell Phones		3,000.00 KES	3,000.00 KES	3,000.00 KES
Water	Installation	3,640.00 KES	0.00 KES	0.00 KES
	Registration	5,000.00 KES	0.00 KES	0.00 KES
	Consumption per season	5,500.00 KES	6,325.00 KES	7,273.75 KES
Total Costs of Services and Deliveries		17,140.00 KES	9,325.00 KES	10,273.75 KES
Total Cost Evaluation		174,347.14 KES	181,222.14 KES	202,174.89 KES