HOGESCHOOL GENT
LID VAN DE ASSOCIATIE UNIVERSITEIT GENT

Departement Biowetenschappen en Landschapsarchitectuur

Academiejaar 2009 - 2010

Inventory of problems in the cultivation of *Jatropha curcas* and *Melia volkensii* at Kiambere, Kenya

Inventarisatie van knelpunten bij de teelt van *Jatropha curcas* en *Melia volkensii* in Kiambere, Kenia

Masterproef voorgedragen door

Silke Nowak

tot het bekomen van de titel en de graad van

Master in de biowetenschappen: tuinbouwkunde

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Promotor	Copromotor	Author (Auteur)
Prof. Dr. Ir. Geert Haesaert	Prof. Dr. Ir. Geert Baert	Silke Nowak

Woord vooraf - Foreword

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Abstract

This thesis is highlighting the problems in cultivating *Jatropha curcas* and *Melia volkensii* in arid and semi-arid areas. A *J. curcas* and *M. volkensii* plantation at Kiambere (Kenya) was evaluated and used as a trial ground. *J. curcas* turned out to be susceptible for a large range of pests and diseases. Identified insects on the plantation are *Calidea dregii, Heliothrips haemorroidales, Scirtothrips kenyensis, Ferrisia virgata*, *Stomphastis sp.*, *Pempelia morosalis, Aphtona sp.* and termites. Fungi that attack *J. curcas* at Kiambere were plated out on PDA and identified as *Fusarium spp*., causing root rot and *Alternaria* and *Sirosporium spp.*, causing leaf spots. *Trichothecium spp.* were also identified but are probably not causing plant pathogen effects. To avoid resistance, chemicals with another mode of action like thiacloprid, deltamethrin, triadimefon, fluoxastrobine, trifloxystrobine and prothioconazole can be added to the spraying system on the plantation to alternate with the current used products. Five soil profiles were described and the growth parameters of 25 *J. curcas* plants around each profile were measured. This showed that the growth is positively related to the soil volume and the thickness of the A horizon. Three different amounts of fertilizer (0 g, 50 g and 100 g) were tested on *M. volkensii* seedlings. The optimum health and stem diameter was reached at the 50 g treatment. Adding 100 g leads to luxury consumption. Plant height was not affected. Leaf analyses showed a maximum quantity of several elements in leaves from the 50 g treatment. The literature often shows unrealistic scenario's and the economical profitability of cultivating *J. curcas* on drylands can be doubted. *M. volkensii* shows more advantages but also here consciousness is recommended because of the little available information.

KEYWORDS: *Jatropha curcas*, *Melia volkensii*, pests, diseases, resistance, soil, fertilization

Deze thesis brengt de problemen in the teelt van *Jatropha curcas* en *Melia volkensii* in droge- en semidroge gebieden naar voor. Een plantage in Kiambere (Kenia) van *J. curcas* en *M. volkensii* werd geëvalueerd en gebruikt als proefgebied. *J. curcas* bleek gevoelig te zijn voor een hele reeks van ziekten en plagen. Op de plantage werden *Calidea dregii, Heliothrips haemorroidales, Scirtothrips kenyensis, Ferrisia virgata*, *Stomphastis sp.*, *Pempelia morosalis, Aphtona sp.* insecten en termieten geïdentificeerd. De schimmels die gevonden werden op *J. curcas* zijn uitgeplaat op PDA en ze werden geïdentificeerd als *Fusarium spp*., schimmels die wortelrot veroorzaken, en *Alternaria* en *Sirosporium spp*., schimmels verantwoordelijk voor bladvlekken. Ook *Trichothecium spp.* werden geïdentificeerd maar veroorzaken waarschijnlijk geen plantpathogene effecten. Om resistentie te vermijden kunnen nieuwe pesticiden met een ander werkingsmechanisme worden toegevoegd aan het huidige assortiment. Voorbeelden zijn thiacloprid, deltamethrin, triadimefon, fluoxastrobine, trifloxystrobine en prothioconazole. Vijf bodemprofielen zijn beschreven en rond elk profiel werden de groeiparameters van 25 *J. curcas* planten opgemeten. Dit toonde aan dat de groei positief gecorreleerd is met het bodemvolume en de dikte van de A horizont. Drie verschillende bemestingshoeveelheden (0 g, 50 g en 100 g) zijn getest op *M. volkensii* zaailingen. De optimale gezondheidstoestand en stamdiameter van de zaailingen werd bereikt bij de 50 g behandeling. De 100 g behandeling induceert luxeconsumptie. De planthoogte werd niet beïnvloed. Bladanalyses toonden een maximale hoeveelheid van meerdere elementen in de bladeren van de 50 g behandeling. De literatuur geeft vaak een onrealistisch beeld weer en de economische rentabiliteit van het telen van *J. curcas* in deze gebieden is twijfelachtig. *M. volkensii* heeft meer voordelen maar ook hier is voorzichtigheid aanbevolen vanwege de kleine hoeveelheid beschikbare informatie.

KERNWOORDEN: *Jatropha curcas*, *Melia volkensii,* ziekten, plagen, resistentie, bodem, bemesting

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Introduction

The climate is changing fast and desertification is becoming highly problematic in tropical areas all over the world. At the same time, the global population is increasing rapidly. We have to find better ways to use the available land as optimal as possible and to avoid further desertification and degeneration of valuable areas. This will not only limit the negative environmental effects, but it will also offer jobs and improve the life quality of people living in these areas. Drylands are difficult lands to exploit but also have great potential if managed properly.

In this work, we want to treat this subject by highlighting the problems in cultivating two crops in arid and semi-arid areas.

The first crop, *Jatropha curcas*, is a small tree of which the seeds can be used for producing biodiesel. It is known as a drought resistant plant with a high adaptation capacity. Yield and profit data seem very promising and the demand for biofuels is increasing. Given that *J. curcas* can grow on wasteland, which is not suitable for agricultural food crops, *J. curcas* is not competitive with food crops and the food-fuel discussion is not applicable when growing *J. curcas* on drylands.

The second crop, *Melia volkensii*, is a tree that is grown for its wood quality. It is a fast growing tree which delivers high qualitative wood comparable to mahogany. The tree is known to be very unsusceptible for pests and diseases and highly drought tolerating.
Both crops seem to have the potential to grow on drylands and this way restore the soil and protect the area against desertification. Moreover, the trees have interesting applications in today's environment-minded world.

A background information study about arid and semi-arid lands and the practical use of drylands will be assessed first. In this study, the emphasis lays on the characteristics, the problems, the challenges and some forestry-related examples of drylands. Water and nutrient management form the biggest issues and the possibilities for these aspects are described accurately. This way, a global view of the current state and the potential of drylands can be achieved.
After that, a precise description of *Jatropha curcas* and *Melia volkensii* in all their aspects will be done. Also an inventory of the problems, described in the literature, in cultivating both crops, will be made.

The purpose of this background information study is to collect interesting and useful information to gain a deep insight into the subject.

Knowing all this, it is important to test the theory in practice. This will be done through a comprehensive evaluation of a pilot plantation of *Jatropha curcas* and *Melia volkensii* at Kiambere, Kenya. This plantation from the company Better Globe Forestry, is located in semi arid land and forms a suitable testing area. The management system of the plantation will be described to clear out the occurring problems. The problems concern pests and diseases on *Jatropha curcas*, a high variation in growth of *Jatropha curcas* plants and the lack of information about correct fertilization practices for *Melia volkensii*.
The pest and diseases occurring on the plantation will be described and the identified and the current spraying system will be analyzed. The results can be compared with the literature to see if new pest organisms are found. The management system of the pests and diseases can be optimized and eventually, alternative measures can be proposed.
The heterogeneity of the growth of *J. curcas* will be brought in relation with soil characteristics to see if there is a relation between both factors. If there is a relation, soil improvement measures can be proposed to improve the growth of *J. curcas*.
For *M. volkensii*, an exploring fertilizer trial will be performed to gain initial information about the effect of fertilizer on the growth of *M. volkensii* seedlings and the effect of different amounts of fertilization.

The evaluation of the plantation will not only lead to improvement proposals in managing the plantation at Kiambere, it can also be useful in other dryland agricultural or forestry systems.

At last, the study will also reveal inaccurate or incorrect information in the literature about the cultivation of *J. curcas* and *M. volkensii* in arid and semi-arid lands and its economical and environmental profitability.

Literature study

1 Arid and semi-arid land

1.1 Introduction

Aridity can be defined as the deficit between the availability of water in the soil and evapotranspiration (ETP). Evapotranspiration is the sum of the vegetation transpiration and the environment natural climatic evaporation of the soil.
Arid and semi-arid lands (ASAL) in East Africa are defined as areas with an annual rainfall of less than 800 mm.
The evapotranspiration in the ASALs in Kenya amount 2300-2500 mm a year.
Eighty percent of the total land mass in Kenya, this is over 62 million hectares, can be defined as arid or semi-arid land (Verlodt, 2009a).

1.2 Climate

In ASALs, the rainfall is low and badly distributed. In East Africa, the rain falls in two rainy seasons a year. Therefore, there are two active periods of vegetation in the East African zone determined by water availibility and not limited by temperatures. During this active vegetative period, the hydric potential of rainfall is less than 400 mm (Verlodt, 2009a).

In the sub-Saharan zone, the temperature and evaporation are continuously relative high. Nevertheless, the annual evaporation and annual mean temperatures are closely related to elevation (Verlodt, 2009a).

1.3 Vegetation

In dry and hot areas, the natural vegetation had adapted his morphology and physiology to the aridity. For example baobab trees (*Adansonia digitata)* and *Commiphora* drop their leaves to avoid water loss caused by transpiration and they have water reserves in their stem and roots. Olive trees and acacias have adapted their leaves to avoid evaporation. Olive trees have small leaves covered with hair to reduce the leaf area receptive to sunlight. The hair also prevents transpiration and the leaves turn their smallest side to the sun during the day. Also acacias have hairy leaves to avoid excessive transpiration and the leaves are waxy to offer extra protection against water losses.

Some other crops complete their development cycle very quickly so that the cycle is finished when the water reserve in the soil is finished (Verlodt, 2009a).

The root system of trees is very deep, strong and good developed. Trees also create a micro climate because of the shade and organic litter they offer. That is why trees are better adapted to the drought than grass vegetation. Nevertheless, the balance is brittle. When a forest is destroyed, soils are directly exposed to sunshine, the evaporation will increase fast and the area will become even more arid (Verlodt, 2009a).

1.4 Soils

A big problem of soils in drylands is erosion. Also water retention capacity and rooting depth of the soil is important. The main soil types that occur in arid and semi-arid areas are calcisols, gypsisols, solonchaks, solonetz, arenosols and durisols.
Problems in using soils in these areas for agriculture or forestry plantations, are the quality of the irrigation water (often too salt) and the salinity of the saline-alkaline soils. Management practices to improve soil characteristics are lowering the salinity by rinsing out the salts and lowering the Na content in the rooting zone by adding soluble Ca. This way, adsorbed Na will be shut out. At that moment, it's also important to rinse the removed Na. Gypsum ($CaSO_4.2H_2O$) is the most used chemical soil improver. Physical solutions are deep ploughing when shallow gypsum horizonts are present, breaking the hard B horizonts or lime layers, profile inversion when the topsoil doesn't have the required properties and mixing sand in the upper horizonts of soils with fine texture (Baert, 2009).

The soil map of Kenya however shows that lixisols and cambisols are the main soil groups in the area of the plantation at Kiambere, where the experiments were conducted. These soils are often acidic and poor in nutrients (1).

Lixisols have a CEC (cation exchange capacity) < 24 cmol(+)/kg clay and a base saturation ≥ 50 %, according to the definition of the FAO and WRB (World Reference Base for Soil Resources). Lixisols have a weak microstructure and a massive macrostructure and slaking and caking of the surface soil is a big problem. It are strongly weathered soils which are chemically poor. Aluminum toxicity and strong phosphorus fixation can occur (Baert, 2009).

Lixisols have a higher clay content in the subsoil than in the topsoil due to pedogenetic processes such as clay migrate on. They have a fine texture and occur in regions with a tropical, subtropical or warm temperate climate with a pronounced dry season, notably on old erosion or deposition surfaces. One of the most important measures to manage lixisols is preservation of the surface soil (FAO, 2006). Cambisols are characterized by slight or moderate weathering of the parent material and by absence of sufficient quantities of illuviated clay, organic matter, aluminum and/or iron compounds. They consist of medium and fine-textured materials (FAO, 2006).

2 Practical use of drylands

2.1 Water management on drylands

When using drylands for farming, there are limiting factors to control.
Nambiar and Brown (CIFOR, 1998) defined the ecological capability of a site as:

- Bounded by the inherent soil and biophysical constraints
- The responsiveness of the soil to management inputs
- The genetic potential of the species and their interaction with the environment of the site.
- For tropical sites, this means mainly low nutrient reserves, poor nutrient retention ability and susceptibility to drought.

The main limiting factor remains water. Water is present all over the world (groundwater, rain, rivers, oceans, ...) but useful water, this means non saline and non polluted water, becomes more and more rare and expensive (Verlodt, 2009a).

On average, it takes 14 000 l of water to produce 1 l of biodiesel from rapeseed or soybean and 20 000 for 1 l of biodiesel from *Jatropha* (Valentine, 2009). Water stress may decrease rates of growth below commercially viable levels. It is therefore very important to conserve the little available water and to use the available water economical and efficient (CIFOR, 1998).

To use the available water efficient, farmers can build dams, boreholes and they can also harvest water from run-off. Also irrigation is a good option for farmers in semi-arid and arid areas (Muchiri, 2009a).

A table with detailed information about the different water resources with the origin, type of harvesting, techniques of capture, mobilization and storage and use, is added in Appendix I (Verlodt, 2009b).

Using traditional irrigation with earth channels or flood irrigation, a lot of water is lost. These losses can be avoided by using waterproof channels covered in cement or plastic film, or by the use of HDPE gutters or plastic pipes (Verlodt, 2009c).

Using drip irrigation, the crops use a minimum of water for a maximum output. This has the biggest effect in sandy soils, where the water use efficiency (kg of yield per m^3 of water) can be doubled or tripled using drip irrigation instead of traditional earth channel irrigation. This will be translated in increased yields for the farmer. It is a suitable option for farmers in semi-arid and arid areas. In times of expensive fuel, diesel and petrol, pumps are often too expensive to use. Drip irrigation reduces the used water amount and the fuel consumption. It will also allow crops to mature earlier then crops relying on rains so that farmers are able to sell their products all year round at higher prices. However, this concerns fruit trees and legume crops. For dense plantation crops like maize or wheat, this is not a realistic system and another strategy is required (Muchiri, 2009a).

Water losses trough run-off, especially on slopes, can be reduced by ploughing contour lines, covering the soil with vegetation and water and soil conservation structures to avoid dam siltation (Verlodt, 2009c).

However, the main loss of water in soils is due to evapotranspiration (evaporation by the soil and transpiration by the plants). This is a natural phenomenon, which is increased by high temperatures, wind and soil texture. Techniques to decrease water losses by evaporation are planting shrubs and trees or putting artificial windbreaks covering the soil with mulch (plastic or vegetative) and ploughing after rainfall, this causes a destruction of capillarity and creates an artificial mulch with a superficial dry layer. This conserves the moisture in the dept and favours infiltration of the next rainfall.
A technique to decrease water loss by transpiration is a natural or artificial windbreak, which will decrease the turbidity of the air and thus transpiration of plants. Preventing the growth of weeds by chemicals or covering the soil with plastic film eliminates the competition for water between crops and weeds (Verlodt, 2009c).

Water requirements also depend on soil properties like structure, fertility, texture and chemical properties and on the needs of the crops growing on them.
The soil texture is important for moisture retention (Verlodt, 2009c).
Small amounts of water are retained by sandy soils, while clay retains high amounts. Sandy soils are thus not adapted for annual crops with a superficial root system, unless the soil's water retention capacity is enhanced by the incorporation of clay (very difficult) or organic matter (manure or compost). This can be mixed with soil at the bottom of the planting holes before planting. This way, young plants with an undeveloped root system can take advantage of an improved water reserve around the roots.
For agricultural practices, loamy and mixed textural soils are preferable in these regions.
Most soils in arid and semi-arid lands have a low organic matter content and a fragile structure. When these soils have a loamy clay texture, a crust will often be formed leading to low infiltration rates and high run-off, resulting in water loss and soil erosion (Verlodt, 2009c).

2.2 Nutrient management on drylands

2.2.1 Soil degradation

Besides water, soil fertility is also an important dictating factor to yield. Overemphasis on rain has even prevented soil improvement initiatives on many farms in East Africa (Muchiri, 2009a).

Soil degradation is a major limiting factor for farmers. Soil degradation is caused by deforestation, water and wind erosion, salinisation, sodification, acidification, leaching, toxicity and physical and biological degradation.
On slopes where the ground cover has been removed, erosion is most severe. For instance, soil loss during the peak of the rainy season from a traditional cultivated maize field (20% slope) in the Ethiopian highlands was estimated to be 19,5 t/ha. Soil loss in the same period and area from a four year old *Juniperus* forest (65% slope) was 0,02 t/ha. This is a thousand fold difference between cropped and forest areas. Restoring degraded lands is very difficult and can take decades, so it is important to handle preventive instead of curative. Without soil and water conserving practices, cultivated land will become degraded and the productivity capacity will decrease dramatically. In the end, soil degradation leads to desertification (ILCA, 1993).

6,15 billion hectares or 47,2% of the world's land area are drylands. Of this, 3,5 tot 4 billion hectares are either desertified or prone to desertification. Desertification causes a big loss of soil organic carbon. To preserve soil organic carbon, land management practices like afforestation with appropriate species, soil management on cropland and restoration of degraded soils and ecosystems are necessary. Soil management practices include application of manure, which will also improve the activity of soil fauna, vegetative mulching, water harvesting and irrigation systems (Lal, 2009).

Besides low soil organic carbon concentration, deficiency of N is also an important factor causing low productivity. Most of these soils are also coarse-textured, have low water and nutrient retention capacity and have low soil fertility (Lal, 2009).

Sandy soils and leached acid soils (pH<6) have poor major nutrients (N, P, Ca, Mg) and oligo-elements. Calcareous soils are basic (pH>8) which makes phosphorus and oligo-elements uptake very poor (Verlodt, 2009c).

The International Centre for Tropical Agriculture (CIAT) estimates that the average African farmers apply only 10% of the nutrients their farms require during the planting season. Fertilisation and manure is thus necessary and can improve soil fertility (Verlodt, 2009c).

The very old, highly weathered and low fertile dryland soils have thus following limiting factors: organic matter (usually <0,5%), CEC (<5 cmol(+)/kg soil), the low colloidal fraction, total P (<200 mg/kg), available P (8-30 mg/kg, Olsen method) and the fragile soil status (Lal, 2009).

Figure 1 shows the vicious circle of soil degradation in semi-arid lands. This figure shows the problems leading to degraded soils, but also shows the places where corrective measures can be taken.

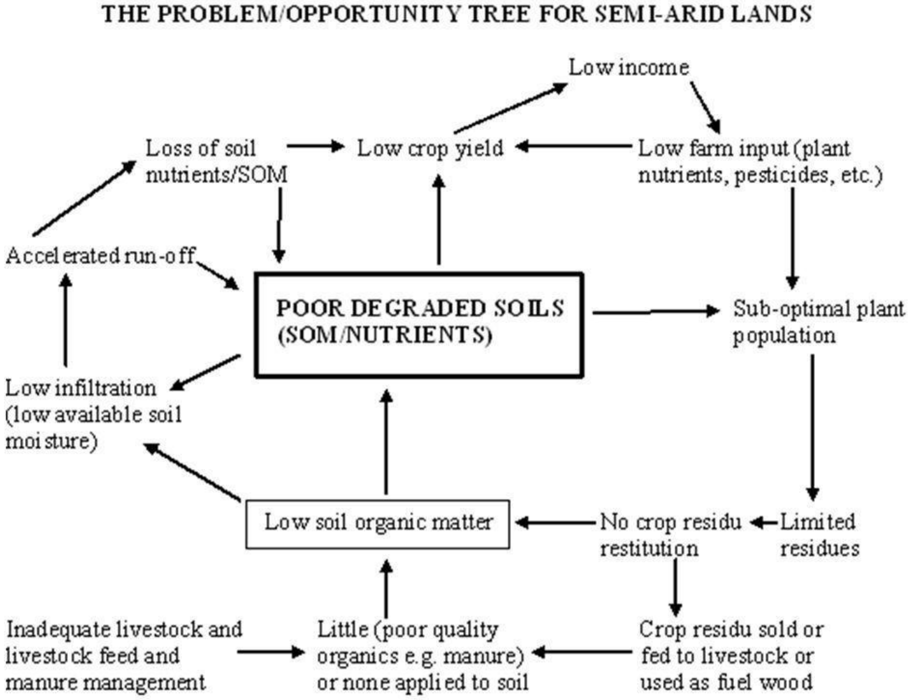

Figure 1: The conflict that lead to non-sustainable land use for a typical substance in semi-arid lands (Source:KARI & NARL, 2001)

~Figuur 1: Het conflict dat geleid heeft tot een niet-duurzaam bodemgebruik semidroge gebieden~

2.2.2 Corrective measures

A degraded soil, deficient in nutrients, can be improved by adding organic material into the soil through composting. The major amount of carbon in compost will fix elements like nitrogen, phosphorus, potassium, calcium, magnesium and others (Muchiri, 2009a).

Crop residues can be used to improve the soil fertility, but crop residues are not a new source of nutrients. Therefore, their addition is not enough to correct the nutrient deficiencies in the soil. Compost, manure or (in)organic fertilizer is necessary to cover the deficiency (ILCA, 1993).

Fertilizers are often too expensive for farmers in semi-arid areas. In that case, compost manure offers a cheaper option. Compost manure will increase organic matter and keep the soil fertile. It also has a beneficial effect on the water retention capacity of the soil. Compost manure is, compared to fertilizers, cheap to make and is rich in nutrients. It is also rich in carbon chains, which can fix crucial nutrients such as nitrogen, calcium, potassium, magnesium and other required minerals (Muchiri, 2009b).

Table 1 shows the effect of manure on soil surface chemical properties in West Africa.

Table 1: Effect of manure (ton/ha) on soil surface chemical properties in West-Africa (samples taken after the first harvest after application of the manure) (Source: ILCA, 1993)

~Tabel 1: Effect van bemesting (ton/ha) op chemische eigenschappen van de bodemoppervlakte in West-Afrika (stalen genomen na de eerste oogst na bemesting)~

Manure application	pH	Organic matter (%)	Total nitrogen (mg/kg)	Available phosphorus (mg/kg)
0	5.37	0.39	202	10.3
	(4.98)[a]	(0.29)	(153)	(5.3)
20.0	6.21	0.58	285	22.9
	(4.98)	(0.29)	(153)	(5.3)
NR[b]	5.8	0.33	164	9.6
	(5.1)	(0.26)	(131)	(4.6)
3.6	6.51	0.18	NR	5.7
	(6.18)	(0.15)	(4.3)	
2.1	5.04[c]	0.31	NR	NR
	(4.86)	(0.28)		
3.1	5.45	0.31	150	11.0
	(5.20)	(0.28)	(138	(6.1)
10.1	5.68	0.33	169	26.8
	(5.20)	(0.28)	(138)	(6.1)

a. Values in parenthesis are soil properties in non-manured plots.

b. Not recorded.

c. pH in KCl, otherwise pH in water.

This table shows that application of manure has indeed a positive effect on the organic matter contents. Also the total nitrogen and available phosphorus amount has increased.

Anti-erosion measures are also very important, they can keep the little soil fertility that is left and conserve the top soil from being washed away. Ripping, ploughing and weeding should be done along contour lines. Check-dams have to be constructed in gullies to put a brake on the erosion (Vandenabeele, 2009a).

2.3 Farming on drylands

2.3.1 General

Drylands are difficult environments for living and farming. It are the most remote parts of Kenya with poor communication, transport and information infrastructure.
In the drylands, the human population growth rate is one of the highest in the country. This population growth has lead to reduced resource base, precipitating food insecurity and poverty. For example the annual farm income for an average household with 5 family members in the Ukambani districts, is 69 820 Kenian Shilling. This means 13 964 Kenyan Shilling a year per person (100 Ksh is about 1 euro). This is below the absolute poverty line.
But in these areas, farming is the only activity that can give people some profits.
The profitability of crops and trees commonly grown in the south eastern dryland districts is illustrated in Table 2 using value costs ratios (VCRs) of the top three enterprises in each category. This ratio should be minimum 2. This means that, for every unit of input a farmer invests in his crop, he has to earn that unit back plus another unit (Wekesa, 2009).

Table 2: VCR for different crops, tree species and fruit species (Source: Wekesa, 2009)

~Tabel 2: VCR voor verschillende gewassen, bomen en fruitsoorten~

Crops	VCR	Tree species	VCR	Fruit species	VCR
Pigeon peas	2,62	Mukau	2,99	Pawpaw	7,63
Green grams	2,54	Eucalyptus	2,85	Mango	6,62
Maize	1,44	Mpingo	0,85	Guava	4,10

The most profitable crop is pigeon peas (*Cajanus cajan*) with a VCR of 2,62, the most profitable tree mukau (*Melia volkensii*) with a VCR of 2,99 and the most profitable fruit species pawpaw (*Asimina triloba*) with a VCR of 7,63. In general, fruit species are most profitable, followed by tree species and crops.

However, one has to be cautious in the interpretation of the results. Pawpaw is most profitable but also a big water demander, and less a dryland species than mango (*Mangifera indica*) and guava (*Psidium guajava*). Mpingo (*Dalbergia melanoxylon*) is a very profitable wood species, but a very slow grower. The value of Eucalyptus can decrease dramatically as a result of die-back during dry years and mango will need additional watering in dry years to avoid fruit abortion. Growth of mukau and mpingo will just stagnate during drought and continue when it starts raining again. This leaves pigeon peas, green grams (*Vigna radiate*), mukau and guavas as the most risk-free species as a buffer against climatic variation.
The high profitability of fruit species is probably due to high yields and high product prices. The low profitability of crops could be due to low yields as a result of declining soil fertility,

poor product prices and high costs of production. The selling price of the products is also an important factor which can vary over season, region, completion with other sellers and the economical environment. These VCR are thus not static values. (Wekesa, 2009).

Lubulwa (1995) notes growing of following crop species in eastern Kenya: maize, sorghum, millet, cowpea, pigeon pea and beans. The production of maize and sorghum is characterized by the use of adapted cultivars. Very few smallholders use nitrogen fertilizers. Usually, boma manure (farm yard manure) is available to smallholders but most of them don't apply it efficiently. Mulching and using crop residue to reduce runoff of top soil and for soil conservation is not common because it conflicts with the demand for the same biomass for use as livestock feed.

Vandenabeele (in Muchiri, 2009a) proposes an integrated farming system for farmers in semi-arid areas to perceive maximum yields. An integrated farming system means practicing both crop growing and animal keeping on the same site. This way, farmers can benefit from symbiotic relations between the different crops and animal species. Dung from the animals can be mixed with fall-offs from trees and shrubs to make compost. This compost manure will enrich the soil with nutrients. Crops can be protected against wind by trees. Trees will also keep the crops cool by preventing excessive evaporation of water from the soil.

The land equivalent ration (LER) evaluates intercropping among different crops in relation to monoculture of the same crops. This model determines the number of hectares needed for the productivity of monocultures which are equivalent to 1 ha of intercropping productivity. A LER>1 means that intercropping is advantageous because more land would be required in monoculture to get the same productivity then with intercropping (Ceccon, 2007).

Table 3 shows the LER values of different intercrop systems with *Eucalyptus urophylla*, beans and rice.

Table 3: Land equivalent ratio of intercropped systems, using as a base the cylindrical volume of Eucalyptus urophylla at 4 (after the first rainy crop harvest) and 16 months (after the second rainy crop harvest) and the productivity (kg/ha) of rice and beans, over two years (Source: Ceccon, 2007)

~Tabel 3: LER van tussencultuur systemen, met als basis het cilindrisch volume van Eucalyptus urophylla op 4 en 16 maand en de productiviteit (kg/ha) van rijst en bonen over 2 jaar~

System	*E. uro*	EPM I	3PM	PM	Total
First year					
Eucalyptus × Beans (rainy season)	1.04	0.86	–		1.90
Eucalyptus × Beans (dry season)	2.25	0.78	–		3.02
Eucalyptus × Rice	1.10	–	0.91		2.01
Total					6.93
Second year					
Eucalyptus × Beans (rainy season)	1.32	0.40	–		1.72
Eucalyptus × Beans (dry season)	1.32	0.44	–		1.76
Eucalyptus × Rice	1.78	–	0.50		2.28
Total					6.21

All the LER values are bigger then 1, this means that intercropping is advantagous in every system in comparison with monocultures.

It is obvious that the yield variability is strongly tied to climatic factors. Because of the dependency on the rains, a proper water management is a crucial factor in farming on drylands. Also proper soil management is very important, as both are discussed earlier in this work (Lubalwa, 1995).

2.3.2 Case study: Kibwezi Mukuyu Farm

The Kibwezi Mukuya Farm in Kibwezi, Kenya from Jan Vandenabeele is a beautiful example of how to get maximum potential out of semi-arid land. On this farm, Vandenabeele applies an integrated management system of agriculture to get maximum yields (Vandenabeele, 2009b).

Vandenabeele grows mangoes, mukau, *Jatropha curcas,* neem, *Acacia* spp., cherry tomatoes, cow peas, *Opuntia ficus indica* and some other indigenous plants. He also keeps sheep, donkeys and bees (Vandenabeele, 2009b).

The animals provide dung and, together with plant residues of the farm, this can be used to make compost which enrich the soil. The trees are, besides their wood yield, used as windbreaks and prevent excessive evaporation from the soil.

The vegetables and sheep are for private use as well as for selling (Vandenabeele, 2009b).

Next to the farm is a little river. The water of that river is being pumped towards several water basins spread all over the plantation. The water basins are very simple but efficient. The bottom and the water surface are covered with plastic. From there, the water is distributed by a low-pressure drip irrigation system. The main pipe, leaving at the water basin, is connected with a bucket of fertilizer to distribute the fertilizer together with the water (fertigation). Then the main pipe splits up in little pipes that are spread all over the plantation. These pipes have little holes through which a particular quantity of water escapes (Vandenabeele, 2009b).

The farm is also a test/training centre for integrated management of natural resources in semi-arid areas. Vandenabeele wants to invite local farmers to show them the possibilities of their land and to train them in using simple, cheap but efficient systems on their own farms (Vandenabeele, 2009b).

A problem appearing on the farm and being relevant for this thesis, is the problem of cancers on mukau trees. Little is known about the cause of these cancers, the damage that they bring on the quality of the wood or their capacity to spread and infect neighbouring trees (Vandenabeele, 2009b).
At this moment, there are no cancers found on the pilot plantation in Kiambere. But in the future, when the whole area around the dam is being planted full with mukau, these cancers may appear and may cause serious problems. It is therefore important to find out more about the cancers so they can be avoided and suppressed if necessary. This item is further discussed below (Vandenabeele, 2009b)

2.4 Dryland forestry

2.4.1 Introduction

Tropical dryland forests can be divided into different ecosystems. There are dense dryland forests, open forest and woodland formations, single trees and scrublike savannahs (FAO, 1999).

The Forest Bill 2005 (Muchiri, 2009a) defines different forestry terms as following:

- “Forest” is any land dominated by trees of any size, whether commercial or not, which have the potential of influencing the climate, having any influence on soil and water regime and providing a habitat for wildlife. Forests also include woodlands.
- “Indigenous forests” are forests which are naturally regenerated from native trees to the country or area.
- “Woodland” is land where trees smaller than 10 meters are organized in an open structure, which originates from natural regeneration.
- At last “plantation forests” refers to forests which are formed by afforestation or reforestation for commercial purposes.

There are 238 million ha of dryland forests in the world, Africa alone has 64% of that amount. For almost 50 years, drylands have been weakened through repeated drought and human intervention. Because of the open access to the forests and the fact that fuelwood has been considered as a free resource with the only price the cost of harvesting it, fuelwood has been removed in large amounts. Also a lot of trees have been cut down to clear the land and using it for agricultural purposes.
This unrestricted forest clearance has far exceeded the capacity for natural regeneration of the ecosystem (FAO, 1999).
The current destructive trend should be reversed because of the important role of indigenous forests in soil and water conservation, biodiversity conservation and contribution to the country’s socio-economic development. Forest plantations must help to reverse this trend by commercializing wood products and by learning the people how to handle indigenous trees and forests appropriately. These plantations can produce wood through sustainable production systems on a limited land area (Mbugua, 2000).

Table 4 shows the total forest plantation area in the top 10 countries in 2001 (Bull et al., 2005).

Table 4: Summary of forest plantation area in top 10 countries (Source: Bull et al., 2005)

~Tabel 4: Samenvatting van bosplantage oppervlakte in de top 10 landen~

Country	Plantation area [ha]	Percentage of total forest area in country [%]
China	54,083,000	33.1
India	32,578,000	50.8
United States	16,238,000	7.2
Indonesia	9,871,000	9.4
Brazil	4,982,000	0.9
Thailand	4,920,000	33.3
Chile	2,017,000	13.0
Malaysia	1,750,000	9.1
New Zealand	1,542,000	19.4
Australia	1,396,000	0.9

About 28 million ha of forest plantations in tropical areas can be considered as forest plantations for wood production, they are mainly located in the humid tropics. It is estimated that more than 500 million ha of degraded land can be planted or replanted with trees. However, only 1.7 million ha of forest plantation is established a year (FAO, 1999).

2.4.2 Economical significance of trees

Wood is being used for different purposes. Long, straight poles are used by power and lighting companies and for domestic power and horticultural lighting. The smaller poles can be used for construction, fencing and as props in the flower-growing sector.
The bigger trees are used for timber.
What cannot be used for all of the above can be used to produce charcoal or wood fuel (Njoka, 2009).

Then there are also the trees producing eatable fruit and seeds.

At last there are trees producing gum, rubber, essential oils used in health and cosmetics industries, vegetable oils and oils used for producing bio-fuel.

Trees are growing as a major investment product. It is a profitable investment because of following reasons (Solberg, R., 2009):

- The demand for hardwood is increasing fast. This is due to the exhaustion of the resources and the growth of the market. China alone will absorb huge amounts of teak, mahogany and other species for making furniture, floors, etc.
- Many 'cash crop trees' produce products that can be used for food, cosmetics, health, etc. The market for these products is big and still increasing.
- Big tree plantations can contribute to global trading of 'carbon-credits'. This means that companies which want to evade their emission restrictions, can do this through buying 'carbon credits' from companies in other countries. The companies selling 'carbon credits', have a business producing a positive emission. Tree plantations are obviously one of the most important sectors producing positive emission through carbon fixation and oxygen releasing. These plantations will be able to earn a lot of money, just by planting trees.

2.4.3 Environmental significance of trees

2.4.3.1 Environmental effects

Plantation forestry not only offers opportunities to meet the demand for wood and to reduce deforestation, but it can also restore degraded soils and enhance biodiversity. Trees can enhance the productivity of lands that have been degraded by deforestation.

Because of the high yields of forest plantations, the affected area is smaller and concentrated, so there is space for other land use and restoration of natural forests. Development of improved forest planning and operations can minimize site impact, increase utilization and minimize or avoid adverse environmental effects (CIFOR, 1998).

2.4.3.2 Trees and climate change

Climate change is mainly due to an increase of greenhouse gasses in the atmosphere. Burning of fossil fuel but also massive deforestation and destruction of vegetation that conducts carbons, plays a major role.

About half of the biomass of trees conducts of carbon. The chemical association with oxygen (CO_2) is one of the most important greenhouse gasses. It occurs naturally in the atmosphere but increased from pre-industrial times (285 ppm) to recent times (380 ppm). This will further increase drastically, unless we take major measures.

Global warming will make dry regions even more dry and moist regions even more moist. As three quarters of Kenya are already considered as dryland, global warming will be felt enormously in Kenya. However, East Africa will have more precipitation than North –and South Africa. The predicted increase of temperature and precipitation in East Africa is shown in Table 5 and Table 6. The numbers are based on climate data sets in 21 different global climate change projections by IPPC (Vandenabeele, 2009c).

Table 5: Predicted increase of temperature in East-Africa (Source: Vandenabeele,2009c)

~Tabel 5: Voorspelde temperatuursstijging in Oost-Afrika~

Months	**Increase in temperature (°C)**		
	Minimum	**Median**	**Maximum**
Dec-Jan-Feb	2.0	3.1	4.2
Mar-Apr-May	1.7	3.2	4.5
Jun-Jul-Aug	1.6	3.4	4.7
Sep-Oct-Nov	1.9	3.1	4.3
Annual	1.8	3.2	4.3

Table 6: Predicted increase of precipitation in East-Africa (Source: Vandenabeele, 2009c)

~Tabel 6: Voorspelde neerslagstijging in Oost-Afrika~

Months	**Percentage change in precipitation**		
	Minimum	**Median**	**Maximum**
Dec-Jan-Feb	-3	13	33
Mar-Apr-May	-9	6	20
Jun-Jul-Aug	-18	4	16
Sep-Oct-Nov	-10	7	38
Annual	-3	7	25

This shows an increase from 1980-1999 to 2080-2099, estimated by the Intergovernmental Panel on Climate Change (IPPC) established by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP).
However, this will differ strongly from region to region, depended on topography, location and altitude. There will also be more extreme seasons, higher minimum temperatures and fewer cold nights. By 2080, ASAL will be increased with 5-8 percent in Africa.
Global warming is unstoppable, but Kenya as a country can contribute to achieve the Kyoto norms. Important is afforestation and stopping deforestation. This way, carbon can be moved from the atmosphere to the plants and the soil. It is also important to use the available water efficiently, as described in ‘Water management on drylands’ (Vandenabeele, 2009c).

Sustainable forest management of all types, natural as well as planted forests, will sequester carbon and provide climate-friendly materials, cellulose and fibre and renewable fuel. It also provides other economic, environmental and social advantages for local as well as foreign people, like biodiversity, soil conservation, poverty alleviation, etc. Wood products represent long lasting carbon pools. Sustainable management of the whole global forest sector is thus very important in controlling climate change.

2.4.4 Social significance of trees

The desert in Africa is moving south very fast. In 20-30 years from here, most land suitable for agriculture will be gone, unless massive reforestation is practiced. Massive reforestation will also hinder global warming, a big issue these days. But plantation forestry can also offer jobs to local people, and creating employment is the first step to get out of poverty. This way, people moving to from rural to urban areas will decrease, which prevents the further extension of the slums (Solberg, J., 2009).

2.4.5 Managing dryland forest plantations

Sustainable forest management includes managing soil, water and carbon balance. In dryland areas prone to desertification, measures to protect and restore the soil are essential. It is possible to enrich the soil, but this has the disadvantage of increasing the vulnerability to fire passage. Rotation is also an important factor in preserving soil fertility (FAO, 1999). Nutrient and soil management is also discussed in 'Nutrient management in drylands'.

Another important factor in managing a dryland forest plantations, is the choice of the species. Plantation managers often choose for exotic, fast growing species. These trees have a high productivity and profitability in short-term and are easy to manage and control. But exotic species are often not adapted to the site, so they will be more vulnerable for pests, diseases and fire. They can also decrease the biodiversity dramatically. It is often better to choose indigenous trees, adapted to the site. Matching species and site is thus very important. However, fast growing exotic trees can also reduce the affected area by using the planted area more effective and thus leave more space for wild plants without threatening the biodiversity. This is a discussion which will not be further debated in this thesis.

A mixed composition of species is better than monoculture. Mixed forest plantations are less vulnerable for pests and diseases and fire due to the multi-layered composition (FAO,1999).

The results of an experiment on the effects of rubber/banana intercropping are shown in Table 7.

Table 7: Effects of rubber/banana intercropping at (a) the whole crop level and (b) the component rubber crop level during the initial phase of rubble growth (i.e. up to 28 weeks after planting) (Source: Rodrigo et al., 2005)

~Tabel 7: Effect van rubber/banaan tussencultuur systemen op (a) het gehele gewas en (b) rubber gedurende de initiële fase van rubbergroei (tot 28 weken na het planten)~

	R	BR	BBR	BBBR
(a)				
Total mean dry matter (gm^{-2})	179 d	430 c	782 b	1097 a
Land equivalent ratio		1.49 c	2.17 b	2.62 a
Leaf area index	0.26 d	0.62 c	1.19 b	1.74 a
(b)				
	R	BR	BBR	BBBR
Plant weight (kg)	3.50 c	4.50 b	5.50 a	5.70 a
Crop performance ratio		1.23 b	1.47 a	1.48 a
Leaf area per plant (m^{-2})	5.10 c	6.50 b	7.60 a	8.00 a

Treatment codes R, BR, BBR and BBBR refer to the sole rubber crop and single, double and triple row rubber/banana intercrops, respectively. Means with the same letter within rows are not significantly different ($P < 0.05$).

All measured parameters at the whole crop level are significant better when growing rubber and banana as intercropped instead of growing them monocropped. The effects become bigger with more rows of banana. Also at the level of the rubber crop, the parameters are higher with intercropping. But here there is no significant difference anymore between 2 and 3 rows of banana.

In sustainable management of forest plantations on drylands, the main principles of farming on drylands are still important. Planting must be done very carefully. In fertile areas with enough rainfall, mistakes can be corrected. But in arid and semi-arid areas, a minor mistake can be fatal for the seedling. Workers must be informed about the correct way of planting and the risks of making mistakes. It starts with proper selection of the seedlings. Eliminating 10-20 % of the seedling may seem wasteful, but it will give a better yield because the weak trees will die or give problems anyway. Good seedling management also includes performing the planting process as quickly as possible, avoiding direct sunlight on the roots or dehydration. It is therefore also important to water the seedlings before transplanting. After planting, mulching must be done. This will decrease warming of the soil and thus decrease burning of the seedling. Also important are anti-erosion measures. It is important to keep the little soil that is left and to avoid further washing away from the top soil. This can be done through ripping, ploughing, weeding and constructing check-dams in gullies. Weeding will also reduce the competition for water and nutrients between weeds and the trees. Depending on the species of the planted tree, it is necessary to water the seedlings the first years. When mature trees also need watering, there can be set up a watering system like drip irrigation (also see ‘Water management on drylands’ and ‘Nutrient management on drylands). At last, pest and disease control is indispensible. It is important to know the problem, so measures can be taken to avoid further contamination and to suppress the problem (Vandenabeele, 2009a).

2.4.6 Forestry in Kenya

2.4.6.1 General

In 1994 there was a comprehensive study from the FAO about the forestry status in Kenya.
The study showed that the most used forest plantation management system in Kenya is the ‘shamba system’ (‘shamba is Swahili for ‘land’), this is a system of non-resident cultivation (NRC). In this system, there’s a beneficial relation between the Forest Department and the cultivator. The benefits are lower costs, an improved production, improved survival and more employment.
The FAO presents in their report, known as the Kenya Forestry Masterplan Project (KFMP), some measures to improve the current system of NRC. A list of the most important measures can be found in Appendix II (Mbugua, 2000).
The projections resulting from the implementation of the proposed measures in short term are present in Table 8 and Table 9:

Table 8: Projected area of forest plantations ('000 ha) (Source: Mbugua, 2000)

~Tabel 8:Geschatte oppervlakte van bosplantages ('000 ha)~

Scenario/Year	1995	2000	2005	2010	2015	2020
Current scenario	148	134	118	107	93	78
Future scenario	148	145	154	164	166	174

Table 9: Projections of sustainable wood yields from forest plantations ('000 m^3) (Source: Mbugua, 2000)

~Tabel 9: Geschatte duurzame houtopbrengst van bosplantages ('00 m^3)~

Current Trend/Year	1995	2000	2005	2010	2015	2020
Timber	1,768	2,078	1,760	1,804	1,901	2,214
Woodfuel	354	416	352	361	380	443
Master-Plan Scenario						
Timber	1,791	2,167	2,002	2,362	2,704	3,174
Woodfuel	358	433	400	473	541	636

In the current scenario, the forest plantation area is decreasing to almost half of the area in 2020 in comparison with 1995. Following the proposed measures, the area should increase lightly.
The sustainable wood yields from forest plantations in the current scenario is lightly increasing for timber as well as woodfuel. The trend is however not constant, the yield is fluctuating strongly over the years.
In the master plan scenario, the yield is increasing even more and this with less fluctuations.

As a result of one of the recommendations of the report , the Kenya Forest Service (KFS) was established. They are in charge of conservation and sustainable management of forestry in Kenya for environmental stability and socio-economic development.
According to information from the Kenya Forest Service, Kenya has currently over 9,3 million hectares of farm forestry and agro-forestry systems. Dryland forests cover about 35 million hectares of Kenyan land. There are currently over 125 000 hectares of plantation forests. The natural indigenous forests are estimated on 1,4 million hectares and are spread all over the country (Kenya Forest Service, 2009).

The report of the FAO predicted a forest plantation area of 164 000 ha if the recommendations were followed. This is not achieved completely, the forest plantation area in 2000 was only 125 000 ha. The situation has not changed a lot since then. But this is anyway better than the predicted 107 000 ha, when no measures would have been taken. According to the report, sustainable forest plantation management can contribute to the national economy if good practices are applied. The big challenge is to put the recommended measures in practice (Mbugua, 2000).

Besides the Kenya Forest Institute, there is also the Kenya Forestry Research Institute (KEFRI). They conduct and disseminate forestry research findings. They also co-operate with other forestry institutes, in national as well as international sphere (KEFRI, 2009).

2.4.6.2 Market information

A table with forest products market information in Kenya is added in Appendix III. Cypress, pine, *Grevillea* and *Eucalyptus* are the most important timber species and the price is decreasing from cypress over pine and *Grevillea* to *Eucalyptus.* The price is also fluctuating over the different provinces. Forest products are also used for charcoal, industrial firewood, semi-processed transmission poles, treated transmission poles, logs, construction wood and fencing posts. Acacia and black wattle are used for charcoal. Species used for timber are also used for logs. Wood for the other purposes is mainly from *Eucalyptus* trees.
Prices for all types of forest products are the highest in Nairobi (Deprins, 2009).

In 1999, KEFRI started a large scale study to know the prices and the evolution of the prices for wood products, mainly in Western Kenya. They found that the major tradable tree products were charcoal, sawn wood, transmission poles, firewood and construction poles with an aggregated value of Ksh 1.6 billion.
The graphs in Appendix IV show the detailed evolution of the prices of charcoal, cypress sawn wood, king posts, firewood and transmission poles between 1999 and 2008 in different Kenyan regions. Between 1999 and 2008, the prices of charcoal rose by 150 % , sawn wood by 260 % and saw logs by 275 % (Cheboiwo, 2009).

3 *Jatropha curcas*

3.1 Introduction

Jatropha curcas L. is a small tree or shrub in the family of the *Euphorbiaceae*. It has a lot of different common names like physic nut, Barbados nut, poison nut and purging nut. In scientific articles, the name 'physic nut' is most used (CAB International, 2005). *J. curcas* becomes 3 to 5 meters high and has a smooth gray bark. Under optimal conditions, it can even grow up to a height of 8 to 10 meters. It has been described as resistant to drought and pests. But *J. curcas* is an emerging crop all over the world, also in Kenya. This increased domestication and establishment as monocrop, causes an increasing number of reports of pests and diseases on *J. curcas*. This will be discussed later in 'Pests and diseases' (Otieno et al., 2005).

Physic nut is an easy to establish energy crop with a lot of untapped potentials. At this moment, *J. curcas* is often used as an hedge-plant and thus not on large plantations as a yield crop, while it does has the economical potential. It is very important for African farmers, for Western industries and for protection of the environment because it prevents further erosion of the soil and because it is able to restore wasteland.

The economical lifespan, this means the length of the period in which seed production is possible and rentable, is about 50 years (KEFRI, 2007).

Contrary to most other energy crops, *J. curcas* can grow on wasteland and thus not form a concurrent for food crops. However, there are some questions about the economical profitability of growing *J. curcas* on wasteland and financial studies about this are necessary.

It even has the potential to turn wasteland into restored land through combating desertification and preventing erosion. This phenomenon is illustrated in Figure 2, which shows the evolution from wasteland to restored land after planting *Jatropha* on the site (Yammama, 2009).

Figure 2: Restoration of wasteland planted with J. curcas (Source: Yammama, 2009)

~Figuur 2: Herstelling van schraal land door beplanten met J. curcas~

3.2 Classification

Domain:Eukaryota
Kingdom:Viridiplantae
Phylum:Spermatophyta
Subphylum:Angiospermae
Class:Dicotyledonae
Order:Euphorbiales
Family:Euphorbiaceae
Genus:Jatropha
Species:Jatropha curcas L.

3.3 Habitat

J. curcas is a succulent which sheds its leaves during the dry season. This way, *J. curcas* is adapted to grow under arid and semi-arid conditions. Most *Jatropha* spp. grow in seasonally dry areas like grassland-savanna, thorn forest scrub and thicket. In its natural habitat, *J. curcas* is mainly known as weed. Besides that, *J. curcas* is also introduced as a crop in dry areas all over the world with an annual rainfall between 300 and 2500 mm (optimum 1800 mm), an altitude between 0 and 1500 m above sea level and average annual temperatures between 18 and 36 °C.

J. curcas naturally occurs on areas with altitudes from 0-500 meters above sea level, with temperatures from 20-28 °C, with an average rainfall between 300 and 1500 mm per annum and in a latitude range from 23°N to 23°S. This area is marked on the map in Figure 3, the *J. curcas* 'belt' is the global indication of the most suitable areas to grow *J. curcas* (Abdel-Hamid, 2009).

Figure 3: Global indication of the most suitable climate conditions for the growth of J. curcas (Source: Abdel-Hamid, 2009)

~Figuur 3: Globale indicatie van de meest geschikte klimaatcondities voor de groei van J. curcas~

J. curcas does not tolerate frost and cold night temperatures. Soils are preferred to be well-drained with good aeration. *J. curcas* can grow on marginal soils with low nutrient content and tolerates sodic and alkaline soils. This, together with the high drought resistance, makes *J. curcas* not competitive with food crops. J. curcas can also grow in heavy soils, but root development will be limited (CAB International, 2005).

J. curcas needs a soil depth of at least 45 cm and the slope of the surface should not be higher than 30 %. It has low nutrient requirements. The soil must have a pH ≤ 9 and Ca and Mg fertilization could be necessary in case of very acidic soils (Achten et al., 2007).

3.4 Morphology

J. curcas is a perennial, woody succulent shrub or small tree. This tree can be propagated vegetative as well as through seed. *J. curcas* reaches an average height of 3 to 5 meters and can reach a maximum height of 8 to 10 metres. The green parts contain a sticky juice and the branches contain latex. The bark is smooth, greenish-yellow or pale brown coloured, papery and often peeling (CAB International, 2005).

3.4.1 Leaves

The leaves (Figure 4) are bright green coloured, 10-15 x 7,5-12,5 cm big and 5- to 7-shallow lobbed. They are stalked and smooth and are arranged alternately. The petioles are round and smooth (CAB International, 2005).

Figure 4: Leaves J. curcas (2)

~Figuur 4: Bladeren J. curcas~

3.4.2 Flowers

J. curcas is monoecious with unisexual flowers. Hermaphrodite flowers do occur in rare cases (KEFRI, 2007). The inflorescence has a lot of little, yellow flowers (CAB International, 2005). The male flowers (Figure 6) have 10 stamens which are united at the base in two separated wreaths of each 5 stamens. The wreath of stamens in the middle is strongly united, while the stamens in the outside wreath are less united. Flowering occurs under moist conditions and cross-pollination is established by insects (KEFRI, 2007).
The male flowers stand at the end of the branches on short, articulated pedicles. Female flowers (Figure 5) don’t have articulated pedicles. Flowers have a small bract (CAB International, 2005).

Male flowers have a 5-leaved calyx and 5 petals. Ten stamens occur in 2 wreaths, less or more united as explained earlier. The outer stamens are a little longer than the calyx.

The female flowers also have a 5-leaved calyx and 5 petals. The ovary is oblong and smooth. There are 3 short styles (CAB International, 2005).

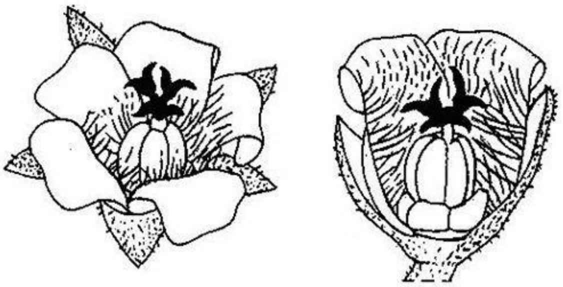

Figure 5: Female flower (left) and open female flower (right) (2)

~Figuur 5: Vrouwelijke bloem (links) en dwarsdoorsnede vrouwelijke bloem (rechts)~

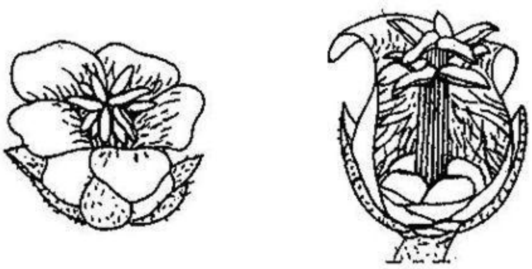

Figure 6: Male flower (left) and open male flower (right) (2)

~Figuur 6: Mannelijke bloem (links) en dwarsdoorsnede mannelijke bloem (rechts)~

3.4.3 Fruits

The fruit (Figure 7 & Figure 8) is oval and 3-4 cm long. It has 3 compartments. Initially, the fruit looks green but later it will turn yellow and then black (CAB International, 2005).

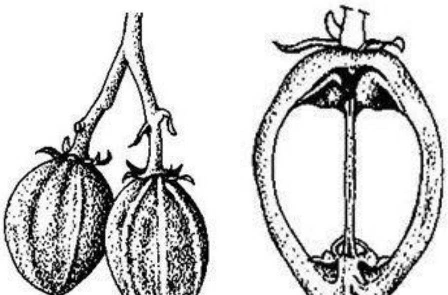

Figure 7: Fruits (left) and longitudinal section of fruit (right) (2)

~Figuur 7: Vruchten (links) en dwarsdoorsnede vrucht (rechts)~

Figure 8: Fruit of J. curcas (3)

~Figure 8: Vruchten van J. curcas~

3.4.4 Seeds

In each compartment of the fruit, there is 1 seed (Figure 9 & Figure 10). This makes that fruit contains 3 seeds. The seeds become mature when the fruit changes from green to yellow. The seeds are black, 2 cm long and 1 cm thick and have a thin shell. There are 2370 seeds in 1 kg and germination rates go from 70 to 100 % (CAB International, 2005).

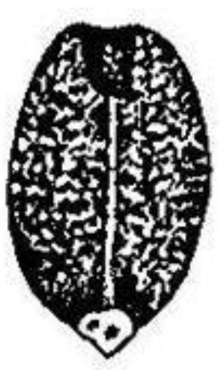

Figure 9: J. curcas seed (2)

~Figuur 9: J. curcas zaad~

Figure 10: J. curcas seeds (4)

~Figuur 10: J. curcas zaad~

The seeds contain 24,60 % crude protein, 47,25 % crude fat and 5,54 % moisture. Triglyceride is the dominant lipid in the seed oil.
Secondary metabolites extracted from leaf, fruits, latex and bark contain glycosides, phytosterols, flavonoids and steroidal sapogenins that have a wide range of medicinal applications (Akintayo, 2003).

Figure 11 shows the fatty acid composition of *J. curcas* oil.

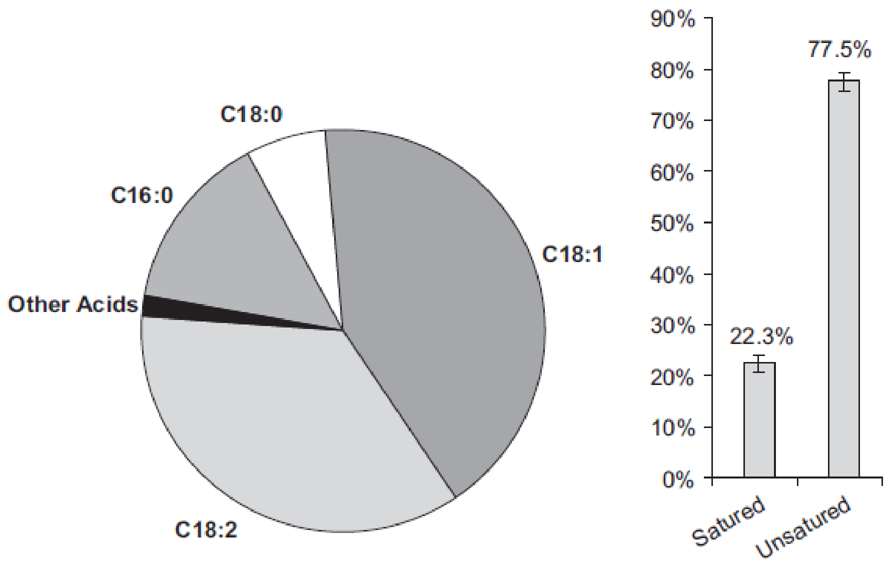

Figure 11: Fatty acid composition of J. curcas oil (Source: Achten et al., 2007)

~Figuur 11: Vetzuursamenstelling van J. curcas olie~

The fatty acid composition of *J. curcas* oil is dominated by oleic acid (C18:1) and linoleic acid (C18:3). The maturity stage of the fruits at the moment of harvesting influences the fatty acid composition of the oil. The J. curcas oil meets the quality standard of rapeseed as a fuel. However, the quality of the oil is dependent on the environment and genetics (Achten et al., 2007).

3.5 Development and genetics

J. curcas is a diploid species wit 2n=22 chromosomes.

The tree is not sensitive to daylight. Rainfall and temperatures induce dormancy, temperatures below 15 °C will cause the dormant stage (Mc Lea, 2009).

Under moisture conditions, the seed will start to germinate. The seed shell splits and the radicula comes out. One central taproot and four peripheral adventive roots are formed. A taproot will not be formed on cuttings for vegetative propagation (KEFRI, 2007). After the first real leaves are formed, the cotyledons wither and fall of. The further growth is sympodial. Vegetative growth mainly occurs in the rainy season.

Flowers can be pollinated by different insects. Staminate flowers usually open later then pistillate flowers, promoting cross-pollination. But there are also cases observed where staminate and pistillate flowers open at the same time. This mechanism is probably influenced by the environment.

After pollination, a trilocular ellipsoidal fruit is formed. The exocarp remains fleshy until the seeds are mature. It takes 90 days from flowering to seed maturation (CAB International, 2005).

J. curcas established from seed can produce seed for about 50 years with a plateau on 20-30 years age, plants established from cuttings produce seed for about 10-15 years (KEFRI, 2007).

Allelopathic effects from *J. curcas* can result in dying, reduced germination and reduced seedling vigour of neighbouring plants. The identified chemicals responsible for the allelopathic effects are vitexin, isovitexin, stigmasterol and beta-sitosterol. In cropland, it can be harmful for pigeon pea (*Cajanus cajan*), rice, chickpeas and lentils. The allelopathic effects from *J. curcas* plants which are growing in the wild, can be harmful for native species and can reduce biodiversity (KEFRI, 2007 & CAB International, 2005).

Because of its adaptation ability, *J. curcas* has spread beyond its original habitat. This proves that *J. curcas* has a large genetic potential. Although, the full potential is far from being realized. Improved varieties with desirable properties for specific growing conditions are not available, making growing *J. curcas* a risky business.

Crop improvement programs are lacking globally. Genetic improvement is however possible through assessment of variation in wild sources, selection of superior/elite genotypes, application of mutation, alien gene transfer through inter-specific hybridization and biotechnological interventions to bring changes in those genes which determine the desired properties. Genes determining drought resistance, rooting volume, number of branches, vulnerability for pests and diseases and oil content of the seed are interesting to use in breeding programs. Eventually, productivity improvement can be achieved through development of pistillate plants and exploiting by heterosis (Divakara et al., 2009).

3.6 Growing *Jatropha curcas*

When growing *J. curcas*, the land must be prepared before using it. There must be enough aeration in the soil so tilling must be done, also to improve water infiltration. Also clearing and ridging is important. Field draining must be done if necessary. But land preparation is very dependent on the site: soil texture, acidity, drainage etc. When *J. curcas* is grown as an intercrop, the land will be prepared as per requirements of the main crop (KEFRI, 2007).

After the land is prepared, the seeds can be sown, in case of dried seeds after one night soaking. When the seeds are sown directly on the site, this must be done in the beginning of the rainy season and at a depth of 2-3 cm. When there is a lot of drought stress, it is better to sow the seeds first in tubes in the nursery, to water them until they have developed a desirable root density. The poly-ethylene tubes must be filled with soil characterised by a high concentration of organic material. One seed is sown in every bag and they must be watered every 3 days when it's not raining. A slow releasing fertilizer will stimulate growth. Germination takes place after 12 days and lasts 2 weeks. Germination rate is higher with fresh seeds. Intervals of pre-soaking and drying and partial removal of the testa will improve germination. After that, the seedlings are raised in the nursery until they are 30-40 cm high, this takes about 3 months (KEFRI, 2007).

Then they can be transplanted into the field. Recommended spacing between plants is 2x1,5 m to 3x3 m. This way, the number of trees per hectare will be 1600 to 2200. Wider spacing will give larger fruit yields because of the reduced competition for water and nutrients.
It is favourable to establish the plantation in a way that machinery is able to move through the plantation (KEFRI, 2007).

Vegetative propagation is also possible. For that, cuttings from 60-120 cm are placed 20 cm into the soil. Best planting time is 1-2 months before the start of the rainy season. The roots begin to grow after 2-4 weeks. The first seed yield will be higher than with generative propagation if the cuttings are taken from a mature plant, but the life span of the plant will be lower. Vegetative propagated plants will not form a central taproot. They will only form pseudo-taproots penetrating only 1/2 - 2/3 from the soil depth penetrated by a taproot from a generative propagated plant. It is therefore that plants from cuttings are more sensitive to drought (Yammama, 2009).

To improve growth, side branch development and seed production, *J. curcas* can be pruned (KEFRI, 2007). Pruning must be done to decrease apical dominance and stimulate lateral development. This way, vegetative growth in the juvenile stage is stimulated and more branches will be formed. Pruning is best done 25 cm above the base of the branch. After that 3-4 new branches will be formed (Mc Lea, 2009).
Weeding is important to eliminate competition for water, nutrients and light, and the weed can be used as mulch (KEFRI, 2007). Mechanical weeding must be done every month and chemical weeding must be done quarterly with alternately 3,5 l/ha glyfosate and 3,5 l/ha fusillade (fluazifop-P-butyl) to avoid resistance. Glyfosate is a wide range herbicide and must thus be used between the rows while fusillade has a specific activity against grasses and can be sprayed over the whole area (Mc Lea, 2009).

Because of the relatively high susceptibility for pests and diseases, a pest –and disease control program is necessary (Hunter, 2009).

Fertilization definitely has a correlation with yield, but it is however found to be less important than pest prevention and ridged soil. Ridged soil has the advantage to be porous, so water will be held. On ridged soil it is also easier to apply fertilization and to prevent pests (Hunter, 2009). But fertilizers do have a positive effect on the growing cycle. More nitrogen and potassium will increase the vegetative growth and phosphorus will encourage flowering and root growth. It is therefore good to apply nitrogen, potassium and phosphorus in the beginning of the growing season and phosphorus just before flowering (Mc Lea, 2009).

An experiment was conducted on wasteland in India to examine the effects of N and P fertilization on the growth of *J. curcas*. Different amounts of nitrogen and phosphorus were applied through urea and single super phosphate respectively. N and P fertilization was repeated three times and observations were taken during 2004 and 2005. The results are showed in Table 10 (Petolia et al., 2006).

Table 10: Effect of N and P fertilization (in kg/ha) on height, canopy and seed yield and total dry matter accumulation (Source: Petolia et al., 2006)

Tabel 10: Effect van N en P bemesting (in kg/ha) op hoogte, bladerdek en zaadopbrengst en totale droge stof accumulatie~

Treatments	Plant height (cm)		Plant canopy (cm)		Total dry matter accumulation (kg/ha)	Seed yield (kg ha^{-1})		Oil yield (kg ha^{-1})
	2004-05	2005-06	2004-05	2005-06	2005-06	2004-05	2005-06	2005-06
Nitrogen								
N_0 (0 kg)	87.5b	163.7c	151.3b	352.3c	7740.3c	22.3b	254.4c	80.32c
N_{30} (30 kg)	98.0a	184.6b	162.1ab	406.8b	8960.2b	32.2a	332.4b	109.97b
N_{45} (45 kg)	104.9a	196.8ab	170.6a	436.8ab	9589.4ab	35.6a	436.9a	141.73a
N_{60} (60 kg)	107.1a	201.9a	176.2a	461.8a	10226.4a	34.6a	467.2a	150.91a
Phosphorus								
P_0 (0 kg)	90.9b	169.4b	152.4b	360.3b	8251.3c	23.9b	305.6c	94.61c
P_{10} (10 kg)	97.3ab	186.6a	163.3ab	418.4a	8928.3b	31.2a	354.3b	115.20b
P_{20} (20 kg)	102.8a	192.7a	169.3a	431.2a	9379.6ab	35.0a	403.7a	131.51a
P_{30} 930 kg)	106.5a	198.2a	175.1a	447.8a	9957.0a	34.6a	427.3a	141.62a
S.Em (±)*	2.8	3.8	4.9	10.6	223.2	1.5	15.5	5.19

* S.Em- Standard error of mean; **CD- Critical difference;

The means of N and P levels followed by different letters differ significantly at $P<0.05$

N and P obviously have an effect on all observed parameters. The higher the dose, the bigger the plant height, plant canopy, total dry matter accumulation, seed yield and oil yield and this for both elements. The treatments with maximum fertilization (30 kg N and 30 kg P) give the bests results. This is not surprising because 30 kg of fertilizer is a very low amount. The results are thus all in the linear part of the growth- and yield curve and the plateau where luxury consumption starts, is not reached by far. But in poor African regions, an amount of 30 kg is realistic, higher amounts would be too expensive.

An often used growing system is growing *J. curcas* as an intercrop with for example cassava or vanilla. Intercropping spreads the risk of a low yield due to drought, pests, diseases or other crop failures. Other crops can also benefit from shadow from the *Jatropha* trees. They will not be exposed to direct sunlight and the shadow will keep them cool (Yammama, 2009).
Table 11 gives the results of an experiment conducted at Soil Conservation Farm, India. In this experiment, *Jatropha* was planted on 1 August 2004. The plants were pruned on 22 January 2007. Summer groundnut was sown on 15 March 2007, seven rows of groundnut were sown in between 2 rows of *Jatropha* (Singh et al., 2007).

Table 11: Growth parameters of J. curcas after pruning (Source: Singh et al., 2007)

~Tabel 11: Groeiparameters van J. curcas na snoeien~

	Intercropping (*Jatropha* + Groundnut)		*Jatropha* sole crop	
Parameter	Maximum	Minimum	Maximum	Minimum
Height (m)	2.88	2.48	2.62	1.19
Girth (cm)	67	38	37	25
No. of branches per plant	32	18	28	19

The intercropping system of *J. curcas* and groundnut gives better maximum and minimum height, stem diameter and number of branches per plant then *Jatropha* in a monocrop system. These results confirm the proposition of the advantage of intercropping in comparison with monocropping.

Most *J. curcas* planted from seed will not yield in the first year, planted from cuttings they can give yield in the first year if the cuttings are taken from mature plants. However, total yield will be lower with vegetative propagated plants than with generative propagated plants (Hunter, 2009).

When the fruits are yellow, they are ripe. They will dry up and form a black, hard hull. The yellow stage is the best time for harvesting. Harvesting can be done by shaking and collecting the seeds off the ground.
One single plant in a plantation can give a yield from 2 to 2,5 kg seeds per year once the production optimum is reached at an age of about 6 years. (KEFRI, 2007).

The development of the seed yield during the first 4 years on 'Eagle Farm' from the company Viridesco in Mozambique, is shown in Table 12 (Hunter, 2009).

Table 12: Yield development of J. curcas on Eagle Farm (Source: Hunter, 2009)

~Tabel 12: Opbrengsontwikkeling van J. curcas op Eagle Farm~

	Planting year	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6 onwards
Kg / bush	0.00	0	0.3	0.6	1.1	1.7	2.3
Tonnes / ha of seed	0	0	0.5	1	2	3	4

On this plantation, there is also no yield in the first year. But after that, the yield is increasing highly within the following years. After 5 years, the yield per ha is 3 tonnes of seed or 1,7 kg per bush. A cost/benefit comparison is made in 'Economical applications'.

After harvesting, the fruits must be dried before dehulling. Drying is best done by spreading a layer of fruits on a plastic sheet or a surface of concrete. When the seeds are purposed to be sown, the fruits cannot be dried in full sunshine as this reduces the germination rate. Decapsulation of the seed can be done by hand or with a little 'nut cracker'. After careful drying, seeds can be stored in a well-ventilated shady room (KEFRI, 2007).

The following map (Figure 12) shows the *Jatropha* seed production areas in Africa, based on the annual amount of seed yield. The light colored areas are the areas with the highest potential for growing *J. curcas* (Muys et al., 2009).

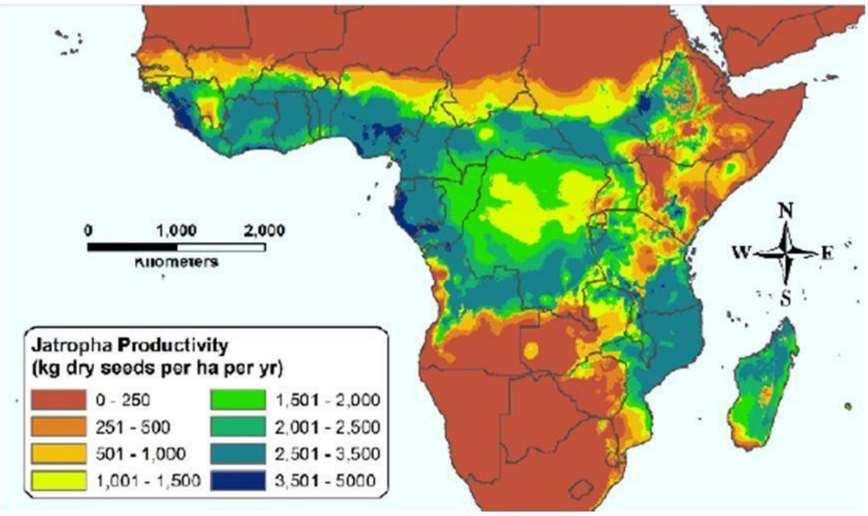

Figure 12: J. curcas seed production areas in Africa (Source: Muys et al., 2009)

~Figuur 12: J. curcas zaadproductie gebieden in Afrika~

The production areas on the map in Figure 12 match with the '*Jatropha* belt', which is shown in Figure 7 .

3.7 Economical applications

Planting *J. curcas* can be used to gain the so called ‘carbon credits’, as discussed in ‘Economical significance of trees’ (Horka, 2009). This is illustrated in Table 13, which shows that planting *Jatropha* has a negative ecological footprint and thus can be used as a carbon sink (Kolnes, 2009).

Table 13: Carbon footprint of J. curcas (Source: Kolnes, 2009)

Tabel 13: Koolstof footprint van J. curcas~

CGH emissions from sannah vegetation removal	**kg C/ha**	**kg CO_2/ha**
Living woody biomass (assessed from field test)	1382	5066
Living tree foliage (assumed to be 1/40 of woody biomass)	35	127
Living grasses (typical svannah)	6500	23833
Living roots (assuming 1/3 vegetations underground, 1/3 above ground	3941	14450
total	11857	43476
Carbon storage in a jatropha plantation	**kg C/ha**	**kg CO_2/ha**
Jatropha living biomass, assuming: 4200 trees/ha 7.5 kg dry matter / tree 3.0 kg C / tree	12600	46200
Carbon footprint (Negative = Excess storage) Ex. re-growth of grass		**-2724**

Anyhow, this table is assuming 4200 trees/ha. This is not very realistic. Based on water and nutrient requirements and the availability of these growth parameters, we see in practice that a planting density of 1100-2500 trees/ha is more realistic. The data thus must be considered critically.

Extractions of all parts of the plant are being used in traditional medicine since a very long time. It can work as a laxative, as cough treatment and for healing wounds (CAB International, 2005). It helps against toothache and strengthens gums. The oil can be used externally against skin diseases and rheumatism (CAB International, 2005).

Besides the medical purpose and the carbon credits, *J. curcas* can be used to produce a traditional fertilizer. The press cake resulting from processing the seed for oil can be used as manure (CAB International, 2005).
The seed cake contains 6% N, 3% P and 1% K with traces of Ca and Mg (Mc Lea, 2009).

But the most important economical application of *J. curcas* is the use of oil from the seeds. Seeds contain 30-40% oil which is suitable as biofuel for diesel engines but which is also useful for lighting, in soap and for candle making (CAB International, 2005).

Figure 13 shows the processing of *J. curcas* seeds in comparison with the fossil oil processing. This shows that using *Jatropha* as fuel will also give useful byproducts (the byproducts from processing fossil oil are not mentioned in the figure) (Achten et al., 2009).

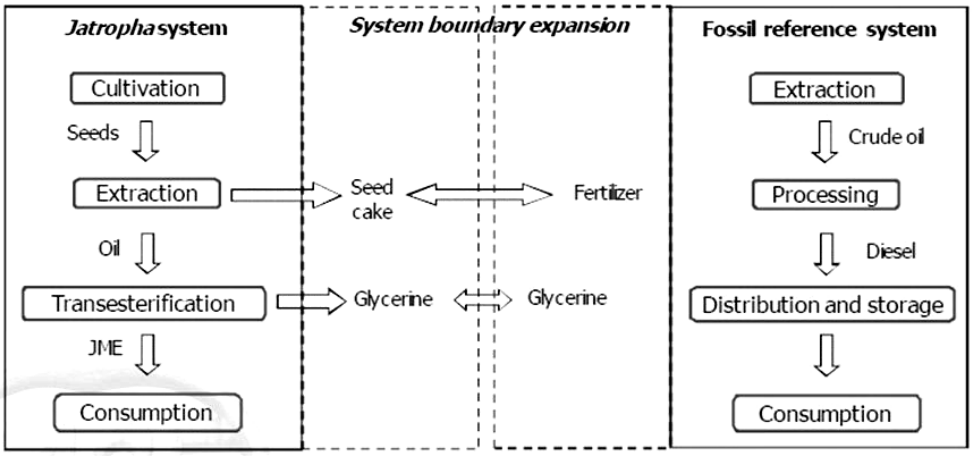

Figure 13: Comparison of processing of J. curcas and fossils (Source: Achten et al., 2009)

~Figuur 13: Vergelijking van de verwerking van J. curcas en fossielen tot brandstof~

Table 14 shows the economical value of the press cake and oil per kg seed (Lestari et al., 2009).

Table 14: Economical value of press cake and oil per kg seed of J. curcas (Source: Lestari et al., 2009)

~Tabel 14: Economische waarde van press cake en olie per kg zaad van J. curcas~

Components	Seed (%)	EUR/kg	EUR/kg seed
a. Partially fractionated seed			
Crude fat (Oil)	35	0.6	0.21
Unfractionated press cake	65	0.035	0.023
Total a	**100**		**0.23**
b. Total fractionated seed			
Crude fat (Oil)	35	0.6	0.21
Fractionated press cake			0.24
Crude Protein	17	1	0.17
Fiber/lignin	38	0.15	0.06
Carbohydrate	5	0.25	0.01
Ash	5	0	0
Total b	**100**		**0.45**

Total fractionated seed is more rentable than partially fractionated seed with an economical value of the press cake and oil of 0,45 EUR/kg seed against 0,23 EUR/kg seed.
To compare the income with the cost, Table 15 and Table 16 with production and harvest costs are added (Openshaw, 2000).

Table 15: Establishment costs J. curcas for commercial production (units: $ per ha) (Source: Openshaw, 2000)

~Tabel 15: Kosten voor economische productie van J. curcas (eenheid: $ per ha)~

Operation	Labour	Materials/machines	Total	Remarks
Ploughing	0.8	9.0	11.8	Animal drawn plough
Digging pit	6.5	0.0	6.5	1600 pits per ha
Applying FYM (Farmyard manure)	1.5	7.5	9.0	1 kg per hole
Seeding	0.5	2.8	3.3	two seeds per hole
Filling pit	3.3	0.0	3.3	
Weeding	6.5	0.0	6.5	
Applying fertilizer	1.1	20.5	21.6	160 kg NPK, two dressings
Year 1. Initial Establishment	22.2	39.8	62.0	
Year 2. Weeding	6.5	0.0	6.5	
Applying fertilizer	1.4	6.9	8.3	170 kg seed cake
Total year 2	7.9	6.9	14.8	
Year 3. Applying fert.	3.5	16.9	20.4	420 kg seed cake
Year 4. Applying fert.	7.1	33.9	41.9	840 kg seed cake
Year 5. Applying fert.	14.1	67.7	81.8	1680 kg seed cake
Year 6 and onwards. Applying fertilizer	21.2	101.6	122.8	2520 kg seed cake

[a] Labour wage $1 per day. Cost of seed cake ex-factory $35/t. Transport to farm $5/t. Handling $0.3/t. Spreading $8.4/t. 1 tonne of seed cake is equivalent to 150 kg. NPK (40:20:10).

Table 16: Harvesting cost Jatropha fruit and wood (units: $ per ha) (Source: Openshaw, 2000)

~Tabel 16: Oogstkosten voor Jatropha vruchten en hout (eenheid: $ per ha)~

Yield/ha (tonnes)	Collect	Remove coat	Shell	Total
Fruit				
Year 2 (0.50)	1.15	1.15	0.92	3.22
Year 3 (1.25)	2.87	2.87	2.31	8.05
Year 4 (2.50)	5.75	5.75	4.60	16.10
Year 5 (5.00)	11.50	11.50	9.20	32.20
Year 6 (7.50) and onwards	17.25	17.25	13.80	48.30

Table 17 resumes the income and costs, showing the profitability of *J. curcas*. The costs are based on Table 15 and Table 16, the estimated seed yield on Table 12 and the economical value on Table 14.

Table 17: Profitability of J. curcas of the first 10 years

~Tabel 17: Winst van J. curcas in de eerste 10 jaar~

Year	Estimated seed yield (ton/ha)	Production costs ($/ha)	Harvesting costs ($/ha)	Total costs ($/ha)	Total income ($/ha)	Profit ($/ha)
1	0	62	0	62	0	-62
2	0,5	14,8	3,22	18,02	299,25	281,23
3	1	20,4	8,05	28,45	598,5	570,05
4	2	41,9	16,1	58	1197	1139
5	3	81,8	32,2	114	1795,5	1681,5
6	4	122,8	48,3	171,1	2394	2222,9
7	4	122,8	48,3	171,1	2394	2222,9
8	4	122,8	48,3	171,1	2394	2222,9
9	4	122,8	48,3	171,1	2394	2222,9
10	4	122,8	48,3	171,1	2394	2222,9

It has to be mentioned that the costs for producing fuel from *Jatropha* seeds, can increase intensively due to the use of pesticides because of the high risk for pests and diseases on *Jatropha* in comparison with other crops. Also the cost of investments like land and machinery are not counted in this model. The calculated profit is thus not realistic, and has to be examined from case to case, depending on the site, climate, etc.

3.8 Pests and diseases

In this thesis we will only discuss the pests and diseases on *J. curcas* that appear in Kenya. We do this because the amount of pests and diseases that are found on *J. curcas* all over the world is too extensive.

It has been described to be hardy and resilient to pests and resistant to drought. However, with increased domestication and growing as monocrop the number of incidences of pests and diseases are increasing (Otieno et al., 2005).

3.8.1 Pests

3.8.1.1 Thrips (Thysanoptera: Thripidae)

The thrips species found on *J. curcas* include *Heliothrips haemorrhoidalis* (greenhouse thrips) and *Scirtothrips kenyensis*, both species are very polyphagous. Thrips can cause early leaf fall and can also be vectors for diseases. A thrips plague can be detected through a silvery or scratchy view of the leaves. The red nymphs appear on the underside of the leaves in big groups, as shown in Figure 14 (Otieno & Mwangi, 2009).

Figure 14: J. curcas leaf attacked by thrips (Source: Otieno & Mwangi, 2009)

~Figuur 14: J. curcas blad met thrips~

The life cycle of thrips contains the egg stadium, nymph stadium, pre-pupa and eventually adult stadium. The time required to complete the life cycle depends on species, temperature and other environmental circumstances.
Adults place their eggs in the leaves. The nymphs feed 4 to 5 days and then drop from the plant to pupate in the soil. After 2 days of pupation the adults begin to feed.
Feeding happens through rasping/sucking to extract plant fluids, leaving stippling on the leaf surface. This will result in chlorotic spots. Brown spots on the fruits may also occur, and if present during growth this can result in cracks.
Males are rare and reproduction is mainly parthenogenetic, with females producing up to 47 eggs during their lifetime of about 1 month with an average temperature of 21-28°C (CAB International, 2005).
Dimethoate is active against thrips (Otieno & Mwangi, 2009).

3.8.1.2 Rainbow shield bugs or blue bugs (Heteroptera: Scutelleridae)

Callidea dregii is the most common blue bug in Kenya (Figure 15). They are mobile and can fly from one place to a neighboring plantation. It are sucking bugs and they vary from metallic-blue to green and black. They pierce young seeds, which causes shedding.

They can be controlled by fenthion (Otieno & Mwangi, 2009).

Figure 15: Rainbow shield bug on J. curcas plant (Source: Otieno & Mwangi, 2009)

~Figuur 15: Rainbow shield bug op J. curcas plant~

3.8.1.3 Mealy bugs (Homoptera: Pseudococcidae)

Mealy bugs suck out the plant's sap, resulting in yellowing, withering and drying of the plants and shedding of leaves and fruit. The leaves and fruits become covered with a lot of sticky honeydew (Figure 16) , which serves as a medium for a lot of fungi. Mealy bugs can also transmit several plant viruses.

On *J. curcas*, there are 2 species of mealy bugs described: *Ferrisia virgata* (striped mealy bug), one of the most polyphagous mealy bugs known, and *Planococcus sp.* (common mealy bugs) (Otieno & Mwangi, 2009).

There is found a correlation between population density and daily maximum and minimum temperatures, but not between population density and relative humidity.

The adult females are oval, grayish-yellow with two longitudinal dark stripes on the dorsum and become 4-4,5 mm long (CAB International, 2005).

Fenthion is a good chemical to destroy mealy bugs (Otieno & Mwangi, 2009).

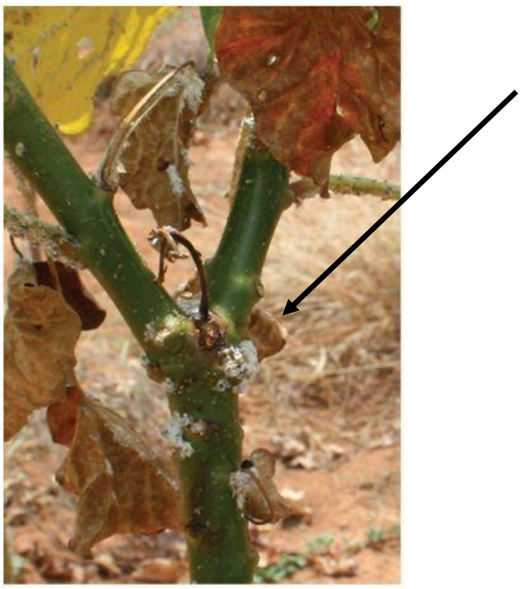

Figure 16: J. curcas under attack of mealy bugs (Source: Otieno & Mwangi, 2009)

~Figuur 16: J. curcas met mealy bugs~

3.8.1.4 Whiteflies (Hemiptera: Aleyrodidae)

Both adult and nymph stages of whiteflies (Figure 17) feed by sucking plant juices. This causes chlorotic spots on the leaf surface. Eventually, the whole leaf turns yellow and falls off. They are also important vectors for plant viruses.

Whiteflies are tiny, snow-white and look a bit like mots. The most common whitefly is *Bemesia tabaci* (Otieno & Mwangi, 2009).

Figure 17: Whiteflies on a J. curcas leaf (Source: Otieno & Mwangi, 2009)

~Figuur 17: Witvliegen op een J. curcas blad~

3.8.1.5 Cotton stainer bugs (Hemiptera: Pyrrhocoridae)

Dysdercus suturellus (Figure 18) is a narrow bodied, long legged bug from 3-5 mm length. It has a bright red thorax and brown wings crossed with yellow. It damages the plant by puncturing the fruit which will fall off.

Fenthion and imidacloprid are useful against cotton stainer bugs (Otieno & Mwangi, 2009).

Figure 18: Cotton stainer bug on J. curcas leaf (Source: Otieno & Mwangi, 2009)

~Figuur 18: Cotton stainer bug op J. curcas blad~

3.8.1.6 Golden beetles (Chrysomelidae: Alticinae)

Apthona sp. (Figure 19 and Figure 20) feed on the leaves, leaving holes or skeletons of leaves. The adults often come from surrounding vegetation, they are polyphagous (Otieno & Mwangi, 2009).

Figure 19: Aphtona spp. eating a J. curcas leaf (Source: Otieno & Mwangi, 2009)

~Figuur 19: Aphtona spp. die zich voeden op een J. curcas blad~

Figure 20: Aphtona spp. on J. curcas

~Figuur 20: Apthona spp. op J. curcas~

3.8.1.7 Stomphastis species (Lepidoptera: Gracillariidae)

These moths are generally small. The caterpillars are leaf miners which feed on leaves, forming mines that dry out (Figure 21).
Diazinon can be used to combat the caterpillars (Otieno & Mwangi, 2009).

Figure 21: J. curcas leaf attacked by Stomphastis caterpillars (Source: Otieno & Mwangi, 2009)

~Figuur 21: Stomphastis rupsen op J. curcas blad~

3.8.1.8 Pempelia spp. (Lepidoptera: Pyralidae)

The greenish brown caterpillars of *Pyralidae morosalis* (Figure 22) feed on leaves and stem bark, leaving a web behind. They bore into stems and fruits producing galleries of silk (Figure 23).
Lambda-cyhalothrin destroys the caterpillars (Otieno & Mwangi, 2009).

Figure 22: Pempelia caterpillar has eaten J. curcas leaf (Source: Otieno & Mwangi, 2009)

~Figuur 22: Vraat van Pempelia rupsen op een J. curcas blad~

Figure 23: Web and silk of Pempelia spp. on J. curcas (Source: Otieno & Mwangi, 2009)

~Figuur 23: Web en zijde van Pempelia spp. op J. curcas~

3.8.1.9 Broad mites (Acari: Tarsonemidae)

The adult broad mites are very small (0,2 to 0,3 mm length for females, half of this for males). While feeding on the leaves, they secrete a toxin or growth regulator. Symptoms are shortening of internodes, blistering, shriveling and curling of leaves and leaf discoloration (Otieno & Mwangi, 2009).

3.8.2 Diseases

3.8.2.1 Powdery mildew

Powdery mildew is found to be caused by *Erysiphe euphorbiae* in Kenya. The symptoms are a white floury colour of the leaves, shoots and fruits which turns into black patches after some time (Figure 24). The infection chance increases with a humid environment.
To fight mildew, chemicals based on triadimenol, penconazole, flusilazole, mancozeb and propineb can be used (Otieno & Mwangi, 2009).

Figure 24: J. curcas fruits infected with mildew (Source: Otieno & Mwangi, 2009)

~Figuur 24: J. curcas vruchten besmet met echte meeldauw~

3.8.2.2 Root rot (Phytophtora spp.)

Phytopthora spp. have been reported on *Jatropha* in Kenya. High humidity and temperatures increase the infection danger. Symptoms are yellowing of the leaves, reduced leaf size and eventually death of the plant (Figure 25) (Otieno & Mwangi, 2009).

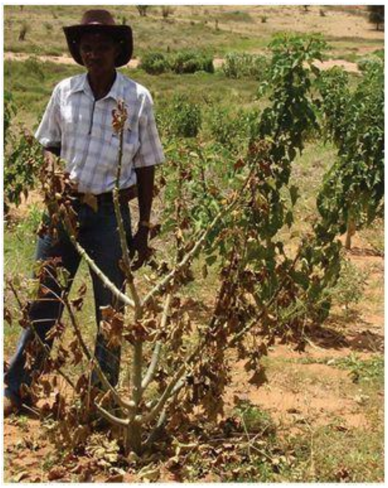

Figure 25: J. curcas plant infected with Phytophtora (Source: Otieno & Mwangi, 2009)

~Figuur 25: J. curcas plant geïnfecteerd met Phytophtora~

The life cycle of *Phytophtora* fungi is illustrated in Figure 26.

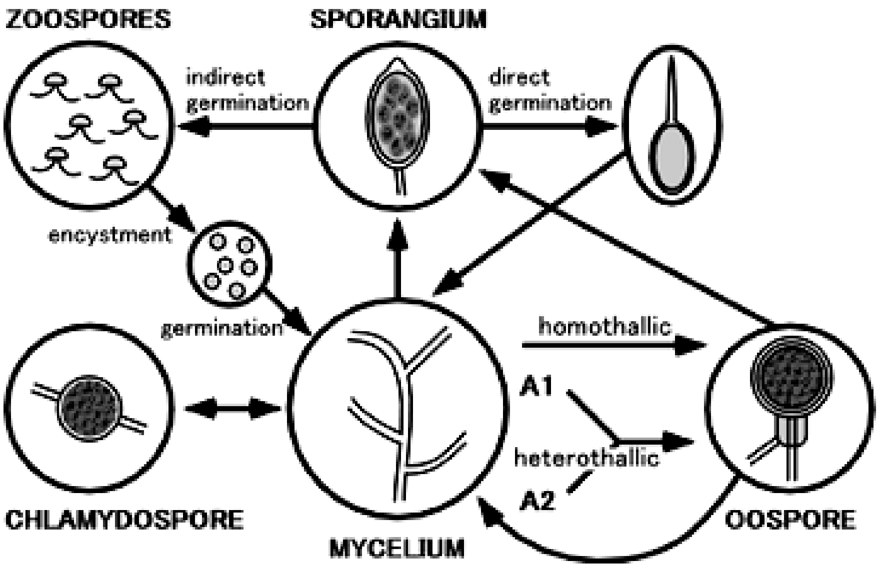

Figure 26: Life cycle Phytophtora spp. (5)

~Figuur 26: Levenscyclys van Phyotophtora spp.~

Copper is effective against *Phytophtora spp*. (Otieno & Mwangi, 2009).

3.8.2.3 Leaf spots

Leaf spots (Figure 27) are mainly caused by the fungus *Alternaria spp.*. The infection causes brown dead portions of leaves. Infected leaves are shed early (Otieno & Mwangi, 2009).

Figure 27: Leaf spots on J. curcas leaf due to Alternaria infection (Source: Otieno & Mwangi, 2009)

~Figuur 27: Bladvlekken op J. curcas veroorzaakt door een Alternaria infectie~

3.8.2.4 Stem cancer

Stem cancers are caused by the fungi *Fusarium spp*., *Alternaria spp*. and *Drechsleria spp*.. They cause brown to dark-brown lesions which are distinctly marked from the healthy green parts. The wounds increase and will eventually girdle the stem. The part of the plant above the wound will dry out but remain standing. More shoots will be produced below the point of infection (Otieno & Mwangi, 2009).
Spraying can be done with tebuconazol, mancozeb and carbendazim.

3.8.2.5 Viruses

The cassava mosaic virus has been detected on *J. curcas* in Kenia. Symptoms are chlorotic spots and reduction in leaf size. This disease is caused by cassava mosaic Gemini virus (CMG) and is transmitted by white flies (Otieno & Mwangi, 2009).

4 *Melia volkensii*

4.1 Introduction

Melia volkensii (mukau) is a tree with a great potential in dryland areas. It has a high value timber and tolerates drought very well. It can be used in agroforestry systems because of its little completion with other crops (ICRAF, 2005). The main priority is to develop an appropriate propagation method, which still causes a lot of problems. It has to be an effective method but still simple enough to be used by local farmers. There's also the need to investigate the genetic variation between the *M. volkensii* trees, used for economical purposes. However it is a high potential tree, little information is available and more research is highly necessary.

4.2 Classification

Domain: Eukaryota
Kingdom: Viridiplantae
Phylum: Spermatophyta
Subphylum: Angiospermae
Class: Dicotyledonae
Order: Rutales
Family: Meliaceae
Genus: Melia
Species: Melia volkensii
(ICRAF, 2005)

Local name: mukau

4.3 Habitat

M. volkensii occurs in the natural latitude range from 5°N – 4°S and on an altitude from 350-1680 meters above sea level. In its natural habitat, the mean annual rainfall varies between 300 and 800 mm in a bimodal rainfall regime and the mean annual temperature is 19-25°C. The temperature can rise up to 33°C and the minimum temperature is 5°C. The dry season is

7-9 months long. The soil texture in the natural habitat of *M. volkensii* is medium with a free soil drainage and neutral soil reactions, often sandy, clay and shallow stony soils (ICRAF, 2005).

4.4 Morphology

M. volkensii (Figure 28) is an open crowned, loosely branched tree, grown for its wood. Mature trees have an average height of 18 m. The average diameter of a mature tree is 1 m. They have a grey, fairly smooth bark which is furrowing with age.
The sapwood has a white color, the heart wood is pale red-brown and the timber is immune to termites (ICRAF, 2005).

Figure 28: M. volkensii at Kiambere

~Figuur 28: M. volkensii in Kiambere~

4.4.1 Leaves

The leaves are bright, light green coloured and bipinnate with opposite leaflets. There are 3-7 leaflets per pinnae, they become hairy during elongation. The leaflets have an oval to lanceolate shape, becoming smaller closer to the apex. The margin can be smooth or serrated. Leaf sizes vary from 4-7,5 cm long by 0,5-2,5 cm wide (ICRAF, 2005).

4.4.2 Flowers

M. volkensii has white flowers in dense-head panicles (Figure 29). The inflorescence is up to 12 cm long, axillary and appears on older branches. The white, tetra- to pentamerous petals are 5-7 mm long, free and they may curl backwards. Male and female flowers occur on the same tree. The number of stamens is equal to the number of petals and they are united in a tube (ICRAF, 2005).

Figure 29: Flower M. volkensii at Kibwezi

~Figuur 29: Bloem van M. volkensii in Kibwezi~

4.4.3 Fruits

M. volkensii has an oval drupe-like fruit (Figure 30). The colour changes from green to pale grey during maturation. Fruit size varies between 2,8-4 cm long by 1,7-2,2 cm wide. The fruits have a very thick, bony endocarp (ICRAF, 2005).

Figure 30: Fruits of M. volkensii at Kiambere

~Figuur 30: Vruchten van M. volkensii in Kiambere~

4.4.4 Seeds

The seeds (Figure 31) are oval and have to be removed from the hard fruit endocarp before sowing. Seed dormancy can be broken by scarification.

Figure 31: Seeds at Kiambere

~Figuur 31: Zaden in Kiambere~

4.5 Development

M. volkensii starts to flower at an age of 2-3 years. Twice a year, early in the dry season, it sheds its leaves. However, on cultivated land, *M. volkensii* keep their leaves longer into the dry season. 2-3 weeks before the start of the rains, the new leaves start to appear (ICRAF, 2005).
Also flowers and fruits are produced twice a year. Fruits ripe at the end of the dry season while the leaves emerge. Flowers are pollinated by bees and sometimes self-pollination does occur (ICRAF, 2005).
From the onset of flowering, it takes 12-13 months for fruits to reach maturity.
Fruits are eaten by animals such as giraffes and goats, this way the seeds are distributed. Once the seed starts to germinate, it takes 4-10 days before germination is completed (ICRAF, 2005).

4.6 Growing *Melia volkensii*

The advantage of *M. volkensii* is the drought and termites tolerance.
Mukau can be propagated vegetative through cuttings as well as generative (ICRAF, 2005).
The difficulty has always been, and still is, the germination (ICRAF, 2005). The problem is the hard shell, so the seed is very hard to extract. The most common way is to collect seeds that have been excreted by goats. These seeds are already extracted because of the juices in the goat's digestion.
It's also possible to use root cuttings but they often result in unstable trees. Stem cuttings can also be used but rooting is difficult to achieve.
In vitro vegetative propagation is a viable possibility but also here rooting is a problem (ICRAF, 2005).
When using seed for propagation, there's also the problem of dormancy. Seed can remain dormant for 2-5 years before natural germination. Therefore, the seed has to be scarified before sowing. This scarification is cutting the seed longitudinally through the integument, perisperm and endosperm from the centre to the micropyle. Without scarification, the seed coat will inhibit the seed to absorb water and the root will not be able to pass the seed coat. After that, the seed has to be soaked in water for 6 hours.
Trees for timber have to be pruned, side branches are removed to achieve a straight stem free of knots (ICRAF, 2005).
Animal damage does occur, especially on seedlings, but no serious pests or diseases have been reported yet in the literature. There have been reported some problems in the nursery, but the cause of this has not been examined yet (ICRAF, 2005).

There has been reported cancer on *M. volkensii* trees at the Kibwezi Mukuyu Farm in Kenya, which is examined and described later in this thesis.

4.7 Economical applications

M. volkensii is one of the most profitable tree species on drylands, as discussed in 'Farming on drylands'.
The round wood from *M. volkensii* is used for building poles. The sawn wood can be used as a light construction building timber and for carpentry. It can also be used to produce musical instruments and wood carvings (ICRAF, 2005).
The timber is of a high quality and close-grained and is produced in a 10-15 year rotation. The darker heartwood is comparable with that of camphor (*Ocotea usambarensis*) and Meru oak (*Vitex keniensis*), which are both highly prized hardwood species from the Kenyan forests. *M. volkensii* wood is durable and resistant against termites (ICRAF, 2005).
Charcoal can also be produced from the wood.
Different plant parts can be used as fodder and mukau produces secondary metabolites which can be used as medicinal products and as pesticides. The flowers are used for honey production. There have been extracted bioactive triterpenoids from the root bark which show marginal cytotoxicities against certain human tumour cell lines (ICRAF, 2005).
In agroforestry, *M. volkensii* also has a purpose as soil improver and conservator (ICRAF, 2005).

Experimental part

5 Description of the company Better Globe Forestry Ltd.

Better Globe Forestry Ltd, part of The Better Globe Group from Norway, is working in Kenya since 2004. Their mission is to fight poverty through massive tree planting, micro financing of farmers for sustainable agricultural programmes, educational programmes and building schools.
Better Globe Forestry Ltd wants to make Kenya a greener and healthier place in which to live. They do this by focusing on the development of profitable, commercial tree plantations in ASALs that will deliver environmental and humanitarian benefits.
BGF recognizes that a good neighbourhood policy is the best way to protect their plantations and they conduct all their transactions with integrity and in accordance with good business ethics and practices. BGF also concentrated on consultancy, implementation and training services for local people. The research done by BGF is still in an early stage, but will increase. The research done at this moment is concentrated on irrigation and water conservation, soil improvement, genetic improvement of mukau, *Acacia senegal* and *Jatropha,* in vitro propagation of mukau and *J. curcas*, pests and diseases management on mukau and *J. curcas* and the silvicultural management of mukau and *J. curcas*.
As final, it has to be mentioned that Better Globe Forestry Ltd. is associated with the publishing of MITI, the first high quality Tree Business Magazine in East-Africa.

6 Description of the pilot plantation in Kiambere

6.1 Geographical aspects

Better Globe Forestry Limited started a pilot plantation in Katithini by Lake Kiambere in Mbeere district (map in Appendix V). Lake Kiambere is an artificial lake created by damming the Tana river for producing electricity.
Kiambere is located 130 kilometres northeast of Nairobi and is elevated 700-800 metres above sea level. It is located in a semi-arid zone, the average rainfall amounts 500-700 mm a year. In 2008 the rainfall in Katithini, measured from March to December, amounted to only 231,5 mm of which 116,5 mm in March-April and 115 mm in October-November. In 2009, the rainfall in March-April amounted to only 67,5 mm. The climate is hot and tropical and evaporation exceeds rainfall by far. Rainfall is irregular and completely dry years do occur.

Around the lake, a buffer zone is created by The Kenya Government for its protection and security. The Tana and Athi Rivers Development Authority (TARDA) manages this buffer zone. TARDA and its parent Ministry of Regional Development are both partners of Better Globe Forestry in the project of the pilot plantation.
Before Better Globe Forestry started to work in this area, farmers had invaded almost the complete buffer zone and used it for cultivating maize, millet, sorghum and cowpeas.
This is subsistence agriculture, most of the time with negative returns, compounded by a general decrease in soil fertility as proper fertilizing is not practised. Neither is soil conservation, explained by the simple fact that establishment of terraces is quite an investment, which nobody wants to do on land that is not in ownership. Result is rampant erosion of the topsoil when the rains break on a completely bare and not protected surface.
Over 65% of the population in the area lives below the absolute poverty limit with an income of less than 1 US dollar a day and the unemployment is big.

The pilot plantation was started in November 2006 and covers 100 hectares of land. This is yet the first phase of a major tree plantation of 5000 hectares in the area around Kiambere dam on the Tana River.
It was noted that the farm was previously under maize cultivation, beans and *Cajanus cajan* (pigeon peas).

6.2 Managing system

6.2.1 Introduction

The pilot project of 100 hectares is used as a trial ground for planting *J. curcas*, *Azadirachta indica* (neem) and *Melia volkensii* (mukau).
It is the largest plantation in Kenya of *J. curcas*, which is planted on 55 hectares with about 50 000 *Jatropha* plants.
On the plantation, trials on different planting/sowing methods, seedling propagation in nursery, planting density and dry seasoning planting with different water intensities have been executed.
The plantation is divided in different parts. The number of seedlings at the end of 2009 in every part of the plantation is given in Table 18 and Figure 32 show a sketch of the arrangement of the plantation.

Table 18: Characteristics of different parts of the plantation

~Tabel 18: Kenmerken van de verschillende delen van de plantage~

Block	spacing (m)	seedlings	area (ha)
I, JC1	1.5x3.5	5.550	2,91
I, JC2	2x3.5	38.948	27,26
I, JC3	2.5x3.5	24.273	21,24
I, neem	4x4	14.665	23,46
I, mukau	4x4	2.517	4,03
II, neem & mukau	4x4	4.749	7,60
trials JC	various	3.168	1,94
trials mukau	4x4	4.937	7,90
TOTAL		98.807	96,34

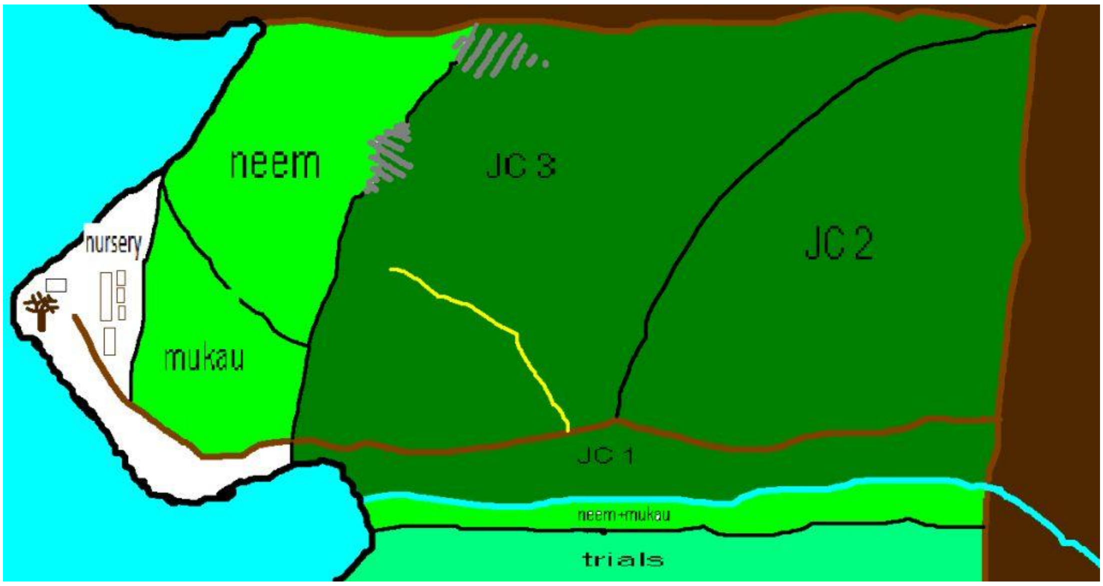

Figure 32: Arrangement of the plantation in different blocks

~Figuur 32: Verdeling van de plantage in verschillende blokken~

The yellow line shows the plot where 2 experiments were conducted: the experiment with the sticky plates (to capture insects) and the experiments to examine the relation between growth of *J. curcas* and soil properties, as discussed later.

6.2.2 Nursery of *Jatropha curcas* and *Melia volkensii*

Growing a good mukau tree, starts with selection of the seeds, the motherplant has to be of good quality. The fruits have to look good, they need to have brown spots, otherwise the fruits are not mature or of a bad quality. The fallen fruits and the biggest ones are the best. Best time for collection in hot areas is April-August with a peak period in July.

The fruits are being depulped to release the nut. Then the nuts have to be air-dried for 2 hours, not in direct sunlight but in the shade.

The seeds of mukau are surrounded by a very hard shell. This nut has to be cracked with a special nut cracker to release the seeds. Also the seeds have to go through a selection, all the pale and very dark seeds have to be eliminated. The seeds have to stay in a Bavistin (systemic fungicide, active ingredient is carbendazim 50 %) solution (20g Bavistin/20 l water) for 1 day to eliminate possible fungi on the seed and this way avoid infection of the little seedling. Next, the top of the selected seeds is removed by pinching. After that, the seeds get a little incision to simplify the germination. This carving is very delicate, because it is important not to damage the embryo.

The seeds are then sowed in the propagator, about 3 cm deep. Here they get a solution of Bavistin (150-200 g/ 100 l water) together with water. In the propagator, the soil is covered from the sun and the temperature is kept between 28°C and 32°C by covering the propagator. The bottom of the propagator is covered with plastic, to avoid fungi, insects or bacteria to come into the propagator. The sand is renewed every time new seeds are being sowed. The propagator is covered with plastic to avoid pollution.

When the seeds start to germinate after about 7 to 9 days, they are planted in a polypropylene bag filled with moist soil and fertilizer (0,5 kg Mavuno/500 polybags). Mavuno contains 10% N, 26 % P_2O_5, 10 % K_2O plus the meso –and micro elements Ca, Mg, S, B, Mn, Cu and Zn. With planting, it is very important to make sure that the soillevel is on the same height of the plant as it was in the propagator because the little seedlings do not have leaves yet and respiration is done through the stem.
The little seedlings are still covered a bit from the sun and they are watered as much as one needs. Mukau trees are very sensitive to doses of water. When they get too little, they will die. When they get too much, they will also die and the line between these two limits is very thin. The daily dose for 1000 seedlings of about 15-20 cm height is 30 litres.

The seedlings in the nursery are being checked on pests and diseases, and if necessary spraying is done. It is also important to select the seedlings in the nursery. Weak, badly formed and undersized seedlings must be eliminated. Eliminating 10-20% of the seedlings in the nursery leads to higher survival rates and better growth and yields.

Seedlings of *J. curcas* stay in the nursery for about 3 months and also receive 1 g of Mavuno fertilizer per seedling.

6.2.3 Field

After 2 to 3 months, the selected mukau and *J. curcas* seedlings are being planted out in the field. Before planting, the soil has to be prepared. This means burning the plants that have to be removed, weeding (manual or with glyfosate) and pitting. While planting the seedlings, it is important that there is a minimal exposure of the root system to the sun. Immediately after planting, every seedling gets 10 litres of water and 50 g of Mavuno; another 50 g of manure is applied 3 months later.

When seedlings of *Jatropha* and mukau are planted out in the field, the immediate surroundings of the seedling has to be mulched without the mulch touching the stem. The mulch will reduce evaporation of water and will decrease the soil temperature. High temperatures can lead to sunburn and even mortality. The mulching material is usually grass. Leaves and twigs are also possible, but they are harder to get.

The little soil fertility still present, must be kept so anti-erosion interventions are very important to conserve the top soil from being washed away. Around every plant there must be soil work done like ripping, ploughing and weeding. Weeding is done two times a year.

Where gullies appear, construction of check-dams made of sticks and stones is very effective in diminishing erosion. In most of the plantation area, soil erosion has been decreased by over 90% after only two years of intervention.

In this climate, it is necessary to water the plants the first year with 5 litres a week, given all at once, if planting is done during the dry season. When the plant is older and the root system is developed well, it will protect itself by defoliation during the dry season and it will immediately regrow after the first rains. So from the moment the plant is more than 1 m high, it is not necessary anymore to water the plant.

J. curcas as well as mukau trees are being pruned. On *J. curcas*, it leads to more branches by reducing the apical dominance, and thus to more fruit yield. Mukau trees are being pruned to create a stem with little side branches or scarves from previous side branches to increase the usable wood yield. Mukau has to be pruned as following:

- During the first months of growth (4-6 months) nip the buds of young branches by hand or remove most grown branches up to workable (no ladder involved) man height (1.5-1.7m), in 2-3 times according to growth;
- Take care to leave some branches along the stem to allow for increased diameter growth so that the stem gets stronger and will not bend easily during strong winds.
- Remove branches when using a two-legged ladder at least 3m high. Don't make wounds by tearing the branches off.
- Avoid the formation of whorls of branches by eliminating them in 2-3 times (eg. whorl of 6-7 branches all within a length of 10-15cm of stem; clean the stem by removing them gradually like firstly 2 branches then another 2-3 and afterwards the remainder, in a period of 3-4 months).
- When pruning a young tree shorter than 4m, eliminate double leaders and try to obtain an equilibrated canopy (e.g. the branches that are left, are distributed along and around the stem, not only at one side of the stem).
- After 2 years, stem diameter is supposed to be thick enough to allow for complete pruning up to 4m and afterwards (3-4 years), up to final length (6-6.5m according to site).

Frequently, the health of plants is being checked. Sick or dead material is removed and a new seedling takes his place. If it concerns a *Phytophtora* or *Fusarium* infection, copper is sprayed on the surrounding plants which will decrease their susceptibility.
When pest insects or a fungi infection are being detected, spraying is done in the attacked area. When it concerns a flying insect of a quickly spreading infection, the whole plantation is being sprayed.

As an example, the detailed management schedule for mukau in arid and semi-arid areas is added in Table 19.

Table 19: Management schedule for mukau (Source: Vandenabeele, 2009b)

~Tabel 19: Teeltschema voor mukau~

year	Item	Remarks
1	clearing & ripping & harrowing	by bulldozer, ripping down to 80cm, and tractor
1	Pitting	20x20x20cm, 400 pits
1	Planting	400 seedlings + 20% beating up (5x5m planting distance)
1	Fertilising	twice 50g fertiliser per seedling
1	Maintenance	ploughing or harrowing, 15-20cm deep
1	spraying with herbicide	close to the trees where the harrowing did not reach
1	1st pruning	up to 1m, at 4 months (secateur and by hand)
1	2nd pruning	at 6 months (pruning saw, secateur and by hand)
1	3rd pruning	at 8 months (pruning saw, secateur and by hand)
2	Maintenance	ploughing or harrowing, 15-20cm deep, 4 times
2	Fertilising	100g fertiliser per tree, mixed with superficial soil layer
2	Spraying with herbicide	close to the trees where the harrowing did not reach
2	4th pruning	with ladder, selectively removing branches
2	5th pruning	with ladder, selectively removing branches
3	6th pruning	with ladder, selectively removing branches
3	Maintenance	ploughing or harrowing, 15-20cm deep, 4 times
3	Fertilising	200g fertiliser per tree, mixed with superficial soil layer
4	7th pruning	up to 5m
4	Maintenance	ploughing or harrowing, 15-20cm deep, 4 times
5-7	Maintenance	ploughing or harrowing, 15-20cm deep, 2 times
8	Thinning	1/4 or 100 trees, DBH 25 cm, 5 m
	volume/ha (m3)	17.17
8-19	Maintenance	ploughing or harrowing, 15-20cm deep, 2 times
20	Felling	300 trees, DBH 50cm, 5m
	volume/ha (m3)	206.06
	TOTAL VOLUME/HA	223.23
	MAI (m3/ha/y)	11.16

6.3 Problems

The farmers around the plantation have never invested in anti-erosion measures or taken initiatives to preserve soil fertility as they are illegal squatters who could be evicted any day. The consequence of this lack of management, is that the top soil, which contains most of the nutrients, has been washed away by erosion. This becomes an even bigger problem when the soil gets in the lake. That way, it contributes to the silting of the lake and it causes serious problems for the power station of KenGen.

Besides the erosion problem, there is also the sensitivity of *J. curcas* to several pests and diseases. Better Globe Forestry has already been cooperating with the Kenya Forest Research Institute (KEFRI) to identify and manage these pests and diseases, but it stays a major problem on the plantation. It is important to notice the presence of an insect or disease immediately, so they can be sprayed before the pest or disease gets the chance to spread all over the plantation.
Root rot is also a very big problem on *J. curcas* as well as on mukau, mainly in the field but also in the nursery.
At this moment, spraying is very intense and some insects and fungi can become resistant to the used chemicals.
This item is discussed in detail under the point 'Managing pests and diseases on *J. curcas* and *Melia volkensii*'.

Another observation is the difference in growth between *Jatropha* trees planted in different areas. Soil fertility varies in the plantation area, and it is not always clear what causes this difference. Soil fertility in general is very low all over the plantation area.
The relationship between the soil and the growth of *Jatropha* trees is further discussed below.

At last there are also some problems with germination in the nursery. Germination percentages are low and infections with bacteria and fungi occur often. This is a source for new experiments to improve germination percentage, perhaps through disinfection of the sowing ground, biological control of seedling fungi, different sowing methods and further on.

7 Managing pests and diseases on *Jatropha curcas*

7.1 Purpose

One of the biggest recent problems in growing *J. curcas*, is the high susceptibility for pests and diseases. To manage these diseases, we must know which organisms cause the problems. After that, a proper measure can be proposed, taking the risk for resistance to pesticides into account. The measure has to be effective, as less vulnerable for the environment as possible and cost-effective.

7.2 Materials and methods

7.2.1 Identification of the pests

At first, the pest organisms present on the plantation were collected on the field. The insects were identified using identification keys.

To get a better view of the seriousness of the insect pests, an experiment with sticky plates was conducted on the plot shown in Figure 32. The sticky plates were attached on the stem of the plants with rope and every plant was individually numbered. Yellow and blue sticky plates (attract different kind of insects) were alternately placed on different heights. ‘High’ placed plates are located at the top of the plant, ‘low’ placed plates at half height of the plant. The plates were not fixed at an invariable height for ‘high’ and ‘low’ because the height of the plants was very variable.

There were 3 sticky plates in one row of *J. curcas* plants with each time 2 plants in between two plates in the rows. Thirteen rows were sampled with sticky plates. Between the rows with sticky plates, there were always 4 rows of plants left in between. This makes a total amount of 39 sticky plates. The organization of the sticky plates is clarified in Appendix VI. The plates were evaluated every week using the ‘Card for monitoring insects on sticky plates’, writing down the number of every insect species per plate. The evaluation of the number of insect species can be made be making the difference in amount with the previous observation. The first observation was done at 2 September 2009.

7.2.2 Identification of the diseases

Samples were taken from the sick plant parts. These samples were chopped and disinfected with commercial javel (NaClO) in the laboratory and then plated out on a medium of water agar in a sterile airflow. The petri scales were closed with parafilm and put in the incubator at 15°C. After 5 days, the first fungi started to grow and every fungus was replaced on a new petri scale. This pattern was repeated until every petri scale only contained one fungus in it's pure form. The fungi stayed in the incubator and were replaced on new medium every 2 weeks. After about 3 months, the fungi were replaced on a PDA medium in the laboratory of Hogeschool Gent at Bottelare. The visual properties were evaluated as a first step of determination. The fungi were replaced on new medium every 1-2 weeks and regularly examined under the microscope. Once they started to sporulate, a detailed determination with the key 'Illustrated Genera of Imperfect Fungi, fourth edition (H.L. Barnett & Barry B. Hunter) ' was possible.

7.2.3 Analysis of the spraying system

At last, the current used spraying system was analyzed by studying the spraying records from June 2008 (no earlier spraying records were available) until May 2009. This can be used to make a 'seasonal calendar' of used chemicals, to count the amount of chemicals used and to calculate the costs of the treatments.
These three aspects can be used to evaluate the current spraying system and if possible propose an alternative reducing the costs, the danger for resistance, the effectiveness and the impact on the environment.

7.3 Results

7.3.1 Identification of the pests

Following insects were identified on the plantation:

- **Blue shield bug – *Calidea dregii***
  Blue shield bugs feed on the flowers, causing big decreases of the seed yield.
- **Thrips – *Heliothrips haemorroidales* and *Scirtothrips kenyensis***
  They occur mainly on seedlings.
- **Striped mealy bug – *Ferrisia virgata***
  This insect appeared mostly around 'boma's' (placed where people used to live and hold animals). It attacks adult plants.
- **Leaf miner – *Stomphastis sp.***
  Leaf miner attacks seedlings as well as adult plants.
- **Caterpillar – *Pempelia Morosalis***
  This caterpillar feeds on the leaves and bores the stem.
- **Golden beetle – *Aphtona sp.***
  Golden beetles only appear when the temperatures are moderate.
- **Termites**

The experiment with the sticky plates was obstructed because 74,4 % of the plates was blown away by the wind. Nevertheless, monitoring was done on the plates that were left and the 'Card for monitoring insects on sticky plates' of 2 September 2009 is added in Appendix VII. Table 20 shows the insects that were found on the sticky plates at 2 September 2009.

Table 20: Insects found on the sticky plates at 2 September 2009

~Tabel 20: Insecten op de vangplaten op 2 september 2009~

Insect	Total amount
Mosquito	6
Coleoptera	16
Small unidentified fly	207
Big unidentified fly	11
Butterfly	1
Ant	4
Spider	1

The experiment was repeated with new plates that were tied better to the plant but still they were blown away after a few days.

7.3.2 Identification of the diseases

Following fungi were identified in the laboratory (up to the level of genus) (Table 21).

Table 21: Identified fungi on J. curcas

~Tabel 21: Geïdentificeerde schimmels op J. curcas~

Sampled organ	**Identified genus**
Roots	*Fusarium*
	Trichothecium
Leaves	*Alternaria*
	Sirosporium

The root samples were taken from plants that were rotting from the root up to the top of the plant. The leaves samples were taken from leaves with leaf spots.
It has to be mentioned that also samples from the stem were plated out, but this only resulted in a bacterial infection. This bacteria is not further examined because this is not the specialty of the laboratory at Bottelare.

Fusarium (Figure 33) is a genus from the phylum of the Ascomycota. It is widely distributed in the soil and in association with plants. It includes a number of economically important plant pathogenic species, for example *F. graminearum*, *F. culmorum, F. solani, F. oxysporum and F. chlamydosporum* which can cause root rot and seedling blight. However, they are not reported on *Jatropha curcas* yet. *Fusarium* species survive saprophytic on plant residues and have a range of alternative host plants.
Protection against and suppression of *Fusarium* infections includes crop rotation, soil measurements, removal of crop residues, chemical suppression by metconazole, prothioconazole and tebuconazole and the use of resistant varieties (Haesaert, 2009).

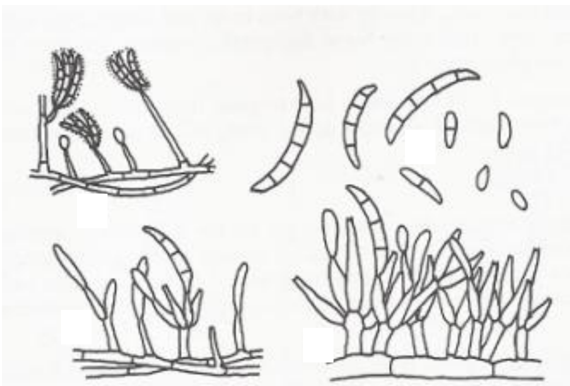

Figure 33: Microscopic structure of Fusarium spp. (Source: Barnett & Hunter, 1999)

~Figuur 33: Microscopische structuur van Fusarium spp.~

Trichothecium (Figure 34) is also a genus from the phylum Ascomycota. It is worldwide distributed in the soil and can cause rot of different plant parts like roots, fruits or leaves, but this is very specific for every crop. The literature does not contain information about the effect of *Trichothecium spp*. on *J. curcas*. The only species in this genus is *T. roseum*. *T. roseum* produces a secondary metabolite called trichothecin which is a mycotoxine. This substance is responsible for the antagonism between *T. roseum* and certain plant-pathogenic fungi. Antifungal activity was reported against *Dibotryon rnorbosum*, *Helminthosporium sativum*, *Botrytis allii*, *Penicillium digitatum*, *Aspergillus niger*, *Paecilomyces varioti*, *Fusarium graminearum* and *Penicillium hagemi (*Freeman & Morrison).
Iprodione and azoxystrobin can be used to suppress *Trichothecium* infections.

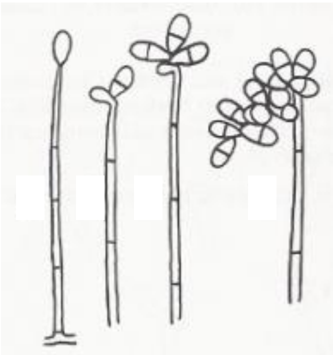

Figure 34: Microscopic structure of Trichothecium spp. (Source: Barnett & Hunter, 1999)

~Figuur 34: Microscopische structuur van Trichothecium spp.~

Also *Alternaria* (Figure 35) belongs to the phylum of the Ascomycota. It causes leaf spots and produces mycotoxines. *A. solani* and *A. alternata* are examples of plant pathogen species.

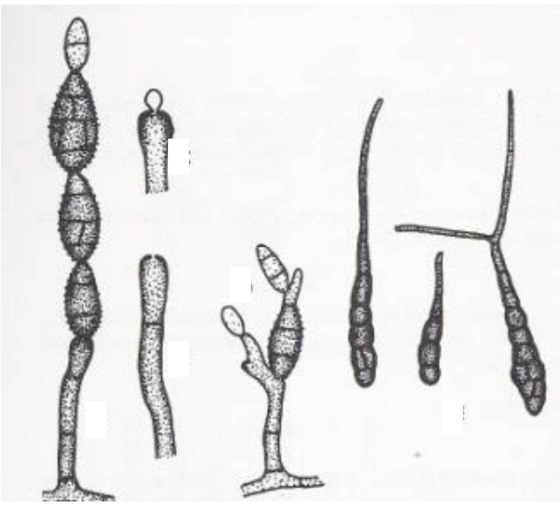

Figure 35: Microscopic structure of Alternaria spp. (Barnett & Hunter, 1999)

~Figuur 35: Microscopische structuur van Alternaria spp.~

The life cycle of Atlernaria is shown in Figure 36 (Haesaert, 2009).

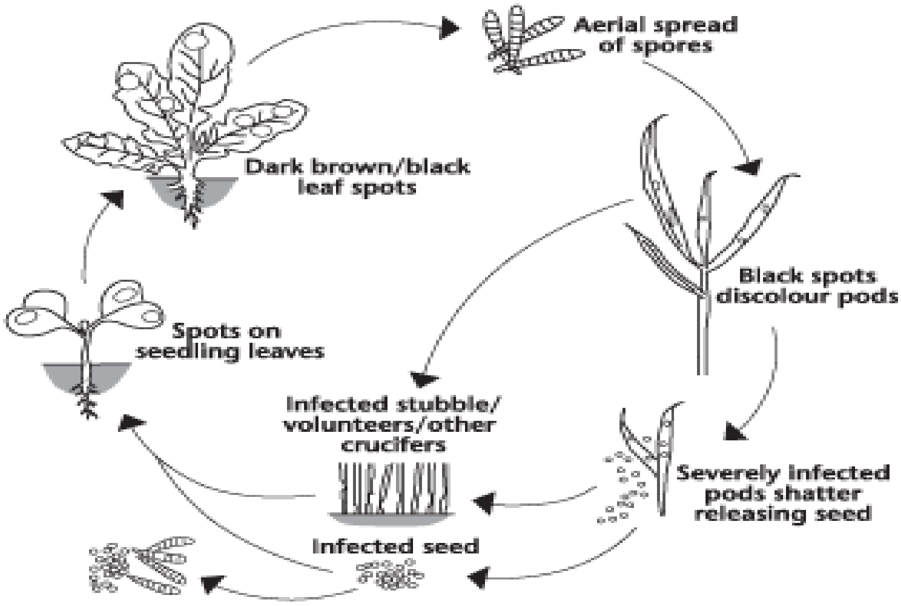

Figure 36: Life cycle of Alternaria spp. (Source: Haesaert, 2009)

~Figuur 36: Levenscyclus van Alternaria spp.~

Iprodione, captafol, chlorothalonil, azoxystrobine and copper can be used for control of *Alternaria* infections.

The last fungus, *Sirosporium* (Figure 37), also belongs to the phylum of the Ascomycota. It also causes leaf spots. Examples of plant pathogen species are *S. carissae*, *S. gliricidiae, S. diffusium* and *S. aeglicola*. Tebuconazole can be used to control Sirosporium infections.

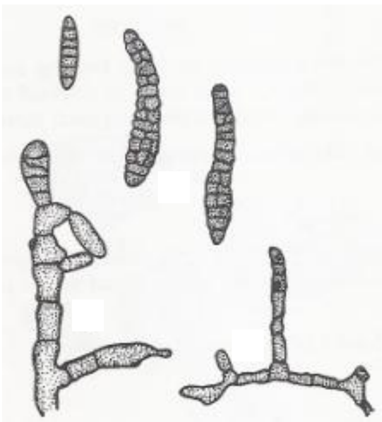

Figure 37: Microscopic structure of Sirosporium spp. (Barnett & Hunter, 1999)

~Figuur 37: Microscopische structuur van Sirosporium spp.~

7.3.3 Analysis of the spraying system

The products used at the plantation are shown in Table 22.

Table 22: Used chemicals on the plantation with target organism and active ingredient

~Tabel 22: Gebruikte pesticiden op de plantage met doelorganisme en actief ingrediënt~

Pest	**Chemical**	**Active ingredient**	**Activity**
Blue shield bug	Lebaycid	Fenthion	Acetylcholine esterase inhibitors
	Imaxi	Imidacloprid	Nicotinic acetylcholine receptor agonists
Thrips	Biomet	Dimethoate	Acetylcholine esterase inhibitors
Mealy bug	Lebaycid	Fenthion	Acetylcholine esterase inhibitors
Caterpillar	Triger	Lambda-cyhalothrin	Sodium channel modulators
	Biomet	Dimethoate	Acetylcholine esterase inhibitors
Leaf miner	Diazol	Diazinon	Acetylcholine esterase inhibitors
	Biomet	Dimethoate	Acetylcholine esterase inhibitors
	Triger	Lambda-cyhalothrin	Sodium channel modulators
Golden beetle	Imaxi	Imidacloprid	Nicotinic acetylcholine receptor agonists
	Lebaycid	Fenthion	Acetylcholine esterase inhibitors
Mildew	Ridomil	Metalaxyl	Interfere with RNA polymerase I
	Antracol	Mancozeb, propineb	Multi-site contact activity
	Copper	Copper	Multi-site contact activity
Root rot	Ridomil	Metalaxyl	Interfere with RNA polymerase I
	Antracol	Mancozeb, propineb	Multi-site contact activity
	Copper	Copper	Multi-site contact activity

Aquawet is added to a lot of chemicals before spraying. It works as a ‘sticker and wetter’ and makes sure that the chemical sticks on the leaves, it avoids run off of the pesticides.

To avoid resistance, it is better to alternate with chemicals with a different mode of action. The chemicals with multi-site activity show the lowest risks for resistance. Chemicals with specific working mechanisms like metalaxyl have a high risk for developing resistance. With these products, alternation is essential, but the risk for cross resistance must be taken into account when alternating with chemicals from the same activity group.

The toxicity of the used chemicals is shown in Table 23.

Table 23: Toxicity of the used chemicals at the plantation (ADI = Acceptable Daily Intake, LD_{50} = Lethal Dose for 50 % of subjects, LC_{50} = Lethal Concentration for 50 % of subjects, DT_{50} = Degradation Time for 50 % of the initial concentration, NOEL = No Observed Effect Level, bw = body weight) (Source: BCPC, 2003)

~Tabel 23: Toxiciteit van de gebruikte pesticiden op de plantage~

Product	ADI (mg/kg bw)	LD_{50} oral intake rats (mg/kg bw)	LC_{50} fish (mg/l water)	NOEL rats
Fenthion	0,007	250	0,83	< 5 mg/kg diet daily
Imidacloprid	0,06	450	211	100 mg/kg diet
Dimethoate	0,002	387	24,5	0,23 mg/kg bw daily
Lambda-cyhalothrin	0,005	79	360	0,5 mg/kg bw daily (dogs)
Diazinon	0,002	1250	2,6-3,2	0,06 mg/kg bw
Metalaxyl	0,03	633	>100	2,5 mg/kg bw daily
Mancozeb	0,05	>5000	0,15	4,0 mg/kg bw daily
Propineb	0,007	>5000	0,4	50 mg/kg diet
Copper	/	700-800	/	/

Product	DT_{50}	Toxicity class WHO	Phytotoxicity
Fenthion	1,5 days	Moderately hazardous	Non-phytotoxic when used as recommended
Imidacloprid	4 hours	Moderately hazardous	/
Dimethoate	7-16 days	Moderately hazardous	Phytotoxicity is depended on crop variety and climate
Lambda-cyhalothrin	7-15 days	Moderately hazardous	/
Diazinon	11-21 days	Moderately hazardous	Non-phytotoxic when used as directed
Metalaxyl	29 days	Slightly hazardous	/
Mancozeb	< 1 day	Product unlikely to present acute hazard in normal use	/
Propineb	/	Product unlikely to present acute hazard in normal use	Non-phytotoxic when used as recommended
Copper	/	Slightly hazardous	Non-phytotoxic when used as recommended

Figure 38 shows the total amount of chemicals (expressed in the amount of the active ingredients) used in the field from June 2008 until May 2009. The graph does not contain data about Ridomil and Antracol because date were not available.

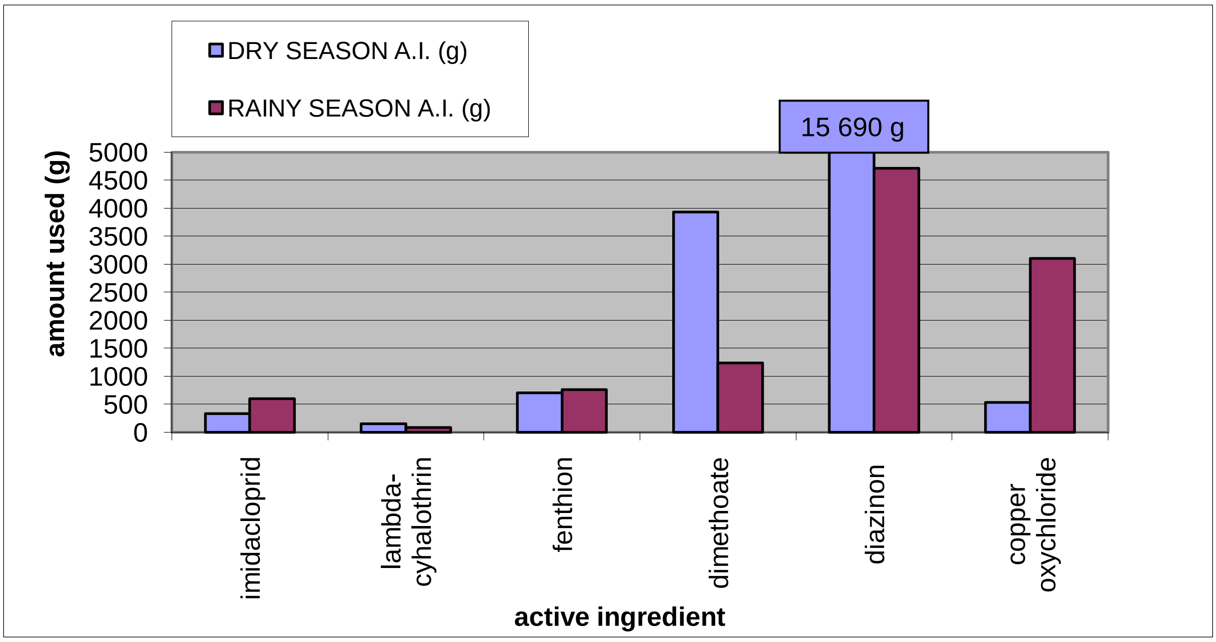

Figure 38: Annual spraying amount per season (A.I. = active ingredient) for 100 ha

~Figuur 38: Jaarlijkse hoeveelheid gespoten pesticiden, ingedeeld per seizoen~

Taking in account the cost of the product, labour (at 155 Ksh/manday), petrol and oil for the motor pump, the total costs for spraying on the field is shown in Figure 39. Also here, Ridomil and Antracol are not included.

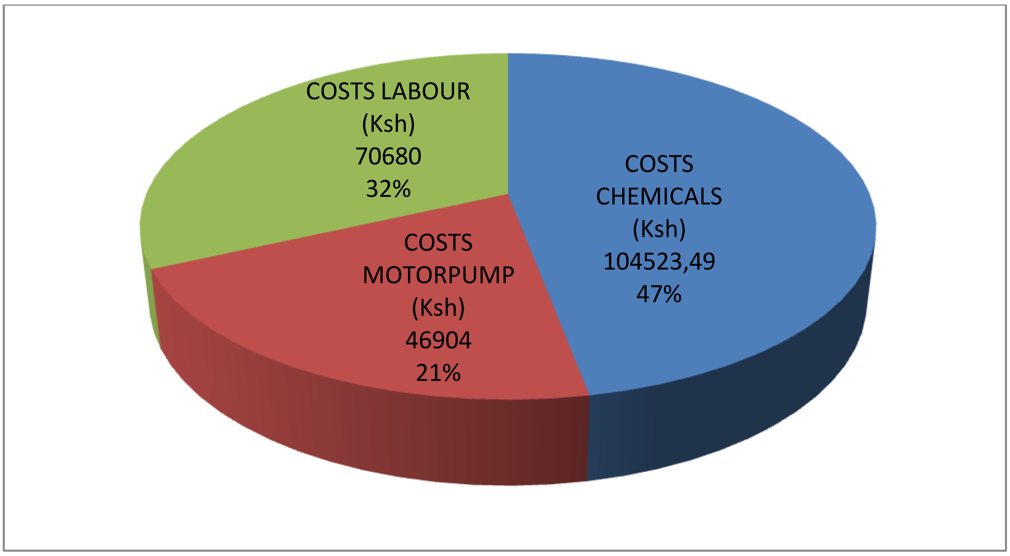

Figure 39: Annual costs for spraying on the field

~Figuur 39: Jaarlijkse kosten voor sproeien op het veld~

The total cost for spraying on the field from June 2008 until May 2009, taking in account the used chemicals (except Ridomil and Antracol), the used oil and petrol for the motor pump and the labour, was 222 107,49 Kenyan Shilling for 100 ha. This is about 2229 euro or 2844,5 USD for 100 ha or 22,29 euro or 28,45 USD per ha.

7.4 Discussion and conclusion

7.4.1 Identification of the pests

The insects found on the plantation match the literature about the pest insects that appear on *J. curcas* in Kenya, except for termites. Insects found were *Calidea dregii, Heliothrips haemorroidales, Scirtothrips kenyensis, Ferrisia virgata*, *Stomphastis sp.*, *Pempelia Morosalis, Aphtona sp.* and termites.

The experiment with the plates does not give useful results because most of them were blown away. We can conclude that sticky plates are not a useful instrument to make an inventory of the insects on this plantation because there is too much wind and the plates are not protected against the wind due to the low canopy of *J. curcas* during the dry season. Perhaps a new method can be searched to attach the plates on a way that they don't fly away and don't tear apart. But however, the insects that are monitored on the remaining plates were not the insects that cause problems on the plantation so the point of further development of this method can be doubted.

7.4.2 Identification of the diseases

The fungi found on samples of the roots were *Fusarium* and *Trichothecium* spp.. Both fungi are not yet described in the literature about fungi on *J. curcas* in Kenya. But a report from KEFRI describing possible fungi did mention *Fusarium* spp.

It is remarkable that *Fusarium* and *Trichothecium spp*. both appear on plants with root rot, while *Trichothecium roseum,* the only known species in this genus, has an antifungal activity against several fungi, among which *Fusarium graminearum*. There could be multiple explanations for this phenomenon.

Firstly, it is possible that the *Fusarium spp*. on the plantation are not *Fusarium graminearum* or other species that are susceptible for the antifungal metabolite produced by *Trichothecium roseum*.

It is also possible that there is found a new, unknown *Trichothecium sp.*, that does not produce antifungal products but this is most unlikely.

Finally, it could be possible that the plants which seemed infected by *Trichothecium spp*., were in fact contaminated with *Fusarium spp*.. The *Fusarium spp*. and thus not the *Trichothecium spp*. caused the root rot. The reason why samples of these plants showed growth of *Trichothecium spp*. and not of *Fusarium spp*., could be attributed to the antifungal effect of the *Trichothecium spp.*. The *Trichothecium spp.* could have caused the death of the *Fusarium spp.* at that specific part of the root that was sampled. Assuming that this last hypothesis is correct, this could be very interesting for controlling *Fusarium spp.* on the plantation. *Trichothecium spp.* could be used as a biological product to control *Fusarium spp.* as it seems to thrive in this area. It is already present as a natural part of the ecosystem and using it as a biological control would mean that the population of *Trichothecium spp.* would be increased up to a level which is high enough to attack *Fusarium spp.* effectively. However, this is all very hypothetically and further examination, also of the possible negative consequences of *Trichothecium spp.* on *J. curcas*, is necessary.

The fungi on the leaves with leaf spots were identified as *Alternaria* and *Sirosporium* spp..
Alternaria spp. were also mentioned in the report from KEFRI. Both fungi are not yet mentioned in the literature as problems of *J. curcas* in Kenya.
All these fungi are members of the Ascomycota. *Fusarium* and *Trichothecium spp*. cause root rot which will eventually lead to the death of the plant. *Alternaria* and *Sirosporium spp*. cause leaf spots, which will make the leaves rot and eventually fall off.

7.4.3 Analysis of the spraying system

The used chemicals are effective against the target organisms, except for metalaxyl. Metalaxyl is used to control powdery mildew, while this is not effective against it.

The analysis of the used chemicals showed that the risk for resistance is already taken into account by alternating with different products. The used insecticides often have a specific activity, increasing the risk for resistance, but have been used alternately with other products. However, these products are often chemicals with the same mode of action, which can be risky for cross-resistance. It is thus better to alternate with products with another mode of action. Thiacloprid for example can be used as an additional chemical against chewing and sucking insects, it is an nicotinic acetylcholine receptor agonist. Also deltamethrin, a sodium channel modulator, can be added to the arsenal of chemicals for the control of caterpillars. Triadimefon can be a substitute for metalaxyl for the control of powdery mildew, as metalaxyl is not effective against this. The fungicides are mostly chemicals with a multi-site activity, so the risk for resistance is lower. However, some possible additional fungicides are fluoxastrobine (against *Alternaria solani* and powdery mildew), trifloxystrobine (broad spectrum fungicide against *Alternaria spp.* and mildew) and prothioconazole (against *Fusarium spp.* and powdery mildew).

The toxicity of the used products is reasonably low. The WHO toxicity class ranges from ‘Product not unlikely to present acute hazard in normal use’ over ‘Slightly hazardous’ to ‘Moderately hazardous’. Also the phytotoxicity is fairly low. The degradation time for 50 % of the initial concentration for most chemicals is low (<1,5 days). For dimethoate, lambda-cyhalothrin and diazinon the degradation time ranges between 7-21 days and metalaxyl has the highest degradation time with 29 days. However, in this climate where rain is very exceptional, chances on leaching of the chemicals into the nearby lake are very small. The amounts that do contaminate the water of the lake, are so small that they won’t affect the fish. Especially when the LC_{50} for fish of the products are taken into account, which are all low except for fenthion, propineb and mancozeb. But these chemicals degrade very fast so chances on leaking in the lake are small. Most chemicals also have low LD_{50} values so normally, they will not have negative consequences for the people who use the water from the lake to cook and to wash themselves. However, fenthion does have a high toxic effect on birds and is most toxic compared to the other products. An alternative for fenthion, for example thiacloprid, is thus recommended.

The total amount of chemicals is not particularly higher in a specific season. The amounts per chemical do differ significantly between the dry and rainy season for dimethoate, diazinon and copper oxychloride. Dimethoate and diazonon are both used a lot during the whole year, but especially during the dry season. This indicates a higher problem of thrips, caterpillars and leaf miners during the dry season than during the rainy season. Copper is mainly used during the rainy season, indicating a higher level of fungi infection (mildew and rootrot) during the rainy season. The rest of the chemicals are roughly spread equally over the seasons, which points out that blue shield bugs, mealy bugs and golden beetles appear in constant amounts over the different seasons.
Knowing this, there can be taken preventive measures against thrips, caterpillars and leaf miners right before the start of the dry season and against fungal infections before the rainy season starts.

The total annual cost for spraying amounts 2844,5 USD for a 100 ha plantation, this means 28,445 USD per ha. In ‘Economical applications’, the total costs for cultivating *J. curcas* was estimated on 171,1 USD per year per ha after 6 years. But this was without the costs for pest management. If we count up 28,45 USD with 171,1 USD, this makes 199,55 USD. This means that the spraying costs represent 14,3 % of the total cost for cultivation. Moreover, not all chemicals are included in this calculation because of the lack of detailed spraying records, so the real cost will be even higher. However, this is based on estimated values, it is obvious that in cultivating *J. curcas*, pest management is an extraordinary important aspect.
Almost half of the spraying cost is coming from the product cost. Making the spraying system less expensive will thus have to be done through reducing the amount of chemicals used (through preventive measurements and alternating between products to avoid resistance) or through choosing cheaper chemicals or products/measurements that have a long term effect.

Most chemicals have a broad spectrum activity, affecting also the natural enemies of several pests. It is thus important to find more specific activity chemicals, sparing beneficial organisms or to spray only when the natural predators are not active or present.
Also biological control is an interesting option, for example the use of lady beetles for fighting thrips. Neem extracts can be used to control thrips, but it is not effective on the adult stage. Preventing caterpillar problems, can be done by catching butterflies with light- and pheromone traps. Antagonistic fungi like *Trichoderma spp.* can be used to control soil born fungal infections. This is an interesting aspect that could be the subject of a more extensive study and could lead to new experiments.

8 Identification of organisms causing cancer on *Melia volkensii*

8.1 Purpose

On the Mukuyu farm at Kibwezi, some *Melia volkensii* trees are suffering from cancers on the stem. They cause irregular swellings and abundant resin production. Until now, there are no visible effects on growth or fitness. But it is nevertheless important to know the cause of these cancers. Especially because Better Globe Forestry is planning to set up a plantation with lots of hectares of mukau. When the infection occurs in a plantation of such a big area, this can become a disaster. It is thus important to know the cause and try to find how infection can be avoided and controlled. Also the effect on the wood quality (the main purpose for growing mukau) has to be examined.

8.2 Materials and methods

An infected tree was cut down. From the stem, a stem slice from about 10 cm thick was taken to examine the wood quality at the laboratory of wood technology from the University of Ghent.

Samples from the bark, heart wood and sap wood were taken, disinfected in the laboratory and plated out on a PDA medium. The fungi were purified by putting every fungus in a separate petri plate, and they were put in the incubator on 15°C. Every week, they were transferred to a fresh medium and they were regularly examined under the microscope until after sporulation to identify them.

8.3 Results

A first visual property of the wood was a pink colorization of the heart wood as well as the sap wood.

The results of the analysis in the laboratory for wood quality, are not yet available at this moment.

The samples grown on PDA, did not lead to the growth of fungi. There was a bacterial infection but the kind of bacteria was not further examined because this is not the specialty of the laboratory at Bottelare.

8.4 Discussion and conclusion

There were no fungi found that could be the cause of the cancer. However, the assumption that the cancer is caused by a bacterial infection is reasonably realistic as other cases of bacterial cancer on tropical trees are known, for example *Pseudomonas syringae* causing cancer on fruit trees including tropical fruit trees. When the results from the laboratory show a decrease in the wood quality, further examination of the possible bacteria is useful and could lead to a management proposal.

9 Relation between soil characteristics and growth of *Jatropha curcas*

9.1 Purpose

On the plantation, there is a big difference in the growth of different *J. curcas* plants. Although the plants have the same origin and were treated similarly, the growth is not homogeneous. The purpose of this experiment is to examine the relation between the soil characteristics and the growth of *J. curcas* to explain the difference in growth. Knowledge about this relation could be useful in choosing the best site for planting *J. curcas* or in improving soil treatments.

9.2 Materials and methods

For examination, a slope situated in block JC3 (planting distance is 2,5 m x 3,5 m) is chosen as research plot (see Figure 32). On this slope, there is a visible difference in growth from the top to the valley. On the top, the trees do very bad and in the valley, they grow well.
To know the potential of this area, two more locations have been examined, both located in block JC3. The first one is a previous 'boma'. A boma is a place where people used to live and where they kept cattle. The second one is on colluvium, the washed away top soil from the slope has all been collected in this place. On both places, the *J. curcas* plants grow remarkably good.

In the plot, 3 pits were dug (shown on Figure 40). One at the top (profile 1), one in the valley (profile 3) and one exactly in the middle (profile 2).
Also on the previous boma (profile 4) and the alluvium (profile 5), pits have been dug.

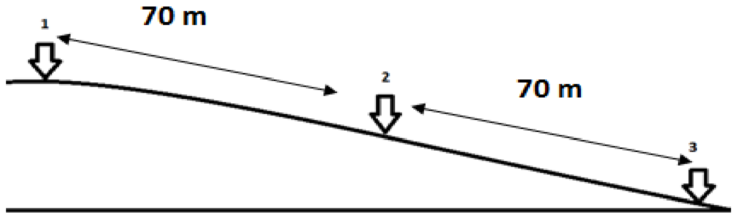

Figure 40: Location of soil profiles 1, 2 and 3

~Figuur 40: Locatie van de bodemprofielen 1,2 en 3~

Around every pit, a group of 25 plants (5x5) has been measured. Three parameters have been measured: the height (from the highest point straight to the ground), the diameter of the stem at 2 cm above soil level and 2 crown diameters perpendicular to each other. The diameters are used to calculate the area of the horizontal projection of the crown, assuming a circle shaped projection. In case of a missing plant or a replant, the measured plant was substituted by another plant outside the square of measured plants, closest to the missing or replanted tree.

In the pits, the soil profile was described. Of every pit, two soil samples have been taken. One from the topsoil (0-20 cm) and one from the subsoil (20-100 cm or up to the stone line).

The collected data is compared with each other to form a conclusion about the soil characteristics and growth.

9.3 Results

9.3.1 Soil profile description

9.3.1.1 Characterization of the site

Five soil profiles where described according to the FAO Guidelines for Soil Description (2006). The top- and subsoil of every pit was analysed for texture and chemical properties.

9.3.1.2 Information on the site

- Date of description:15/08/2009 (for profile 1 and 2) and 18/08/2009 (for profile 3, 4 and 5)
- Authors: Silke Nowak
- Location:
    - District: Mbeere
    - Division: Gachoka
    - Village: Katithini
- Lattitude: 00° 41’ 29,2’’ South, 37° 54’ 43,9’’ East.
- Physiography:
    - south-east orientated slope (profile 1, 2 and 3)
    - previous farm on the slope (profile 4)
    - colluvium at the bottom of the slope (profile 5)
- Vegetation and land use: *J. curcas* plantation

9.3.1.3 General information on the soil

- Parent material: gneiss
- Drainage: well drained
- Moisture condition: very dry
- Depth of groundwater table: very deep, GWT not found
- Presence of surface stones, rock outcrops: few cover of rock outcrops and coarse fragments (2-5 %), little bit more surface stones at the top
- Erosion:
    - Main category: water erosion or deposition through rills and gullies
    - Area affected: >50%
    - Degree: severe, surface horizons completely removed and subsurface horizons exposed, original biotic functions largely destroyed. Gullies up to 50 cm wide and 1 m deep.
    - Activity: active in recent past (until 3 years ago)

9.3.1.4 Profile description

Profile 1

Ah	0-10 cm	sandy loam; yellowish brown (10 YR 5/4) dry, dark yellowish brown YR 4/4) moist; weak structure; loose, slightly sticky, non-plastic; very few fine roots; wavy boundary;
B1	10-35cm	sandy loam; brown-dark brown (7,5 YR 5/4) dry, brown-dark brown (7,5 YR 4/4) moist; strong structure; extremely hard, slightly sticky, non-plastic; very few very fine roots; wavy boundary;
B2	35-45cm	sandy loam; brown-dark brown (7,5 YR 4/4) dry, yellowish red (5 YR 4/6) moist; moderate structure, blocky aggregates of medium size; hard, non-sticky, non-plastic; very few very fine roots; abrupt boundary;
2B	45-50 cm	stone line; very hard, non-sticky, non-plastic; no roots; abundant angular stones, weathered-strongly weathered quartz stones;

Profile 2

Ah	0-17 cm	sandy loam; yellowish red (5 YR 5/8) dry, red (2,5 YR 4/6) moist; weak structure; subangular blocky; soft, slightly sticky, non-plastic; very few very fine roots; smooth boundary;
B1	17-50 cm	loamy sand; yellowish red (5 YR 5/6) dry, red (2,5 YR 4/6) moist; strong structure; slightly hard, slightly sticky, non-plastic; very few very fine roots; wavy boundary;
B2	50-70 cm	loamy sand; yellowish red (5 YR 5/8) dry, red (2,5 YR 4/8) moist; moderate structure, blocky aggregates of medium size; extremely hard, slightly sticky, non-plastic; very few very fine roots; abrupt boundary;
2B	70-75 cm	stone line; very hard, slightly sticky, non-plastic; very few very fine roots; abundant angular coarse gravel, fresh or slightly weathered quartz;

Profile 3

Ah	0-35 cm	loamy sand; yellowish brown (10 YR 5/8) dry, red (2,5 YR 4/6) moist; weak structure, subangular blocky; soft, slightly sticky, non-plastic; very few very fine roots; irregular boundary;
B1	35-75 cm	loamy sand; yellowish red (5 YR 5/8) dry, red (2,5 YR 4/8) moist; weak structure, subangular blocky; slightly hard, slightly sticky, non-plastic; very few very fine roots; wavy boundary;
B2	75-100 cm	loamy sand; red (2,5 YR 5/8) dry, red (2,5 YR 4/8) moist; weak structure, subangular blocky; hard, slightly sticky, non-plastic; very few very fine roots; abrupt boundary;
2B	100-120 cm	stone line; no roots; many subrounded fine quartz gravel , weathered;

Profile 4

Ah	0-40 cm	sandy loam; brown-dark brown (7,5 YR 4/4) dry, brown-dark brown (7,5 YR 4/4) moist; weak structure, subangular blocky; soft, slightly sticky, non-plastic; very few fine roots; wavy boundary;
B1	40-60 cm	loamy sand; yellowish red (5 YR 5/8) dry, red (2,5 YR 4/8) moist; weak structure, subangular blocky; slightly hard, slightly sticky, non-plastic; very few fine roots; irregular boundary;
B2	60-100 cm	loamy sand; strong brown (7,5 YR 5/8) dry, red (2,5 YR 5/8) moist; weak structure, subangular blocky; slightly hard, slightly sticky, non-plastic; very few fine roots; abrupt boundary;
2B	100-110 cm	stone line; no roots; very few subrounded medium quartz gravel, fresh or slightly weathered;

Profile 5

Ah	0-45 cm	loamy sand; brown-dark brown (7,5 YR 4/4) dry, yellowish red (5 YR 4/6) moist; weak structure, subangular blocky; very hard, slightly sticky, non-plastic; few medium roots; wavy boundary;
B1	45-80 cm	loamy sand; yellowish red (5 YR 5/6) dry, red (2,5 YR 4/6) moist; weak structure, subangular blocky; very hard, slightly sticky, non-plastic; few medium roots; wavy boundary; remark: termites nests
B2	80-100 cm	loamy sand; yellowish red (5 YR 5/6) dry, yellowish red (5 YR 5/8) moist; weak structure, subangular blocky; very hard, slightly sticky, non-plastic; few medium roots; abrupt boundary;
2B	100-110 cm	stone line; no roots; very few subrounded fine quartz gravel, fresh or slightly weathered;

In summary, all the described profiles are sandy, hard and dry. There has been a lot of erosion so the top soil is washed away resulting in a lot of stones at shallow depth and locally at the soil surface in the profiles on the top and the middle part of the slope. Lower located profiles contained less stones and thus have a higher potential rooting volume and available water holding capacity.
There are also a lot of gullies on the slope, indicating water erosion.
The organic matter contents is very low in all described profiles. The A horizon is thin at the top but becomes thicker when going down the slope.
The texture was about similar in all profiles, being very sandy. The pits all had very hard walls and few aggregates were formed.
The main visible observable differences between the profiles was volume of the soil (related with depth of stones and stone content), the thickness of the A horizon and the colour (indicating a different organic matter content).

Figure 41 shows the depth of the soil and the thickness of the A horizon in the different profiles.

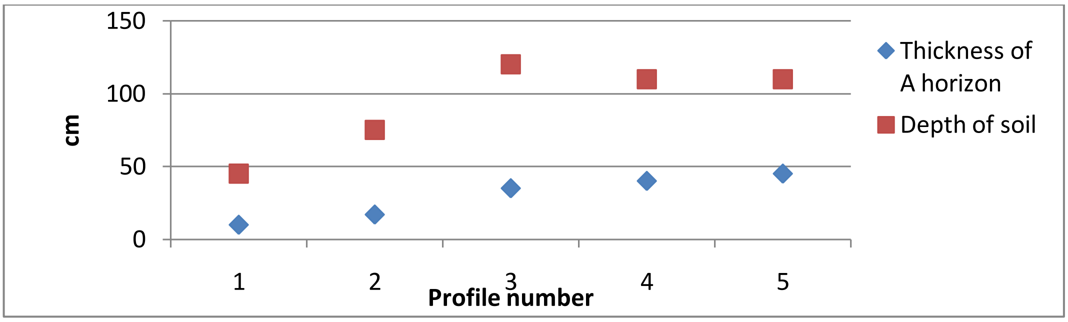

Figure 41: Thickness of the A horizon and depth of the soil at the different profiles

~Figuur 41: Dikte van de A horizont en bodemdiepte in de verschillende profielen~

9.3.2 Soil chemical data

The chemical soil data are presented in Table 24 and Table 25.

Table 24: Chemical soil data for texture, pH and macro elements

~Tabel 24: Chemische bodemanalyses voor textuur, pH en macro-elementen~

Senders Ref.	**Texture**	**pH water**	**pH $CaCl_2$**	**Carbon %**	**Nitrogen %**	**P (ppm)**	**K (ppm)**
Profile 1, top soil	Loamy sand	6,01	4,98	0,16	0,13	12	91
Profile 1, sub soil	Sandy loam	5,39	4,33	0,34	0,1	17	114
Profile 2, top soil	Loamy sand	5,25	4,15	0,08	0,13	11	90
Profile 2, sub soil	Loamy sand	5,12	4,05	0,08	0,13	20	87
Profile 3, top soil	Loamy sand	6,12	4,92	0,21	0,2	7	103
Profile 3, sub soil	Sandy loam	5,19	3,96	0,19	0,17	8	75
Profile 4, top soil	Sandy loam	5,39	4,89	0,48	0,27	31	114
Profile 4, sub soil	Sandy loam	5,03	4,02	0,21	0,13	12	258
Profile 5, top soil	Loamy sand	6,18	5,4	0,32	0,13	17	174
Profile 5, sub soil	Sandy loam	5,83	4,7	0,29	0,17	29	91

Table 25: Chemical soil data for meso and micro elements

~Tabel 25: Chemische bodemanalyses voor meso- en micro-elementen~

Senders Ref.	**Na (ppm)**	**Ca (ppm)**	**Mg (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Cu (ppm)**	**Zn (ppm)**
Profile 1, top soil	262	292	81	23	55	0,5	2,78
Profile 1, sub soil	435	90	170	34	60	0,7	3,62
Profile 2, top soil	270	147	76	63	252	0,84	2,36
Profile 2, sub soil	266	158	89	48	228	0,75	1,99
Profile 3, top soil	220	265	98	130	78	0,75	4,93
Profile 3, sub soil	224	277	113	48	73	0,61	4,99
Profile 4, top soil	252	282	102	121	203	1,18	12,45
Profile 4, sub soil	272	128	73	37	115	0,87	6,47
Profile 5, top soil	212	543	128	323	166	1,11	6,32
Profile 5, sub soil	250	678	257	120	170	0,97	6,41

9.3.3 Growth parameters of *Jatropha curcas*

Table 26 shows the average height, stem diameter and area of the horizontal projection of the crown.

Table 26: Average height, stem diameter and area of the horizontal projection of the crown of the measured J. curcas plants

~Tabel 26: Gemiddelde hoogte, stamdiameter en oppervlakte van de horizontale projectie van de kroon van opgemeten J. curcas planten~

	Top	**Middle**	**Down**	**boma**	**Alluvium**
average height (cm)	120	117	157	216	224
average stem diameter (cm)	19	20	28	32	35
average area horizontal projection crown (m²)	1,38	1,19	2,75	9,17	12,04

These data are presented in graphs in Figure 42, Figure 43 and Figure 44.

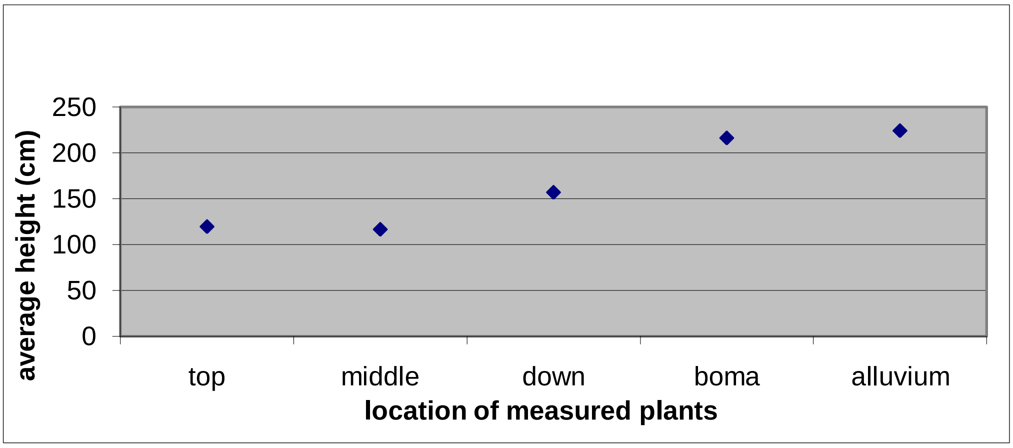

Figure 42: Average height of J. curcas plants

~Figuur 42: Gemiddelde hoogte van J. curcas planten~

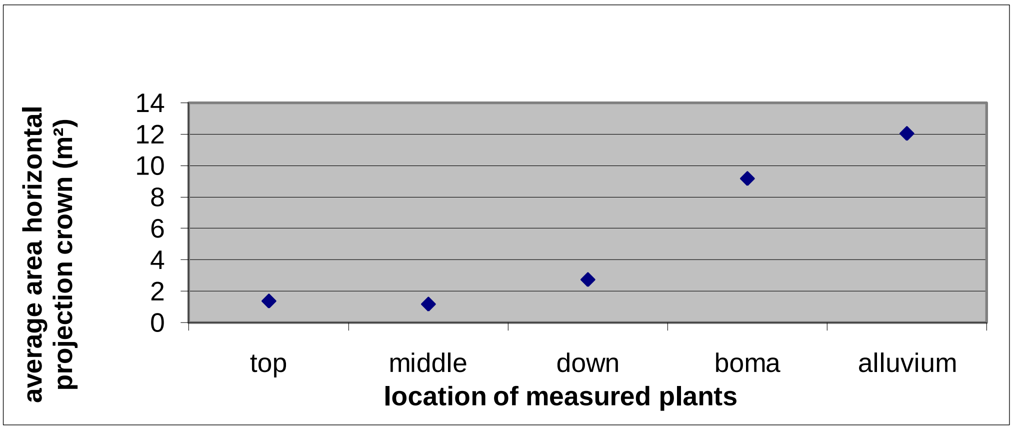

Figure 43: Average area of horizontal projection of the crown of J. curcas plants

~Figuur 43: Gemiddelde oppervlakte van de horizontale projectie van de kroon van J. curcas planten~

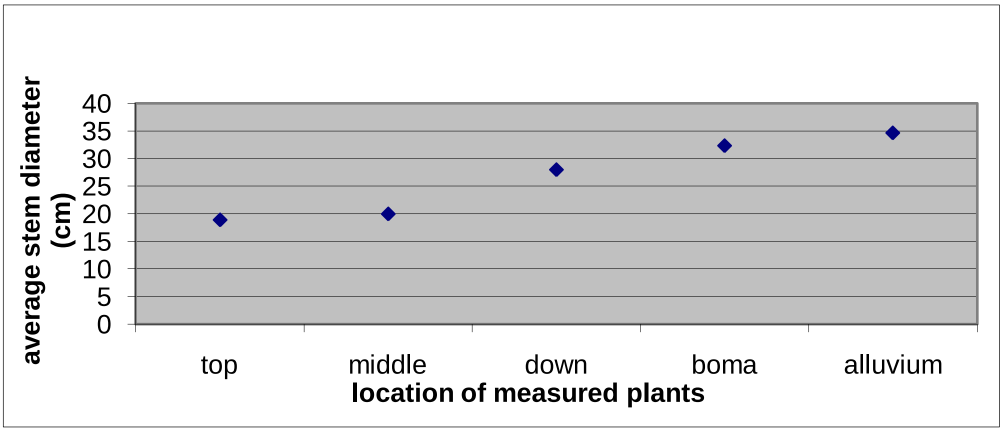

Figure 44: Average stem diameter of J. curcas plants

~Figuur 44: Gemiddelde stamdiameter van J. curcas planten~

9.4 Discussion and conclusion

Some important interpretations from the analyses:

- pH $CaCl_2$ does not change, it is permanent in all seasons (in contrary to pH water) and is used for these interpretations
- most soils are acidic and need liming to pH water 5,5 to neutralize exchangeable Al
- organic carbon % is very low, there is a need for mulching and addition of manure to increase it
- nitrogen % is very low and should be treated like organic carbon
- phosphorus is slightly low to moderate
- potassium is also low, an addition of potash fertilizer is needed
- calcium and magnesium are high meaning they are adequate
- sodium is very high
- for micro nutrients they are adequate since they are needed in small amounts

The analyses show that the organic carbon percentage is extremely low and the sodium amount is unrealistically high. The results from the soil analysis should be evaluated critically because the highly unrealistic data indicate that the quality of the analysis is not sufficient. Therefore, the results will not be used further to evaluate the relation between soil and growth parameters of *J. curcas*.

The difference in growth at the different plots, is mainly due to the difference in depth of the soil and thickness of the A horizon. The A horizon becomes thicker from profile 1 to profile 5 and also the soil depth increases, except for a little decrease in soil depth in profile 4 and 5 compared to profile 3. This trend matches the trend that is found in the average plant height, the average area of the crown and the average stem diameter which also increases from profile 1 to profile 5. The growth parameters show relatively equal data for profile 1 and 2. Profile 3 does significantly better for all parameters, profile 4 is even higher and profile 5 gives maximum results.

There can thus be concluded that the deeper the soil and the ticker the A horizon, the better the growth of *J. curcas*. This can be explained by the fact that a deeper soil gives the roots more space to develop. A better developed root system can absorb more water and nutrients and will thus lead to a better growth. The A horizon is the organic component of the soil. It is therefore logical that a thicker A horizon provides more organic matter and will benefit to the growth of the plants.

The reason why the depth and the thickness of the A horizon evaluates from profile 1 to profile 5, is erosion. Profile 1, at the top of the slope, has lost a big part of its soil volume due to erosion while profile 5, at a colluvium, has collected the washed off soil and has thus a bigger soil volume.

Water will not be absorbed well at the top of the slope, because of the crust at the surface and will run off. At lower points, water will be collected and slowly absorbed into the soil. This way, the plants at lower points will dispose of more moist resulting in a better growth.

The organic carbon percentage is also significantly higher in profile 4 compared to the other profiles. This could explain the high potential of profile 4, where used to be a little farm. The previous use of this piece of land could have caused a higher organic carbon amount, resulting in a better growth. But due to the low reliability of the analysis, this cannot lead to well-grounded conclusions about the relation between organic carbon amount and growth parameters.

10 Impact of fertilization on *Melia volkensii*

10.1 Purpose

The goal of this trial is to find the optimum quantity of fertilizer for mukau seedlings. Until this moment, there is nothing in the literature about this subject. A first attempt is thus needed to gain information about the influence of fertilization on the growth and development of mukau.

10.2 Materials and methods

In the trial, three different quantities of the fertilizer Mavuno has been used : 0 g, 50 g and 100 g. Mavuno is a local fertilizer which contains 10% ammoniacal N, 26 % available P_2O_5, 10 % K_2O, 10 % CaO, 4 % MgO, 4 % S, plus the meso –and micro elements B, Mn, Cu, Mo and Zn.
Every treatment is repeated four times. The design consists of 12 blocks. In every block, 49 seedlings (7x7) are planted. This gives a total amount of 588 seedlings. The planting distance is 4mx4m, so the planting density amounts 625 seedlings/ha.
The numeration of the blocks is shown in Figure 45.

1	2	3	4
5	6	7	8
9	10	11	12

a)

0 g	100 g	50 g	100 g
50 g	0 g	0 g	100 g
50 g	0 g	100 g	50

b)

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

c)

Figure 45: Numeration of the blocks with different treatments: a=numbers of the blocks; b=treatment of the blocks; c=numbers of the plants within one block

~Figuur 45: Nummering van de blokken met verschillende behandelingen; a=bloknummers; b=behandeling van het blok; c=plantnummers binnen het blok~

Every seedling received a single time fertilization at planting. The assessment was done after 2 months.

The parameters measured are health, plant height and stem diameter of every seedling. For health, the seedlings got a score from 1 to 5:
1: very healthy, strong, very dark green plant with strong leaves
2: healthy, green plant with relative strong leaves, a pale or weak shoot can appear
3: not very strong plant, pale green, leaves can be weak
4: sick plant, often attacked by spidermite, weak and yellow
5: dying plant
Died plants were noted as ‘missing’.
The height was measured from soil level up to the apical growing point and the stem diameter was measured with a calliper 5 cm above soil level. Missing plants are not included to calculate average values.

From every plant, the youngest, completely developed leaf was taken and a mixed leaf sample was made for every treatment. These 3 samples were analysed in the lab for macro and micro elements, according to following protocol:

1) The leaves were dried in the sun at the plantation.
2) They were kept dry and cool between newspapers.
3) The leaves were put in the crusher, making sure that the crusher is cleaned very precisely between every sample to avoid pollution.
4) The amount of nitrogen is determined using the method of DUMAS. Therefore, 0,2 g of the crushed samples are put in little tubes and then placed in the machine.
5) The amount of the other elements is determined using the method ICP:
    a. 1 g of every crushed sample is put in the oven for 4 hours at 500 °C.
    b. The incinerated samples are each solved in 5 ml HCl of 6 molair (M) and heated on a plate at 150 °C for 30 minutes.
    c. After 30 minutes, 5 ml HCl is added again to every sample and the samples are heated on the plate at 150 °C for 15 minutes.
    d. After cooling down, the solutions are put in 50 ml flasks. The tubes are rinsed with very clean water are the flasks are filled up to 50 ml with very clean water
    e. The flasks are shaken thoroughly and the samples are put in examination tubes through a filter. This way, the deposit is held back.
    f. The examination tubes are put in the machine.

A mixed soil sample from the trial area was also taken and analyzed at the soils laboratory of KEFRI to know the initial properties of the soil at that area.

10.3 Results

10.3.1 Growth parameters

The average health class, plant height and stem diameter is shown in Figure 46, Figure 47 and Figure 48.

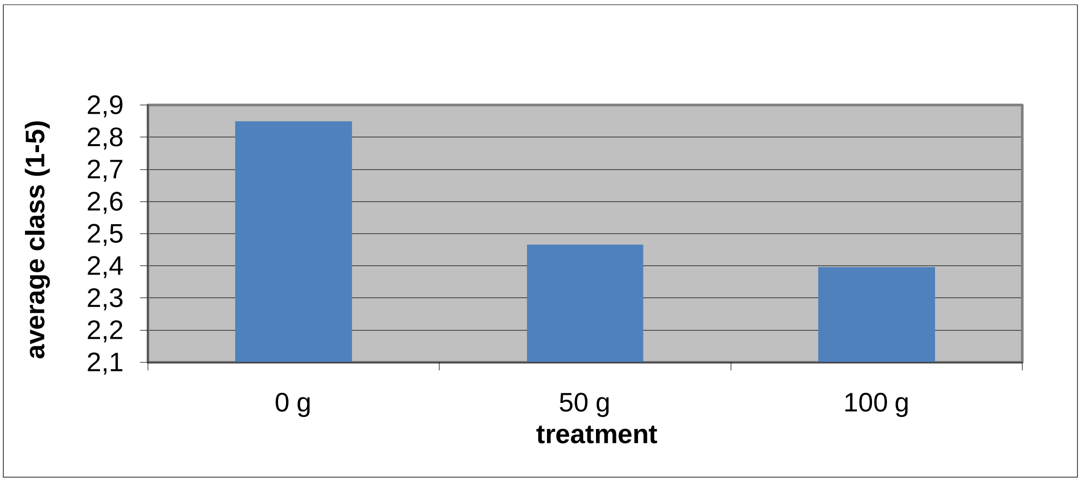

Figure 46: Average health class (1-5) of mukau seedling per treatment

~Figuur 46: Gemiddelde gezondheidsklasse (1-5) van mukau zaailingen per behandeling~

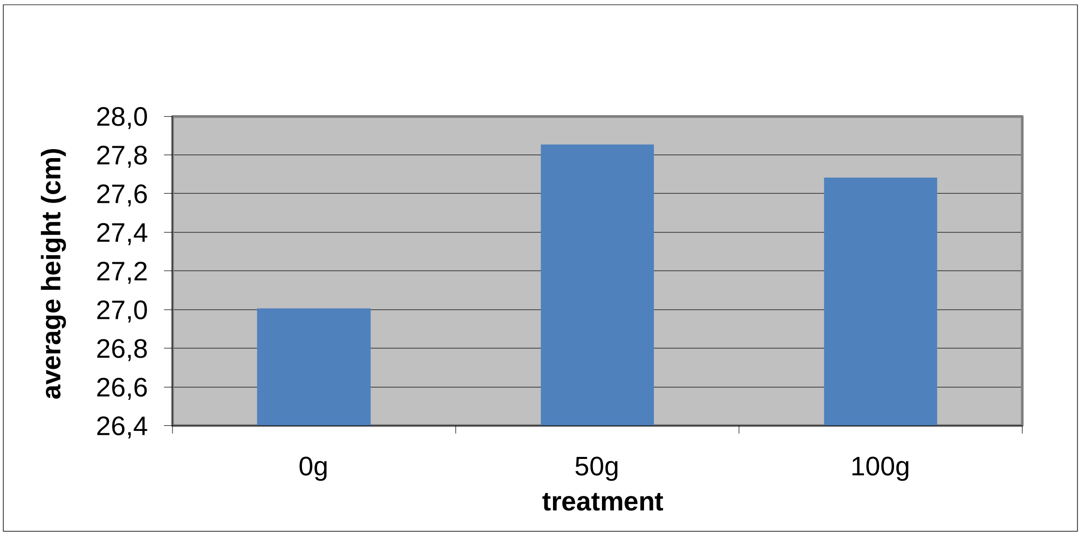

Figure 47: Average plant height of mukau seedlings per treatment

~Figuur 47: Gemiddelde planthoogte van mukau zaailingen per behandeling~

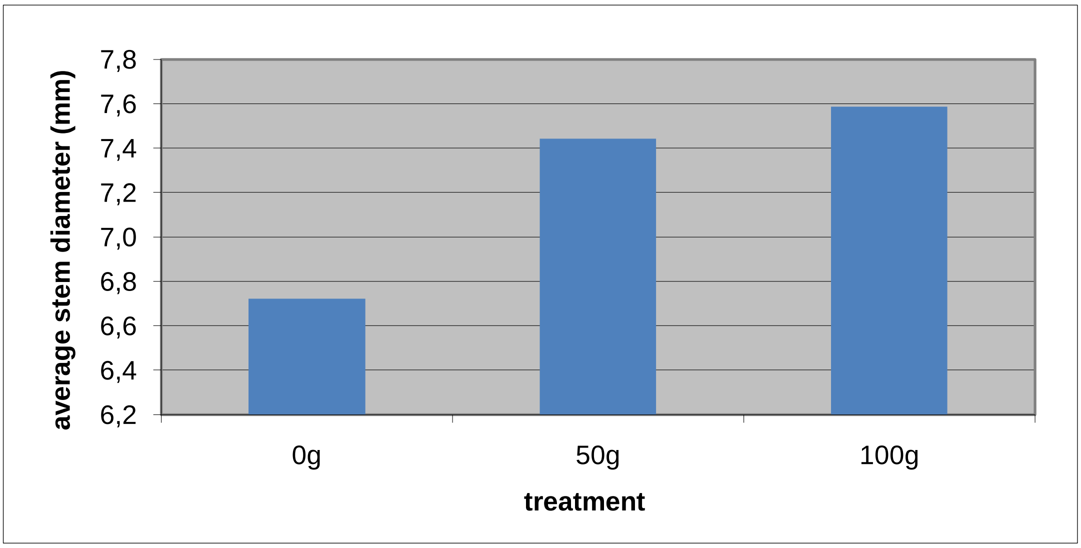

Figure 48: Average stem diameter of mukau seedlings per treatment

~Figuur 48: Gemiddelde stamdiameter van mukau zaailingen per behandeling~

The mortality of the seedlings per treatment is shown in Figure 49.

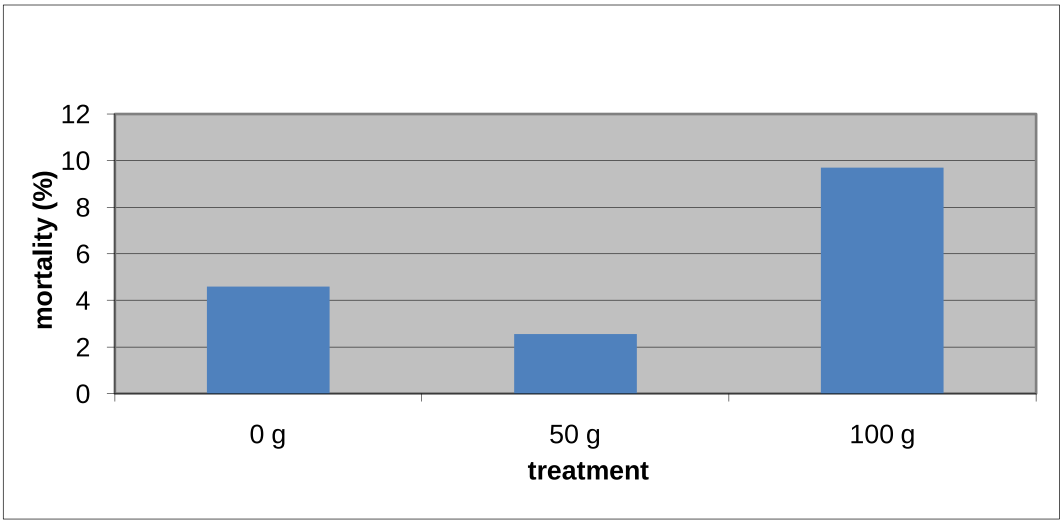

Figure 49: Mortality of mukau seedlings per treatment

~Figuur 49: Sterftecijfer van mukauzaailingen per behandeling~

The results were also tested statistically, using a One Way Anova in the statistical program SAS. The output is added in Appendix VIII. This showed that health and stem diameter significantly differ per treatment with a P value < 0,01 % with a probability of 95 %. The plant height showed no significant difference between the different treatments with a P value of 0,4044.
Health and stem diameter differ significantly between the 0 g treatment and the 50 and 100 g treatment. But there was no significant difference among the 50 g treatment and the 100 g treatment.

10.3.2 Leaf analyses

The complete results from the leaf analyses are added in Appendix IX. Table 27 shows the results for total nitrogen and carbon content.

Table 27: Leaf content of N and C in mukau seedlings per treatment

~Tabel 27: Bladinhoud voor N en C in mukau zaailingen per behandeling~

	N (%)	**C (%)**	**C/N**
0 g	5,960	37,94	6,365
50 g	6,449	37,47	5,810
100 g	5,994	34,03	5,678

Table 28 shows the results from the ICP spectrometric analysis.

Table 28: Leaf content of important elements in mukau seedlings per treatment in ppm

~Tabel 28: Bladinhoud voor belangrijke elementen in mukau zaailingen per behandeling in ppm~

	Ca	**Fe**	**K**	**Mg**	**Mn**	**P**	**S**	**B**	**Cu**	**Na**	**Zn**
0 g	15500	2060	44700	4980	169	8160	4590	55,7	23,5	688	102
50 g	13800	2020	42900	4020	379	8320	4330	47,7	17,8	625	79,5
100 g	12700	3980	38300	3980	488	8070	4370	44,6	21,6	654	80

For comparison, Table 29 is added. It shows the results from a previous leaf analysis on *Azadirachta indica* (*Meliaceae*) in Nigeria.

Table 29: Concentration of inorganic elements (in mg/kg) in Azadirachta indica (Source: Obiajunwa, 2001)

~Tabel 29: Concentratie van anorganische elementen (in mg/kg) in Azadirachta indica~

Element	**Concentration (mg/kg)**
K	15400
Ca	11100
Fe	245,3
Mn	40,8
Zn	58,2
Cu	141,5

10.3.3 Soil analyses

The soil analysis gave following results (Table 30):

Table 30: Results from soil analysis

~Tabel 30: Resultaten van de bodemanalyse~

Texture	Loamy sand	**Na (ppm)**	378
pH water	6,67	**Ca (ppm)**	619
pH $CaCl_2$	5,92	**Mg (ppm)**	256
Carbon %	0,56	**Mn (ppm)**	380
Nitrogen %	0,13	**Fe (ppm)**	33
P (ppm)	18	**Cu (ppm)**	2,01
K (ppm)	158	**Zn (ppm)**	7,43

Also here, the quality of the analysis is doubtful and will not be taken into account in making conclusions.

10.4 Discussion and conclusion

Fertilization has an influence on several growth parameters of *M. volkensii*. The health of the plants which received fertilizer is significantly better compared to plants which did not receive fertilizer. Also the stem diameter is significantly higher when the plants received fertilizer. Fertilization makes the plants thus stronger, healthier and improves the growth of the cambium which is responsible for the increase of the stem diameter.
There is no significantly increase in plant health and stem diameter when increasing the fertilization amount from 50 g up to 100 g. Adding an amount of 100 g of fertilizer, will thus lead to luxury consumption and the advantages are not proportional to the input efforts.
The plant height showed an increase from 0 g to 50 g and a little decrease between 50 g and 100 g at first sight. This would mean that fertilization also has an effect on the apical growth up to a level of 50 g. Higher amounts of fertilizer increase the plant height less, the optimum is reached at 50 g. However, statistic tests showed that the difference of plant height between the different treatments is too small to be significantly.

It is remarkable that the mortality of the plants is higher with 100 g fertilization than with 0 and 50 g. This could be due to a damage of the roots because of the high concentration of fertilizer close to the roots. It is also possible that 100 g of fertilizer increases the EC of the soil up to a level on which water absorption by the plants becomes very difficult and they die.

The leaf analyses show a decrease of Ca, K, Mg and B, all components of the fertilizer, from 0 g to 100 g. The decrease of Ca and Mg can be explained through the nature of nitrogen in the fertilizer, which is ammoniacal nitrogen. This is an acidic working fertilizer and there is a competition between ammoniacal nitrogen and Ca and Mg. Adding more fertilizer means adding more ammoniacal nitrogen, which leads to a higher competition with Ca and Mg and will thus lead to a lower Ca and Mg content of the leaves. The analyses show a very high amount of Fe which is even more increasing with more fertilization. Fe, not a component of the fertilizer, is competing with B and Mg and this could explain the decrease of B and Mg. Also the dilution effect could be a cause for a decrease of these elements. A higher amount of fertilization will lead to a growth boost which can dilute the concentration of elements in the leaves.

The Fe concentration for the 100 g treatment is almost twice as high as the concentration at the 0 and 50 g treatments. This is unusually because iron is not a component of the fertilizer. The iron concentration in the mukau seedlings is also ten to twenty times higher than the iron concentration in *A. indica,* another member of the *Meliaceae*. Also the potassium concentration is almost 3 times higher in the mukau leaves than in the leaves of *A. indica*. This high concentration of K could explain the high amount of Fe because both elements are synergistic. However, it is unusual that the potassium amount in the leaves decreases with adding more fertilization.

The total nitrogen percentage reaches a maximum for the 50 g treatment while the nitrogen percentage at 0 g and 100 g are fairly similar. With increasing the amount of fertilization from 0 to 50 g, there is added more N to the soil, more N will thus be available for the plants and they will absorb more N. When the fertilization amount increases up to 100 g, the plant will have a growth boost which causes a dilution effect of the elements, including a dilution of the N concentration.

The C/N ratio decreases when using more fertilizer. The total amount of nitrogen increases with adding more fertilizer, which will increase the leave area. This causes a higher photosynthetic active area, which will increase the carbon amount. However, the amount of carbon is increasing slower than the increase of nitrogen. This causes a decrease in C/N ratio.

The phosphorus concentration also reaches a maximum for the 50 g treatment. This could be explained similarly to the explanation of the N amount.

The Mn, not a component of the fertilizer, concentration in the leaves is increasing with adding more fertilizer. This can be caused by the synergistic activity between ammoniacal nitrogen and manganese at one side and the synergistic activity between phosphorus and manganese at the other side. Adding more fertilizer means adding more N and P and this will benefit the absorption of Mn.

The Mn concentration in the mukau seedlings is almost ten times higher than the concentration found in the leaves of *A. indica*. It is obvious that the leaf contents of *M. volkensii* differs highly from the leaf contents of *A. indica*.

General conclusion

Jatropha curcas turned out to be vulnerable for a large range of pests and diseases.
The insects that appear on the plantation are *Calidea dregii, Heliothrips haemorroidales, Scirtothrips kenyensis, Ferrisia virgata*, *Stomphastis sp.*, *Pempelia Morosalis, Aphtona sp.* and termites. These are all known as pest organisms on *J. curcas* in Kenya.
Using sticky plates as an early detection method was not satisfactory as they were blown away and did not attract the pest insects.

Four fungi were found to cause problems on *J. curcas* plants. *Fusarium* and *Trichothecium* spp. were sampled from plants with root rot. *Alternaria* and *Sirosporium* spp. were conducted from samples of plants with leaf spot. *Fusarium, Alternia* and *Sirosporium* spp. cause the root rot respectively leaf spots, while the presence of *Trichothecium spp*., an antagonist for several fungi, is probably not directly related to the appearance of root rot. Different hypotheses concerning this issue has been made and it could be interesting to use *Trichothecium spp.* isolates in controlling root rot, caused by *Fusarium spp.*.
The described pathogen fungi cause death and defoliating of the plants and have to be controlled and prevented. They were not yet described in the literature on *J. curcas* in Kenya and have to be taken into account as possible pest organisms on other plantations.

The spraying system on the plantation is reasonably effective and toxicity is fairly low. The spraying system does not affect the quality of the water in the lake in that extent that it becomes dangerous for the fish, the ecosystem or the people living around the lake. The most toxic used product is fenthion, which can be replaced by the less toxic thiacloprid.

The risk for resistance is an issue that needs some more attention trough alternating with products with a different mode of action. Some chemicals that can be added to the assortment of chemicals to use as alternating products are thiacloprid against the chewing and sucking insects, deltamethrin against caterpillars, triadimefon against powdery mildew, fluoxastrobine and trifloxystrobine against *Alternaria spp.* and mildew and prothioconazole against *Fusarium spp.* and powdery mildew.

Thrips, caterpillars and leaf miners form the biggest problem during the dry season and fungal infections during the rainy season.

Some alternative pest management measures are using lady beetles and neem extracts for controlling thrips, using light- and pheromone traps to prevent caterpillar damage and using antagonistic fungi like *Trichoderma spp*. to control soil born fungal infections.

We were not able to identify the cause for stem cancer occurring on *M. volkensii*, but there can be suspected that it concerns a bacterial infection. Further examination in this direction is necessary.

The difference in growth of *J. curcas* at different locations, turned out to be the result of a difference in the depth of the soil and the thickness of the A horizon. A deeper soil and a thicker A horizon gives better growth parameters like stem diameter, plant height and crown area. This beneficial effect is due to a higher rooting volume making water and nutrient absorption more effective and is due to a higher organic matter content in thicker A horizons. Also water retention is a factor in determining the growth of *J. curcas*. There is a crust on the surface of the soil, making water absorption in the soil difficult. Water will run off and mainly on flat surfaces, the water will be able to penetrate slowly into the soil.

Fertilization with Mavuno appeared to influence the health and stem diameter of *M. volkensii* seedlings significantly. Fertilization makes the seedlings stronger and healthier and improves the growth of the cambium. A significant effect was not reported on the plant height, although fertilization seems to be beneficial for this growth parameter at first sight.
The optimum amount of fertilization is 50 g per seedling. Increasing the fertilization amount up to 100 g will lead to luxury consumption and the advantages will not be proportional anymore to the input efforts. Also there is a higher mortality percentage when using 100 g of fertilizer, possibly due to root damaging because of the high fertilizer concentration close to the roots or the inhibition of water absorption due to an increase of the EC of the soil. Also the nutrient content of the leaves reached maximum quantities of several elements in leaves that received 50 g of fertilizer.

We can say that the managing system of the plantation is on a good trail, but improvement is possible through taking into account the previous aspects.

At last, we can conclude that drylands do have high potentials but they are often unexploited because of bad management practices, insufficient knowledge and the lack of investing means. However, we have to be conscious in proposing *Jatropha curcas* as a high potential crop for these areas. The literature often shows promising results, but the reality is usually disappointing. Published information is often based on unrealistically high planting densities, very high yield levels and insusceptibility for environmental bottlenecks and pests and diseases. The reality shows that the economical profitability of *J. curcas* on drylands is very unstable because of the high vulnerability for pests and diseases and the costs for spraying can rise seriously.

Melia volkensii shows less problems and more advantages, but there is almost no literature available about this tree. So also here we have to be conscious and further examination is necessary before jumping on this plant as a ‘wonder crop for drylands’.

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(3) www.heatingoil.com, consulted on 30/04/10.

(4) www.jatrophaparaguay.org, consulted on 30/04/10.

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Appendixes

Appendix I : General overview of the water resources

Table 31: General overvieuw of the water resources (Source: Verlodt, 2009b)

	Water category	Water harvesting type	Origin of water	Techniques of capture and mobilisation	Techniques of storage	General use
Convent ional water	Surface water	Rain water harvesting	Rock, crusted soils, road and roof catchments	-Little catchments: negarims[1], circular bunds, etc..., roof androad catchment -Medium catchment: meskats[2] -Large catchments: tabias[3], jessours[4]	Water holes, basins, pans, cisterns, tanks	Agriculture, cattle, wildlife, domestic use, tree and fruit plantation, cropping and plantation
		Flood water harvesting	Seasonal rivers	-Spreading of flood -Seasonal cultivation after flooding	Water table recharge	Agriculture
			Permanent and seasonal rivers	-Dams -Direct pumping	-Reservoirs -Reservoirs and direct use	Drinking water, irrigation, industry
			Sandy rivers	-Subsurface dams -Sand trap dams -Extraction and pumping from small wells and holes in riverbeds	Direct use	Human and animal needs
	Ground water	Superficial groundwater	Springs	-Underground galleries -Different machines moved by people or animals Pumping with motorised machines -Artesian or pumped -Pumped hot water	-Direct use -Direct use -Direct use and storage in basins -Storage in basins -Storage in basins after colling	Irrigation in oasis, cattle and domestic cure, differed human uses, heating of green houses, industry
		Deep groundwater	Foggara (Khriga) Shallow wells Deep boreholes Very deep water tables			

Non conventional water	Desalination brackish water		Saline groundwater , seawater desalination	Desalination plant (electro dialysis, reverse osmosis)	Direct use or storage in basins for mixing	Drinking water and different uses
	Treated wastewater		Urban used wastewater	Treatment plant (primary, secondary and tertiary levels)	Storage in basins	Restrictive use in agriculture and industry

Appendix II: Measures to improve the current NRC system

Table 32: Most important measures to improve the current system of non-resident cultivation according to the Kenya Forestry Masterplan Project (Source: FAO, 2000)

1	• Capacity building in resource assessment, planning and management, impact assessments and GIS, monitoring and evaluation
2	• Research in non-wood tree products to enhance their economic potential.
3	• Forest inventory (Farm forestry, Indigenous forests and Dry land forests)
4	• Social and economic valuation of the forestry sector
5	• Development of management plans for all forest blocks
6	• Institutional linkages to partners in forest industry
7	• Acquisition of technologies especially in tissue culture
8	• propagation of commercial tree species, utilization and processing of NWFPs
9	• Research on tree improvement and growth modeling
10	• Identification and domestication of fast growing commercial tree species to broaden the resource base
11	• Vigorous promotion and utilization of new and renewable sources of energy with a view to substituting fuel wood, agricultural waste and animals waste

Appendix III: Forest products market information

Table 33: Forest products market information (Source: Deprins, 2009)

TIMBER

Species	Size	Price (Ksh)						
		Coast	Nairobi	Central	Western	Rift Valley	Eastern	Nyanza
Cypress	2"x2"	25	28	25	15	16	24	18
	3"x2"	30	32	30	23	22	32	26
	4"x2"	40	34	32	25	25	36	27
	6"x2"	52	52	48	30	32	42	34
	6"x1"	42	34	32	25	26	32	30
	8"x1"	52	42	40	33	34	38	34
Pine	2"x2"	22	26	24	14	15	20	18
	3"x2"	28	30	28	21	21	30	24
	4"x2"	30	32	30	22	22	34	25
	6"x2"	52	48	45	26	30	40	32
	6"x1"	30	32	32	24	26	32	28
	8"x1"	48	45	36	32	32	36	32
Grevillea	2"x2"	20	18	15	12	13	17	14
	3"x2"	22	19	17	15	15	19	18
	4"x2"	25	22	20	17	17	22	18
	6"x2"	30	30	28	22	21	30	23
	6"x1"	26	24	22	18	17	24	20
	8"x1"	34	30	28	22	20	30	24
Eucalypt	2"x2"	20	18	15	12	13	17	14
	3"x2"	22	19	17	15	15	19	17
	4"x2"	25	22	20	17	17	22	18
	6"x2"	30	30	28	20	20	30	23
	6"x1"	26	24	22	18	17	24	20
	8"x1"	34	30	28	22	20	30	24

CHARCOAL

species	price/bag (Ksh)						
	Coast	Nairobi	Western	Central	Rift Valley	Eastern	Nyanza
acacia	600	750	650	700	550	450	650
black wattle	600	750	650	700	550	450	650

INDUSTRIAL FIREWOOD

species	price/m3 (Ksh)						
	Coast	Nairobi	Western	Central	Rift Valley	Eastern	Nyanza
Eucalyptus/Others	1,100	1,500	1,250	1,250	1,200	900	1,300

SEMI-PROCESSED TRANSMISSION POLES (EUCALYPTS)

species	price/piece (Ksh)			
	Western	Central	Rift Valley	Nyanza
Farm gate	1,400	1,400	1,300	1,300
Factory gate	2,200	2,200	2,200	2,200

TREATED TRANSMISSION POLES (EUCALYPTS)

species	price/piece (Ksh)						
	Coast	Nairobi	Western	Central	Rift Valley	Eastern	Nyanza
Tender prices*	12,000	12,000	12,000	12,000	12,000	12,000	12,000

* To supply to KPLC depots throughout the country

LOGS

species	price (Ksh/m3)			
	Central	Western	Rift Valley	Nyanza
pine	2,800	1,500	2,500	1,500
cypress	3,200	2,000	2,000	2,000
grevillea	2,000	1,200	1,500	1,200
eucalypt	2,000	1,200	1,500	1,200

EUCALYPT CONSTRUCTION WOOD

item	length (m)	price (Ksh/m3)			
		Coast *	Rift Valley	Eastern	Nyanza
Withies	3	30	15	20	20
Small	6	60	40	60	65
Medium	10	200	60	70	85
Large	15	300	80	80	100

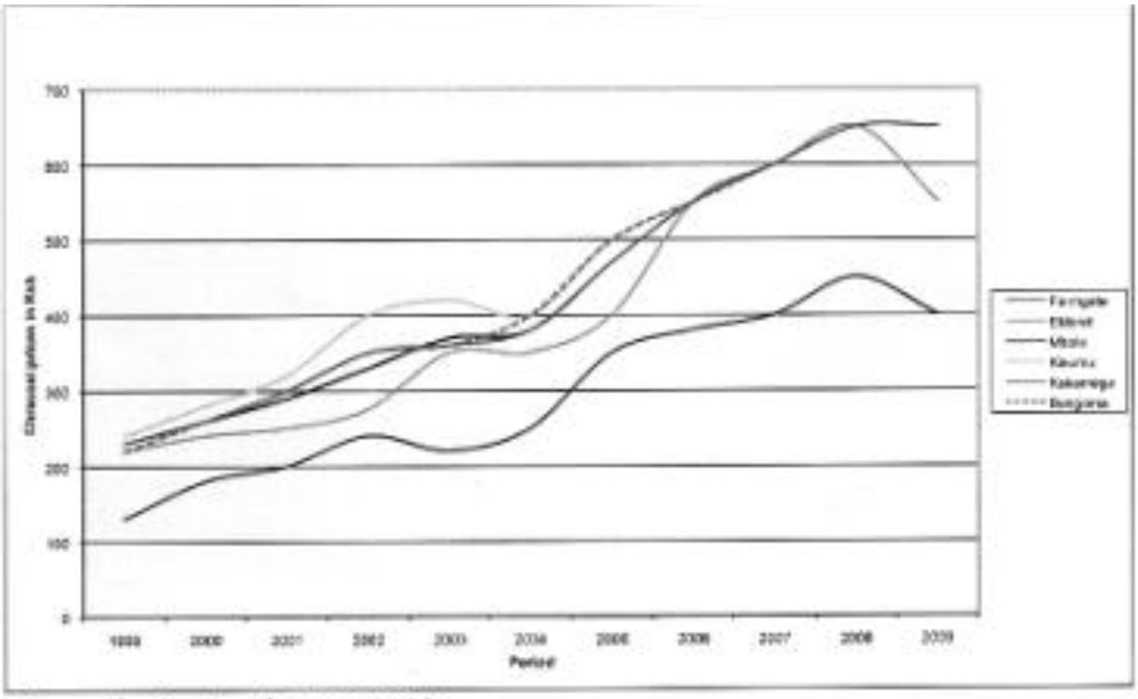
* Mangrove poles

EUCALYPT FENCING POSTS

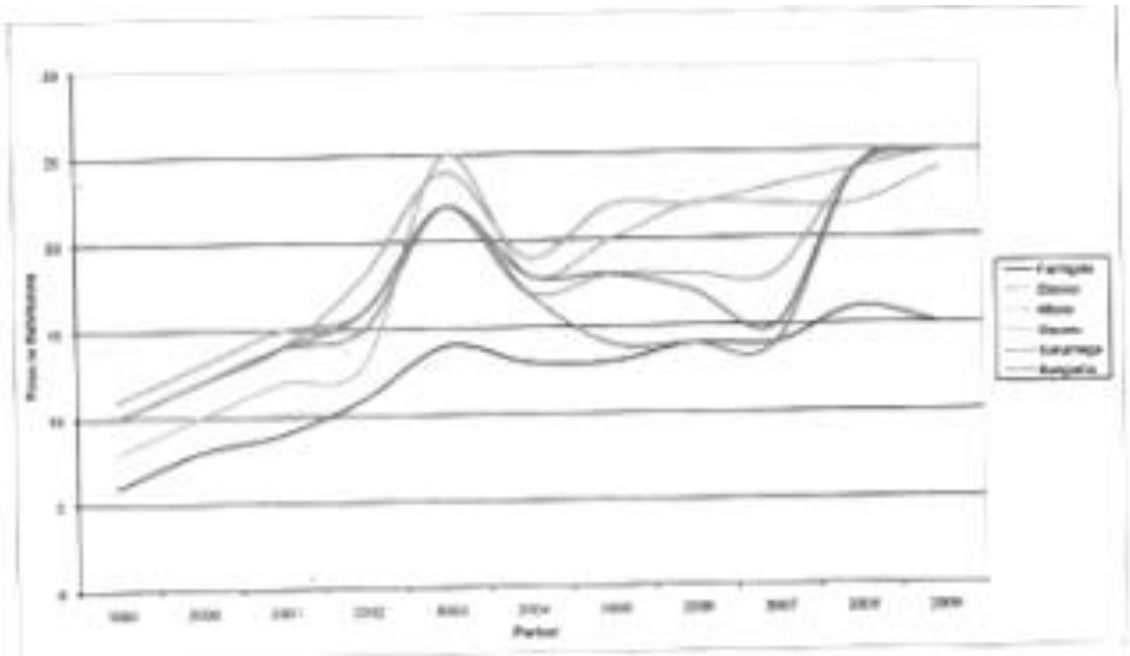
species	length (m)	price (Ksh/m3)				
		Coast *	Western	Rift Valley	Eastern	Nyanza
Small	3	80	40	45	50	60
Medium	3	120	60	70	80	80
Large	3	170	70	80	100	100

* Mangrove poles

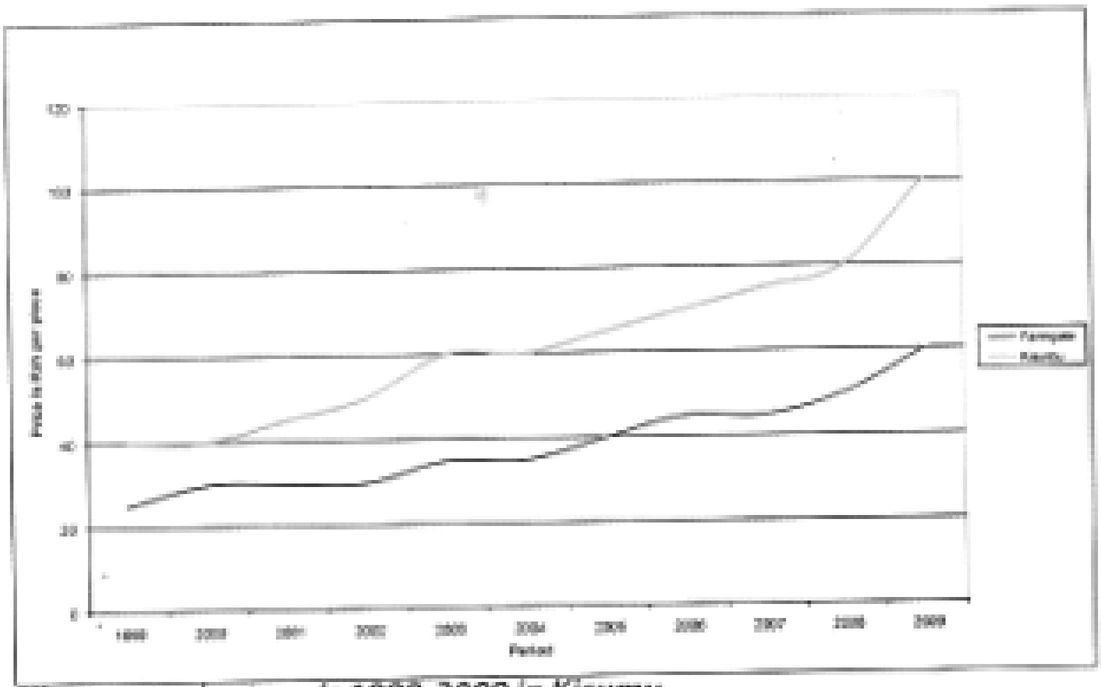
Appendix IV: Detailed evolution of some forestry products



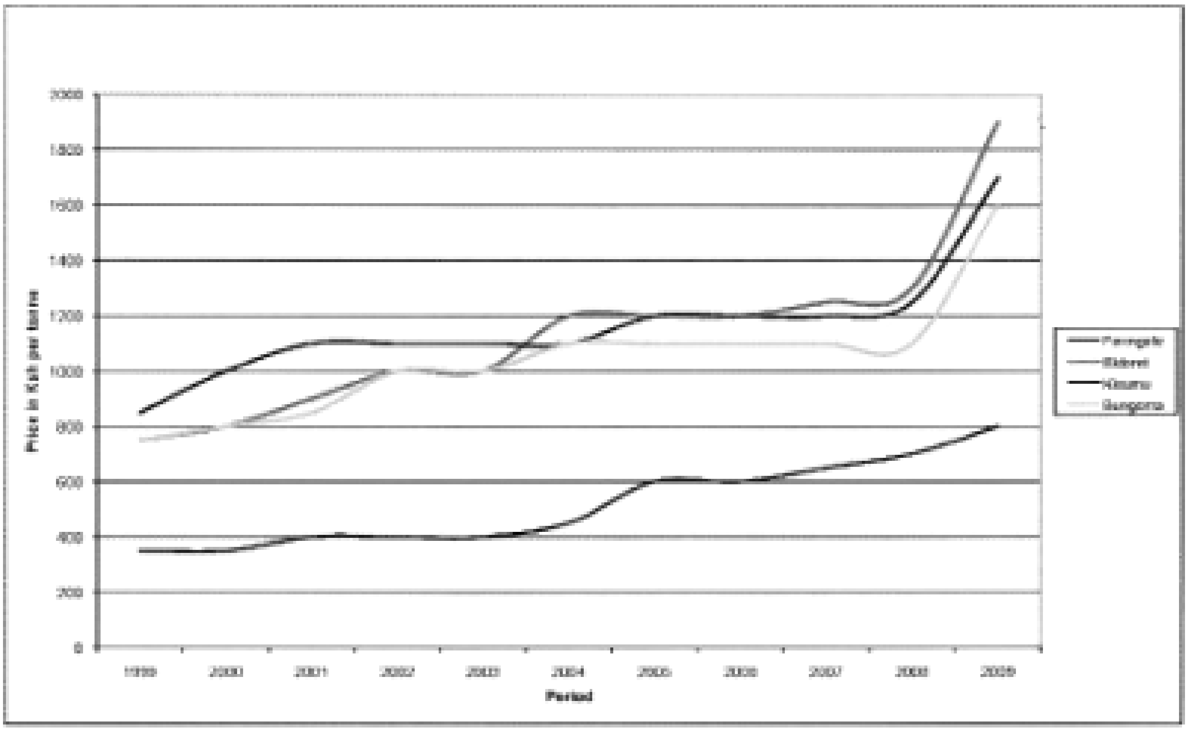
Charcoal price trends 1999-2008



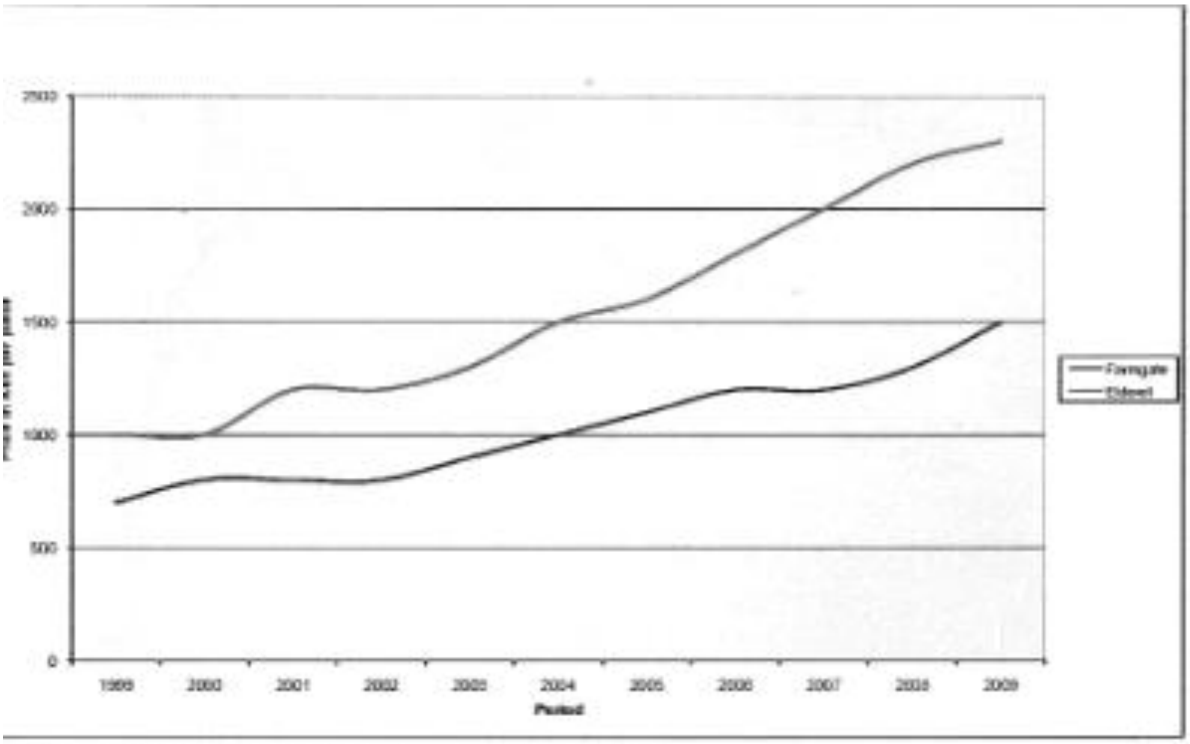
Cypress sawnwood price trends 1999-2009



King post price trends 1999-2009 in Kisumu



Factory gate price for firewood 1999-2009



ıctory gate transmission pole price trends 1999-2009

Figure 50: Detailed evolution of the prices of charcoal, cypress sawn wood, king posts, firewood and transmission poles between 1999 and 2008 (Source: Cheboiwo, 2009)

Appendix V: Map of the pilot plantation

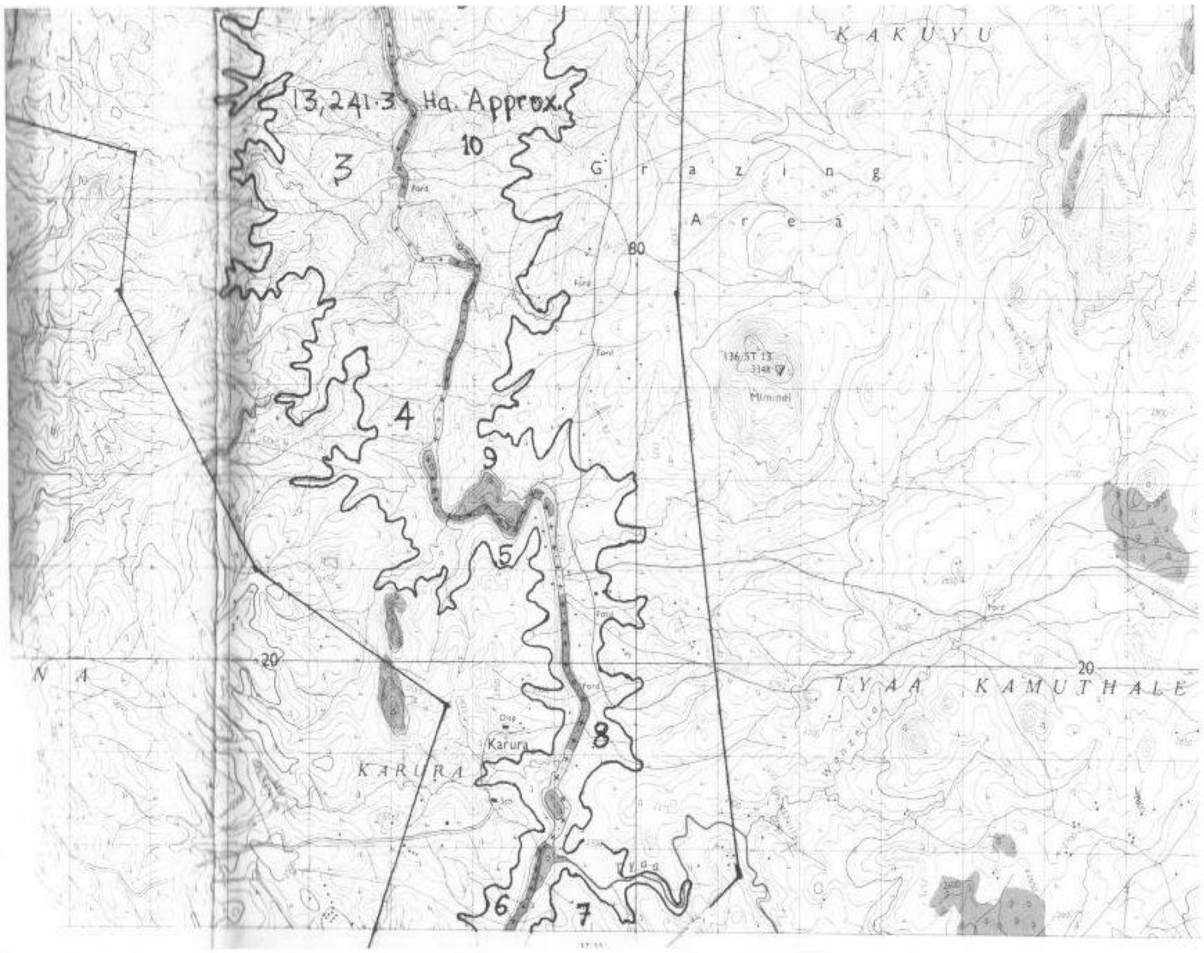


Figure 51: Map of the pilot plantation by Lake Kiambere in Mbeere district (Source: Vandenabeele, 2009b)

Appendix VI: Organization of the sticky plates

Kind of plate:

TOP

YH	BL	YL
BL	YH	BH
YL	BH	YH
BH	YH	BL
YH	BL	YL
BL	YH	BH
YL	BH	YH
BH	YL	BL
YH	BL	YL
BL	YH	BH
YL	BH	YH
BH	YL	BL
YH	BL	YL

DOWN

Number of plate:

TOP

1	2	3
6	5	4
7	8	9
12	11	10
13	14	15
18	17	16
19	20	21
24	23	22
25	26	27
30	29	28
31	32	33
36	35	34
37	38	39

DOWN

<u>Legend:</u>

YH: yellow high
YL: yellow low
BH: blue high
BL: blue low

Figure 52: Organization of the sticky plates

Appendix VII: Card for monitoring insects, 2 Sept 2009

Location: Katithini
Date: 02/09/09
Author: Silke Nowak

Plate number	Name of insect	Number of insects	New insects	Remarks
1	Mosquito	2		
1	Small coleoptera	3		
1	Little unidentified flies	20		
2				Blown away
3				Blown away
4				Blown away
5				Blown away
6	Butterfly	1		
6	Coleoptera	3		
6	Big unidentified fly	1		
6	Small unidentified flies	7		
Plate number	**Name of insect**	**Number of insects**	**New insects**	**Remarks**
7				Blown away
8				Blown away
9				Blown away
10				Blown away
11				Blown away
12				Blown away
13				Blown away

14				Blown away
15				Blown away
16				Blown away
17	Ants	4		
17	Spider	1		
17	Coleoptera	4		
17	Mosquito	3		

Location: Katithini
Date: 02/09/09
Author: Silke Nowak

Plate number	Name of insect	Number of insects	New insects	Remarks
17	Small unidentified fly	10		
18				Blown away
19				Blown away
20				Blown away
21				Blown away
22	Coleoptera	2		Blown away
22	Big unidentified fly	5		Blown away
22	Small unidentified fly	25		Blown away
23				Blown away
24				Blown away
25				Blown away
Plate number	**Name of insect**	**Number of insects**	**New insects**	**Remarks**
26	Little unidentified fly	34		

26	Big unidentified fly	2		
26	Mosquito	1		
27				Missing
28				Blown away
29				Blown away
30	Small unidentified fly	8		
31	Coleoptera	4		
31	Small unidentified fly	57		
32	Big unidentified fly	3		
32	Small unidentified fly	46		
34				Blown away
35				Missing
36				Blown away

Location: Katithini
Date: 02/09/09
Author: Silke Nowak

Plate number	Name of insect	Number of insects	New insects	Remarks
37				Blown away
38				Blown away
39				Blown away
TOTAL	**Mosquito**	**6**		**29 blown away; 2 missing; 8**
	Coleoptera	**16**		
	Small unidentified fly	**207**		
	Big unidentified fly	**11**		

	Butterfly	**1**		
	Ant	**4**		
	Spider	**1**		

Appendix VIII: SAS output One Way Anova fertilizer trial

The ANOVA Procedure

Class Level Information

Class	Levels	Values
TREATMENT	3	0 g 100 g 50 g

Number of Observations Read	588
Number of Observations Used	555

Generated by the SAS System (Local, NET_SRV) on 13mei2010 at 2:41 PM

One-Way Analysis of Variance
Results

The ANOVA Procedure

Dependent Variable: HEALTH (1-5) HEALTH (1-5)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	22.1419280	11.0709640	15.07	<.0001
Error	552	405.6526666	0.7348780		
Corrected Total	554	427.7945946			

R-Square	Coeff Var	Root MSE	HEALTH (1-5) Mean
0.051758	33.31750	0.857250	2.572973

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREATMENT	2	22.14192797	11.07096399	15.07	<.0001

Generated by the SAS System (Local, NET_SRV) on 13mei2010 at 2:41 PM

One-Way Analysis of Variance

Results

The ANOVA Procedure

Dependent Variable: HEIGHT (CM) HEIGHT (CM)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	75.47622	37.73811	0.91	0.4044
Error	552	22971.17243	41.61444		
Corrected Total	554	23046.64865			

R-Square	Coeff Var	Root MSE	HEIGHT (CM) Mean
0.003275	23.44639	6.450926	27.51351

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREATMENT	2	75.47622241	37.73811120	0.91	0.4044

Generated by the SAS System (Local, NET_SRV) on 13mei2010 at 2:41 PM

One-Way Analysis of Variance

Results

The ANOVA Procedure

Dependent Variable: STEMDIAMETER (mm) STEMDIAMETER (mm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	79.339857	39.669928	13.58	<.0001
Error	552	1612.822693	2.921780		
Corrected Total	554	1692.162550			

R-Square	Coeff Var	Root MSE	STEMDIAMETER (mm) Mean
0.046887	23.59063	1.709322	7.245766

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREATMENT	2	79.33985651	39.66992826	13.58	<.0001

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One-Way Analysis of Variance

Results

The ANOVA Procedure

Student-Newman-Keuls Test for HEALTH (1-5)

Note: This test controls the Type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	552
Error Mean Square	0.734878
Harmonic Mean of Cell Sizes	184.8097

Note: Cell sizes are not equal.

Number of Means	2	3
Critical Range	0.1751708	0.209574

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	TREATMENT
A	2.85027	187	0 g

Means with the same letter
are not significantly different.

SNK Grouping	Mean	N	TREATMENT
B	2.46597	191	50 g
B			
B	2.39548	177	100 g

Generated by the SAS System (Local, NET_SRV) on 13mei2010 at 2:41 PM

One-Way Analysis of Variance
Results

The ANOVA Procedure

Student-Newman-Keuls Test for HEIGHT (CM)

Note: This test controls the Type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	552
Error Mean Square	41.61444
Harmonic Mean of Cell Sizes	184.8097

Note: Cell sizes are not equal.

Number of Means	**2**	**3**
Critical Range	1.3181846	1.5770731

Means with the same letter
are not significantly different.

SNK Grouping	Mean	N	TREATMENT
A	27.8534	191	50 g
A			
A	27.6836	177	100 g
A			
A	27.0053	187	0 g

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One-Way Analysis of Variance
Results

The ANOVA Procedure

Student-Newman-Keuls Test for STEMDIAMETER (mm)

Note: This test controls the Type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	552
Error Mean Square	2.92178
Harmonic Mean of Cell Sizes	184.8097

Note: Cell sizes are not equal.

Number of Means	**2**	**3**
Critical Range	0.3492834	0.4178819

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	TREATMENT
A	7.5862	177	100 g
A			
A	7.4435	191	50 g
B	6.7217	187	0 g

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One-Way Analysis of Variance

Plots

Means Plot of 'HEALTH (1-5)' by TREATMENT

Click for description of Means Plot of 'HEALTH (1-5)' by TREATMEN

Generated by the SAS System (Local, NET_SRV) on 13mei2010 at 2:41 PM

One-Way Analysis of Variance

Plots

Means Plot of 'HEIGHT (CM)' by TREATMENT

Click for description of Means Plot of 'HEIGHT (CM)' by TREATMENT

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One-Way Analysis of Variance

Plots

Means Plot of 'STEMDIAMETER (mm)' by TREATMENT

Click for description of Means Plot of 'STEMDIAMETER (mm)' by TRE

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Appendix IX: Results leaf analyses

CENTRUM VOOR TOEGEPAST ONDERZOEK EN DIENSTVERLENING Intern dokument

ICP ANALYSE

Naam analist : Silke (Studente Filip) Dossiernr. :

Analyse datum : 13/04/2010 Programma :

Matrix : plant Elementen : spoorelementen

Labonr	Gewicht monster in g	Totaal volume in ml	Faktor (..ml/..g)	Opmerking
0 g	0,9994	50	50,0300	
50 g	0,9932	50	50,3423	
100 g	0,995	50	50,2513	
			#DEEL/0!	
			#DEEL/0!	
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			#DEEL/0!	
			#DEEL/0!	

Labo Chemische Analysen

SOP : 007.002
Pagina : 1/1
Revisie : 4
Datum : 22.09.04

15.04.2010

08042010

No.	Name	Wght./ Volume	Date	Time	Info	Method	Prot. Fact.	Prot. (*)	C/N Ratio		Content (*)	Peak Area
31	MR056	225.70 mg	14.04.10	16:11		125	0.00	0.000	4.561	N:	7.346	123192
										C:	33.50	129741
32	MR057	216.90 mg	14.04.10	16:23		125	0.00	0.000	3.616	N:	12.91	207411
										C:	46.70	172150
33	MR058	1002.8 mg	14.04.10	16:36		75	0.00	0.000	13.53	N:	0.085	5754
										C:	1.156	20423
34	0 g	205.90 mg	14.04.10	16:48		125	0.00	0.000	6.365	N:	5.960	91262
										C:	37.94	133893
35	50 g	202.90 mg	14.04.10	17:00		125	0.00	0.000	5.810	N:	6.449	97302
										C:	37.47	130423
36	100 g	219.10 mg	14.04.10	17:12		125	0.00	0.000	5.678	N:	5.994	97650
										C:	34.03	127983
37	PL004	212.90 mg	14.04.10	17:24		125	0.00	0.000	36.27	N:	1.336	20755
										C:	48.44	175162
38	BB010	1023.5 mg	14.04.10	17:36		125	0.00	0.000	34.67	N:	0.190	13968
										C:	6.584	116022
39	BB011	1031.6 mg	14.04.10	17:48		125	0.00	0.000	35.81	N:	0.182	13501
										C:	6.533	116035
40	~~Asparticzuur~~ Glutamine.	206.40 mg	14.04.10	18:00		125	0.00	0.000	4.323	N:	9.453	144853
										C:	40.86	144210

(*) [%] for Weights in [mg], [mg/l] for "Weights" in [ml]
Elementar Analysensysteme GmbH VarioMax V5.2 19.Sep.2002 Page 3
CN Mode, N sensitive, C insensitive

Sample Report

Report Author Tania Roeges
Printed: 15/04/2010 11:03 am

0 g

Acquire Date: 15-apr-2010 10:31 am — Sample Type: Unknown

Correction Factor50,0300 SW: 1,0000 NW: 1,0000 IV: 1,0000 FV: 1,0000 AF: 1,0000

Elem	Avg	Units	Stddev	%RSD
B_2497	55,7	ppm	,3	,598
Ca3158	15500,	ppm	25	,162
Cu3247	23,5	ppm	,1	,477
Fe2382	2060,	ppm	9	,449
K_7664	44700,	ppm	27	,060
Mg2852	4980,	ppm	12	,234
Mn2605	169,	ppm	1	,624
Na5895	688,	ppm	1	,080
P_2136	8160,	ppm	41	,500
S_1820	4590,	ppm	25	,550
Zn2062	102,	ppm	0	,269

50 g

Acquire Date: 15-apr-2010 10:35 am — Sample Type: Unknown

Correction Factor50,3423 SW: 1,0000 NW: 1,0000 IV: 1,0000 FV: 1,0000 AF: 1,0000

Elem	Avg	Units	Stddev	%RSD
B_2497	47,7	ppm	,2	,351
Ca3158	13800,	ppm	76	,551
Cu3247	17,8	ppm	,0	,274
Fe2382	2020,	ppm	8	,409
K_7664	42900,	ppm	273	,635
Mg2852	4020,	ppm	21	,523
Mn2605	379,	ppm	1	,344
Na5895	625,	ppm	4	,608
P_2136	8320,	ppm	18	,218
S_1820	4330,	ppm	12	,270
Zn2062	79,5	ppm	,4	,495

100 g

Acquire Date: 15-apr-2010 10:38 am — Sample Type: Unknown

Correction Factor50,2513 SW: 1,0000 NW: 1,0000 IV: 1,0000 FV: 1,0000 AF: 1,0000

Elem	Avg	Units	Stddev	%RSD
B_2497	44,6	ppm	,3	,755
Ca3158	12700,	ppm	59	,465
Cu3247	21,6	ppm	,1	,280
Fe2382	3980,	ppm	9	,228
K_7664	38300,	ppm	170	,444
Mg2852	3980,	ppm	21	,523
Mn2605	488,	ppm	1	,138
Na5895	654,	ppm	4	,598

Color Legend: Pass/Unchecked

100 g

Acquire Date: 15-apr-2010 10:38 am Sample Type: Unknown

Correction Factor50,2513 SW: 1,0000 NW: 1,0000 IV: 1,0000 FV: 1,0000 AF: 1,0000

Elem	Avg	Units	Stddev	%RSD
P_2136	8070,	ppm	22	,272
S_1820	4370,	ppm	11	,258
Zn2062	80,0	ppm	,3	,346

Color Legend: Pass/Unchecked