WATER CONSUMPTION BY *JATROPHA CURCAS, MORINGA OLEIFERA* AND *EUCALYPTUS SALIGNA* AND LOCAL PEOPLE'S PERCEPTIONS IN MPANDA DISTRICT, TANZANIA

BY

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ABSTRACT

In response to rising oil prices and searching for alternative, economically viable and environmentally sustainable forms of energy, certain plant species with biofuel potential have been proposed for large-scale planting in bio-fuel production. Some countries however have been forced to slow down the rate of implementation of commercial planting for bio-fuel production due to limited knowledge on potential environmental impacts of planting bio-fuel species especially on water resources as water scarcity is an increasingly severe problem Word-wide. The aim of the present study was to undertake comparative analysis of water consumption of three widely planted biofuel species – *Jatropha curcas*, *Moringa oleifera* and *Eucalyptus saligna* as a basis for determination of potential impacts on water resources in large scale plantations. The study consisted of two parts; field survey in Mpanda District to assess the extent of cultivation of the three bio-fuel trees and perceptions of local communities on water consumption of these species. The second part was a Greenhouse experiment to determine water use by the selected bio-fuel tree species as a basis for understanding the impacts of large scale planting on water resources. It was observed that the most extensively planted bio-fuel feedstock in the Mpanda District was *J. curcas* (75.3%) followed by *M. oleifera* (22%) and *E.saligna* (2.7%). There was also perception by the majority of people that *E. saligna* consumes large quantities of water from the soil. The Greenhouse experiment revealed that there is no difference in water consumption ($p < 0.05$) between *M. oleifera* and *J. curcas* while water consumption by *E. saligna* was significantly lower. The water consumption per kilogram of biomass production by *J. curcas* was of an average of 220 litres, followed by *M. oleifera* (358 litres) and *E. saligna* (379 litres). The amount of water uptake, especially for *J. curcas* and *M. oleifera*, per unit biomass production is relatively low thus expected to pose less threat to soil water budget when cultivated extensively as cash crop.

DECLARATION

I, PRISCA PATRICK NTABAYE, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

________________________ __________________

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The above declaration is confirmed by;

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Prof. P. K. T. Munishi Date

(Supervisor)

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Dr. L. P. Lusambo Date

(Supervisor)

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LIST OF ABBREVIATIONS

BWS	Bureau Water Standards
FAO	Food and Agriculture Organisation
FGDs	Focus group Discussions
IEA	International Energy Agency
IMF	International Monetary Fund
IUCN	International Union for Conservation of Nature
MDCP	Mpanda District Council Profile
NBTF	National Biofuel Task Force
NGOs	Non Governmental Organisations
SUA	Sokoine University of Agriculture
SVO	Straight Vegetable Oil
TaTEDO	The Tanzania Traditional Energy and Environment Development Organization
URT	United republic of Tanzania
WRC	Water Research Commission
WUE	Water Use Efficiency
g	gram
cm^3	cubic centimeter
ml	milliter
kg	kilogram
µm	micrometer

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Dufey *et al.* (2007) defines biofuels as a term used to describe fuel derived from organic matter for the purpose of transport, electricity generation, or heating and commonly refers to biogas, bioethanol, and biodiesel. Biofuels are a wide range of fuels which covers liquid (ethanol and biodiesel), solid biomass (charcoal, firewood, sawdust) or various gaseous (biogases) fuels that can be manufactured from biomass, such as agricultural crops and the biodegradable parts of wastes (Demirbas, 2009). Around ten percent of the total primary energy supply comes from biomass (IEA, 2007); most of which is used in the form of solid fuel for cooking and heating, especially in developing countries.

Biogas is produced through fermentation and is used for electricity generation. Bioethanol is an alcohol produced through fermentation and distillation of starchy plants (such as sugar and cassava) and grain. It can be used pure or blended with gasoline. Biodiesel is derived from oilseed-bearing plants (Mitchell, 2008). Uhlenbrook (2007) in Hoogeveen *et al.* (2009) defined biofuel as fuel with a minimum of 80 percent content by volume of materials derived from living organisms harvested within 10 years of its manufacture. Biofuels can replace fossil fuels, such as petrol or diesel, either totally or partially in a blend.

The increasing concern of reducing carbon emission into the atmosphere and the sharp rise in the crude oil prices due to the growing worldwide demand for oil, modest increase in economically exploitable oil resources and declining reserves of fossil fuels, has forced the World community to search for alternatives to meet this global demand for energy by the use of alternative and renewable sources. The alternative and renewable sources are said to be capable of providing opportunities for mitigating greenhouse gases due to being able to capture carbon dioxide from the atmosphere (Blesgraaf, 2009).

The intensification of agricultural production systems for biofuel feedstocks and the conversion of existing and new croplands will have environmental effects beyond their impacts on greenhouse gas emissions. The nature and extent of these impacts are dependent on factors such as scale of production, type of feedstock, cultivation and land-management practices, location and downstream processing routes. Evidence remains limited on the impacts specifically associated with intensified biofuel production, although most of the problems are similar to those already associated with agricultural production – water depletion and pollution, soil degradation, nutrient depletion and the loss of wild and agricultural biodiversity (Martin *et al*., 2009).

There are various plants that are named to be potentials for producing biodiesel, the liquid biofuel; among them being *Jatropha curcas* and *Moringa oleifera*. Both of them have got oil-bearing seeds that the oil obtained has got potential to run engines totally or partially in a blend (Bresfaag, 2009); have potentials for improving livelihoods and conserving environment; and potentials for producing biodiesel (Azam *et al.,* 2005). *Jatropha curcas* has been the focus of majority of investors. Hamis (2009) pointed out that approximately 72 percent of the investors in Tanzania are attracted to cultivate *J. curcas.*

Eucalyptus saligna is one of the 600 species of Eucalypts that have many uses to people in their day to day lives, including contribution to significant source of building materials and fuel wood (Munishi, 2007). Being used as fuel wood, *E. saligna* is considered to be one of the solid biofuel source; it is a second generation biofuel source

(Hoogeven *et al.,* 2009). *Eucalyptus saligna* has been selected because being one of the Eucalypt species it has been condemned for a long time for consuming excessive water (Munishi, 2007); therefore, in this study it was used as a reference biofuel tree. Bioenergy currently accounts for roughly 10% of total primary energy supply globally but most of this energy is consumed as wood for cooking in developing countries (IUCN, 2008).

Tanzania as many other nations in the World, is facing severe energy crisis due to present global crude oil price because it mainly depends on imported oil. The price of crude oil has risen from $30 a barrel in 2003 to around $130 a barrel in 2008 (IMF, 2008; Hoogeven *et al.,* 2009) therefore it has improved the relative economic viability of biofuel production.

Tanzania is one of the countries promoting efficient utilisation of biofuels as one of the alternative ways to address energy problem. In addition, there is a hope that biofuel production will improve national energy security/self-sufficiency; diversify energy sources; reduce fuel import bill; improve rural development; create new jobs and income opportunities through bio-energy farms and processing; contribute to environment conservation - climate change and technology transfer through new bio-energy industries.

Jatropha curcas has been observed in many parts of Tanzania for many years. In Mpanda District people of *Pimbwe* tribe in particular, used it as live fences around their homesteads, gardens and farms (Tomomatsu and Swallow, 2007). The plant has been reintroduced as a biofuel crop and people started planting it as a cash crop by intercropping with other food crops such as maize, cassava, groundnuts in their agricultural lands.

Due to the growing demand of biofuels numerous investors from different parts of the World have started cultivation of biofuels in various parts of the country and other companies are currently on the process to start new biofuels producing projects (Zeller, 2009). Mpanda District is one of the areas identified for biofuels production. There is an on-going Germany company in the District and it was estimated that by 2008 nearly 21 000 small holder farmers were contracted to cultivate *J. curcas* in an estimated total area of 12 000 ha (Zeller, 2009).

However, a concern in the present study is the sustainability of biofuels according to its water consumption. If water consumption is not clearly known it may present challenges to the environment and water resource in particular. Therefore, there is a need of investigating the water consumption by *J. curcas* and comparable crops so as to provide recommendations for preparation of proper management and conservation plans of water resource and environment in general.

1.2 Problem Statement and Justification of the Study

1.2.1 Problem statement

Biofuels when produced and used on a sustainable basis, they are carbon-neutral carriers and can make a large contribution to reducing greenhouse gas emissions. Currently, biomass driven combined heat and power, co-firing, and combustion plants provide reliable, efficient, and clean power and heat. Production and use of biofuels are growing at a very rapid pace (IEA, 2007) and has already been adopted in various parts of the World including Tanzania. Despite the potentials of *J. curcas, M. oleifera* and *E. saligna* to livelihood and environment, still there is a concern that cultivation for commercial purpose may cause damage to the environment and water resource in particular. Mpanda District where *J. curcas, M. oleifera* and *E. saligna* are cultivated as biofuels, no study has been done regarding water consumption. There are a lot of knowledge gaps concerning safety of biofuels production to the environment and on water resource in particular. There is little quantitative data available on the water needs, water productivity and water-use efficiency of biofuels (Brittaine and Lutaladilo, 2010). Rumley and Ong (2006) pointed out that water scarcity is an increasingly severe problem across the developing world, with many countries in East Africa already experiencing water shortages.

The sustainability of water availability depends on its proper management strategies. Since little has been done regarding the impacts of biofuels cultivation on water consumption (Gush, 2008) it is therefore essential to know water consumption status of *J. curcas, M. oleifera* and *E. saligna* as it will help in putting forward water conservation strategies in the country.

Besides, the extent of *J. curcas, M. oleifera* and *E. saligna* cultivation as biofuel crops especially in Mpanda District is not well documented. Field experience and rigorous literature search have indicated that little is known on people's perception on water consumption of these study tree species. This acts as a bottleneck to the wider adoption of the crops. It has also become apparent that there is no any experiment that has been conducted to establish an empirical water consumption rate of biofuels, especially *J. curcas, M. oleifera* and *E. saligna.* Hence, this study somehow has filled the gap by determining water consumption of the selected tree species having potentials for biofuel production.

1.2.2 Justification of the study

The study has come – out with the estimated amount of water needed per unit biomass of each tree species in question, therefore, these findings are expected to contribute information that will be put into practice when new locations are sought for biofuel plantations in relation to the soil – water budget in the country and when suggesting proper farming practice for *J. curcas, M. oleifera* and/or *E. saligna* cultivation in the study area and other areas. Study findings have also set a platform for other research activities to fill-up any existing knowledge gap in this field which is still new and needs substantial scientific information to guide implementation. Therefore, determining the water consumption of biofuel crops is essential, as it will provide information that will contribute to the policy process and relevant stakeholders during preparation of short to long-term strategies to guide biofuel production to utilize water resource sustainably in Mpanda District and Tanzania as a whole without jeopardising the water requirement of the future generation.

1.3 Objectives of the Study

1.3.1 Main objective

The main objective of the study was to undertake a comparative analysis of *J. curcas*, *M. oleifera* and *E. saligna* and local people perception on water consumption in Mpanda District, Rukwa Region.

1.3.2 Specific objectives

The specific objectives of this study were to:

(i) determine the extent of *J. curcas*, *M. oleifera* and *E. saligna* cultivation in Mpanda District.

(ii) assess the peoples' perceptions on water consumption by *J. curcas*, *M. oleifera* and *E. saligna.*

(iii) experimentally determine water consumption by *J. curcas*, *M. oleifera* and *E. saligna.*

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Biofuel Crops Production Status in Tanzania

Tanzania is promoting efficient utilisation of biofuels with a great hope of improving energy security at all levels, introduction of alternative or additional cash crops to farmers (small and large scale), creating new jobs and income opportunities through biofuels production, reduction of volumes of oil imports and hence foreign exchange (Sawe, 2008).

Biofuel developments in Tanzania are still in an infant stage but already there are some initiatives in various parts of the country from both local and international investors, producing liquid biofuels (Martin *et al*., 2009). The feasibility study by Kempf (2007) grouped these initiatives in three groups; there are small-scale projects, usually on village level that use the produced seed oil for further processing or consumption, but these are not directly related to a national or international market; the medium-scale projects which are market related because there is interaction with each other through buying and selling of seeds; and a third group which are the projects that are clearly dedicated to large-scale production and export (Kempf, 2007).

There are few local private companies and NGOs that have started to produce straight vegetable oil (SVO) from Jatropha and Oil palm (Mshandete, 2011) at small-scale level. Biodiesel production is being experimented by a local NGO called TaTEDO (The Tanzania Traditional Energy and Environment Development Organization) and is already using SVO to run vehicles (with minor engine modifications) (Messemaker, 2008). Biogas is also wide spread in Tanzania aimed to provide fuel for clean burning cooking stoves. At present there are roughly 1000 biogas plants being installed throughout the country (Martin *et al*., 2009; Mshandete and Parawira, 2009). Moto Poa Company Ltd has installed capacity to produce 2000 tons of ethanol jelly per day, which, is used for cooking application as one of the micro liquid biofuels activities used in cooking applications (Mshandete, 2011).

Commercial biofuels production in Tanzania may have implication to land use change, environment and water resources due to the fact that quite extensive plots of land are requested by investors to implement biofuel production in various parts of the country. Numerous investors from different countries started or are currently starting biofuel projects in Tanzania (Table 1). They mainly focus on sugarcane for bioethanol production or *Jatropha curcas* for straight vegetable oil (SVO) or biodiesel. In other countries, crops like oil palm, *Croton* spp. and sweet sorghum are used (Sielhorst *et al.,* 2008). Currently, *J. curcas* and oil palm are the main feedstock used for producing biodiesel in Tanzania (SEKAB, 2008).

Table 1: A summary of biofuel investments in Tanzania

Company name	**Area/ Place**	**Crop concerned**	**Hectares requested**	**Hectares acquired/ surveyed for granting**	**Current status of the project**
SEKAB BT	Bagamoyo	Sugarcane	24 500	22 500	Seed cane planted and irrigation reservoir constructed
Trinity Consultants/ Bioenergy TZ Ltd	Bagamoyo	*J. curcas*	30 000	16 000	Land surveyed to be granted
Sunbiofuels	Kisarawe	*J. curcas*	8 211	50 000	Derivative title being finalised
PROKON Renewable Energy	Mpanda	*J. curcas*		10 000	Contract farming with 2000 smallholders

Source: (Brittaine and Lutaladilo, 2010)

A few such initiatives have been around and are still around but none of them have made substantial progress to date. This trend may present some challenges due to the fact that the nation still on the process to establish biofuel policy, strategy or legal framework for addressing the production and use of biofuels (Silayo *et al.*, 2008; Sulle and Nelson, 2009). Moreover, without proper land use and environmental management plans, biofuel cultivation might also contribute to global warming if natural forests are cleared for planting biofuels (Silayo *et al.*, 2008).

2.2 An Overview of *Jatropha curcas*

Jatropha curcas, one of many species of the genus ***Jatropha*** in Euphorbiaceae family is a poisonous, multipurpose semi-evergreen shrub or small tree of significant economic importance because of its several industrial and medicinal uses (Makkar *et al.*, 2008 a). It is said to prefer well-drained soils and plenty of sunlight (Mitchell, 2008). The plant grows throughout most of the tropics reaching a height of 6 m (20 ft). It survives on poor stony soils and can be used to reclaim land (Abou-Arab and Abu-Salem, 2009).

Jatropha curcas start yielding from the second year of planting, but in limited quantity. If managed properly, the production rises from 4 to 5 kilograms of seeds per tree from the fifth year onwards and seed yield can be obtained up to 40 to 50 years from the day of planting (Abou-Arab and Abu-Salem, 2009). The seeds of *J. curcas* contain approximately 40 percent non-edible oil with properties that are well suited for the production of biodiesel and this is the reason for the current global interest in the use of its seed oil for biofuel. Other uses of *J. curcas* oil are soap making on a small scale and illumination.

In China, the oil is boiled with iron oxide and used to produce furniture varnish. Extracts of the seed oil have been found effective against a number of crop pests and snail vectors of Schistosomiasis (Brittaine and Lutaladilo, 2010). *Jatropha curcas* is also known as 'Mbono kaburi' in Swahili language and commonly a physic nut in English is one of the plants having oil-bearing seeds that can produce biodiesel. Kempf (2007) noted that, the plant is able to adapt to arid and semi-arid conditions even to a minimum of approximated 550 mm to 600 mm of annual rainfall and marginal soils with low nutrient content. It has a lot of potentials to livelihood including reducing dependence on traditional biomass, creating an employment to local communities through its production activities, facilitating modernisation of agriculture sector and targeting of social services improvement.

2.3 An Overview of *Moringa oleifera*

Moringa oleifera belongs to a family of shrubs and tree Moringaceae. This tree can be found growing naturally at elevations of up to 1000 m above sea level. It is a fast growing tree and has been found to grow to 6 - 7 m in one year in areas receiving less than 400 mm mean annual rainfall (Odee, 1998). The oil content of de-hulled seed (kernel) is approximately forty two percent (42%). The oil is brilliant yellow and is used as a lubricant for fine machinery such as timepieces because it has little tendency to deteriorate and become rancid and sticky. It is also useful as vegetable cooking oil. The oil is known for its capacity to absorb and retain volatile substances and is therefore valuable in the perfume industry for stabilising scents (Foild *et al*., 2001).

The biodiesel derived from *M. oleifera* oil is an acceptable substitute for petrodiesel, also when compared to biodiesel fuels derived from other vegetable oils (Rashid *et al.,* 2008). *Moringa oleifera* has potentials for biogas production also where by a study using an approximately 30 days old plant produced an average feed of 5.7 g of volatile solids, the gas production was 580 liters per kilogram of volatile solids. The average methane content of the gas was 81 percent (Foild *et al*., 2001).

2.4 An overview of *Eucalyptus saligna*

Eucalyptus saligna, also known as Sydney blue gum is a rapidly-growing hardwood reaching a height of approximately 55 meters in its natural habitat (Silva *et al*, 2004). It occurs naturally between latitudes 28° south and 35° south. Mean annual temperature ranges between 14 degrees centigrade to 23 degrees centigrade. It usually grows on moderately fertile loams which are moist but not waterlogged. It is planted commercially in many countries worldwide including Ethiopia (Hunde *et al.,* 2002). The species is an important multi-purpose hardwood which is used for firewood, charcoal, timber, furniture, veneer, bee forage and flooring (Hunde *et al.,* 2002).

2.5 Biofuel Crops and Water

2.5.1 *Jatropha curcas* cultivation and Water

There is suggestion that *J. curcas* has to be grown in degraded and marginal lands or semi-arid lands. Although *J. curcas* has traditionally been used to conserve water in the soil, with leaves providing shade and preventing excessive evaporation, only few studies have been carried out on the overall impact on water levels of intensive *J. curcas* cultivation (Blesgraaf, 2009). The yield in harsh conditions has been also reported to be low. In Swaziland where water is scarce, some farmers who were given *J. curcas* seeds experienced that the plant needs weekly watering for it to thrive well (Friends of the earth, 2009).

2.5.2 *Moringa oleifera* and Water

Moringa oleifera do not need much watering, the trees will flower and produce pods whenever there is sufficient water available. If rainfall is continuous throughout the year, *M. oleifera* will have a nearly continuous yield. In arid conditions, flowering can be induced through irrigation. Minimum annual rainfall requirements for these trees are estimated at 250mm with maximum at over 3000mm. Presence of a long taproot makes it resistant to periods of drought. Temperature preferred by *M. oleifera* ranges between 25-35 degrees celsius (Ramachandran *et al.,* 1980).

Moringa oleifera has got an advantage of being used as purifying agent of dirty water also it has many medicinal uses and has significant nutritional value (Amaglo, 2006; Anwar *et al*., 2007). A survey recently conducted on 75 indigenous plant-derived non-traditional oils in India concluded that *M. oleifera* oil, among others, has good potential for biodiesel production (Azam *et al*., 2005). Its seeds contain protein substances that can purify muddy or dirty water by sedimenting mineral particles and organics in the purification of drinking water, for cleaning vegetable oil, or for sedimenting fibers in the juice industries (Foild *et al*., 2001). It has been employed with particular effectiveness in both Egypt and Sudan for cleaning water from the Nile specifically for human consumption. Also the seeds can be used for the final treatment of waste water by coagulating algae and remove up to 98 percent of them by sedimentation. The treatment also reduces the oxygen demand of the water by approximately 70 percent and its content of both phosphorous and nitrogen by 60 percent (Foild *et al*., 2001; Brittaine and Lutaladilo, 2010).

2.5.3 Effects of *Eucalyptus saligna* on Water

The most controversial Eucalypt plantations water-related issue is the effect on the water content of the soil. It is claimed that Eucalyptus trees absorb more water from the soil than any other tree species. One of the primary concerns about Eucalypt plantations is that they lead to a diminished rainfall in their area of influence. The most significant hydrologic effect of a Eucalypt plantation, as well as any other tree plantations or forest cover, is its interception of rainfall. It has been indicated that, a 6-year-old *Eucalyptus saligna* plantation lost 12.2 % of rainfall water by canopy interception. Also, a study in two watersheds in São Paulo showed that there is nutrient balance and quality water because they were covered by *Eucalyptus saligna* plantations (Ranzini, 1990 in Munishi, 2007).

2.6 Tanzania Policies on Biofuel Production

Government of Tanzania, as many other African countries, has recently reported to have policy challenges critical to biofuels development (Sosovele, 2010). The nation has no specific biofuel policy and regulatory frameworks that takes into account agriculture, land use, water availability, transport and energy in order to guide the biofuel sector, leading to some situations where investors illegally grab land for biofuels production (Henriques, 2008) besides such land being very inexpensive. However there are statements within the energy, agriculture, forest, land and environment policies aimed at improving supply and demand of solid biofuel, liquid biofuel is not mentioned (Mshandete, 2011).

However, in November 2008 the Government initiated efforts towards a biofuel policy, regulatory framework and guidelines for sustainable liquid biofuels development through establishment of the National Biofuels Task Force (NBTF) (Sawe, 2008; WWF, 2008). This draft was discussed by various stakeholders including Non-Governmental Organizations (NGOs) (Sulle and Nelson, 2009). But these guidelines are not suitable tool for this purpose and are inadequate to guide the development of biofuel in Tanzania towards the desired sustainability goals, for example existing conflicts between investors and local communities are among the problems associated with lack of clear policy guidelines. Since investors were given large tracks of land and began cultivation of energy crops even before a policy is in place (Mshandete, 2011).

With growing interest in biofuels worldwide, the requests by foreign companies to invest in biofuel projects in Tanzania also increased. Zeller (2009) noted that in 2008 approximately 35 national and international companies, NGOs and other organisations were active in Tanzania.

2.7 Biofuel Production and the Environment

Interest in biofuels is gathering pace around the world, stimulated by recent high oil prices, wider energy security worries and the specter of climate change. At the moment, biofuels make up only a small proportion of world energy use, but this is expected to increase, due in part to targets and policies that are encouraging uptake of biofuels for transport. It has been estimated that biofuels will provide almost 9 % of transport fuel in Europe by 2020 (Laborde, 2011).

However, there are some key challenges that need clear policies to address them. There has been controversial on biofuel production, which mainly uses food crops, because in some cases it has led to deforestation, and to disputes over rising food prices and land use (Lonza *et al*., 2011). In some of the world's largest bioethanol producers, such as United States of America, the rapid increase in production of bioethanol from corn – driven mainly by economic and energy security concerns - has been partially blamed for increasing the price of corn and other grains in developing countries. There are also disputes over whether corn – based ethanol produces fewer overall greenhouse gas emissions than fossil fuels (Laborde, 2011).

New types of biofuels, such as those using non-food crops and algae, are being developed with the aim of meeting our energy demands whilst avoiding food crisis and land disputes. In addition rapid expansion of supply could have serious negative local environmental impacts on water quality and quantity, loss of biodiversity, effect on food security and prices, human rights of workers and communities in areas where biofuel crops are grown (NCB, 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location of the study area and population size

The study was conducted in six villages (Mamba, Majimoto, Kanindi, Itenka 'A', Kakese and Itenka 'B') of Mpanda District which is one of the three districts of Rukwa Region (Fig. 1). The District lies between latitudes 5^0 15 to 7^0 03' South of Equator and longitude 30^0 to 33^0 31 East of Greenwich. It is bordered by Urambo District (Tabora) to the North Sikonge District (Tabora) to the East, Chunya District (Mbeya) to the East, Nkansi District (Rukwa), to the South, Sumbawanga District (Rukwa) to the South – East, Democratic Republic of Congo (DRC) to the West (separated by Lake Tanganyika) and Kigoma District (Kigoma) to the Northwest. Based on the population census report of 2002, Mpanda District had a population of 412 452 (MDCP, 2008).

3.1.2 Climate vegetation and topography

Mpanda District has an altitude ranging from 1000 meters to 2500 meters above the mean sea level, the average temperature ranges between 26 ºC and 30 ºC annually. The mean annual rainfall ranges from 920 mm to 1200 mm. The most predominant vegetation includes, tropical savannah wooded grasslands and thorny bushes (MDCP, 2008).

The choice of the District was based to the three reasons; it is one of the areas earmarked for allocation for large plots of land for biofuel production, *J. curcas* has been cultivated for more than five years now, it is therefore hoped that the community can tell if they have encountered any water-related effect that could be the resulted from *J. curcas* cultivation.

Another reason is; all the three species under study; *J. curcas*, *M. oleifera* and *E. saligna;* are cultivated in the District.

3.1.3 Land use, economic activities and infrastructure

The District has a total area of 47 527 square kilometers (which is about 4 752 700 hectares) of which 932 136 hectares are ideal for crop production, 2 801 163.7 are under Forest Reserve, 860 000 hectares are under Game Reserves. About 168 400 hectares are water bodies and the remaining land is used for other activities (MDCP, 2008).

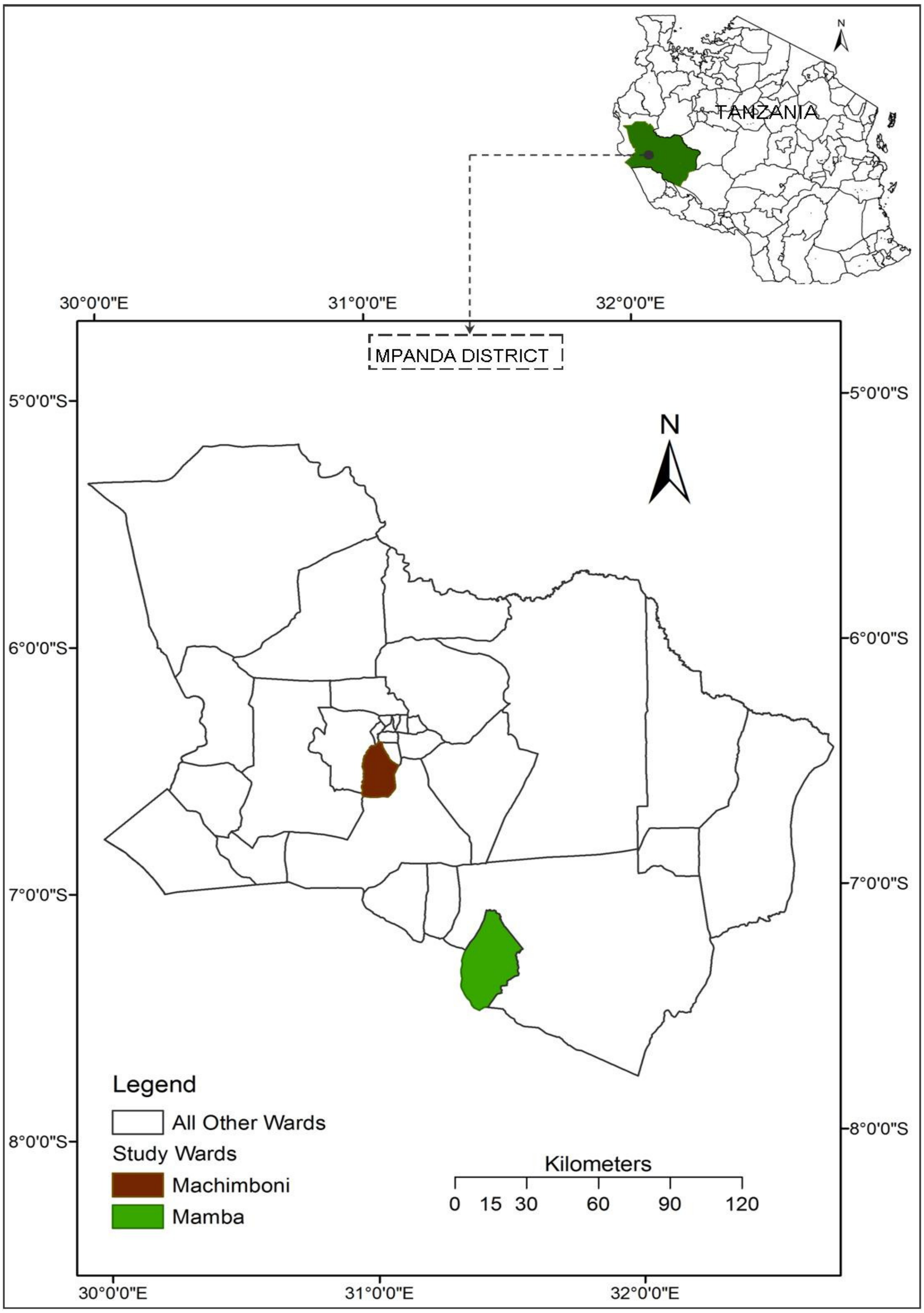

Figure 1: Map of Mpanda District showing wards where the study was conducted

3.1.4 Energy

Charcoal and fuel wood consumption stand about 95 % of the total energy requirement for cooking and other domestic energy requirement in rural and urban areas in Mpanda District. This is about 4 576 200 cubic meters of fuel wood consumed annually in the District. Continued use of wood based energy will have an adverse effect on the existing forests if improper tree harvesting will not be addressed. Therefore, in order to reverse this situation, alternative sources of energy must be encouraged particularly biogas, solar energy, coal and electricity wherever possible (MDCP, 2008).

3.2 Materials for Greenhouse Experiment

Forest soil was collected from SUA Botanic Garden, river sand obtained along Magadu River and farm yard manure. The Phosphorous source used was Triple Super Phosphate (TSP), Potassium source used was Murate of Potash (MoP) and Nitrogen source was Sulphate of Ammonia (SA). Tape water was used for the pot experiment.

3.3 Methods

3.3.1 Field Survey

3.3.1.1 Research Design and Sampling Procedures

A purposeful sampling procedure was used to select villages for household interview. In this case, the sampling frames for this study were the list of households in the village cultivating at least one tree species under the study. According to Kothari (2008), purposeful or deliberate sampling is used when population elements are selected for inclusion in the sample on ease access. A total of six villages were purposely selected where by Mamba, Kanindi and Majimoto villages were from Mamba Ward; Kakese, Itenka ‘A’ and Itenka ‘B’ villages were from Machimboni Ward. A simple random sampling technique was subsequently employed to select respondent households to be included in the study. A random sampling allows selection of a sample from the entire population in such a way that every member of the population has an equal chance of being selected.

The sampling unit for this study was a household. URT (1993) defined a household as a single person or group of people who live and eat together and share a common living arrangement. Kaewsonthi *et al.* (1992) recommended a sample size ranging from 5% to 12%. In this study, 5 % sample size was used. Using a list of households cultivating at least one tree species under the study in the village as sampling frames, in each of the six villages a 5 % sample size was computed to get the number of households to be interviewed see Table 2. Selection of households for interview was through a random sampling, where households were randomly selected from each of the respective village sampling frame.

Table 2: Household sampling

Village	Population	No. of sampled households
Mamba	281	14
Kanindi	302	15
Majimoto	268	13
Itenka 'A'	283	14
Itenka 'B'	245	12
Kakese	263	13
Total	**1642**	**81**

In addition, the District Planning Officer, District Extension Officer, Ward and Village Executive Officers, Village chairpersons, Ward Extension Officers, Extension officers and other officials from PROKON Company were contacted as key informants under key informant interviews.

3.3.2 Greenhouse experiment

The experiment was conducted in the Greenhouse of Crop Science Department at Sokoine University of Agriculture. The experiment used a Completely Randomized Design (Gomez and Gomez, 1984) having six treatments in three replications.

3.3.2.1 Potting mixture

The soil mixture for growing the plants in the Greenhouse was obtained by mixing the top forest soil (0 to 10 centimeters depth), river sand and farm yard manure at a ratio of 4:1:1. The composite sample was air dried and particles like stones and plant residues were removed by using sieve musk of 8 µm openings. Water holding at field capacity of the soil was determined in the laboratory in order to know the amount of water required to be maintained during the experiment.

3.3.2.2 Determination of soil water holding capacity

Soil water holding capacity was determined by using two methods, the total porosity method using bulk density and the saturation of disturbed soil core.

a) Bulk Density Determination

Measurement of bulk density were made by collecting disturbed soil samples of known volume and then drying the sample in an oven at 105ºC for 24 hours to determine the dry weight fraction. Then, the dry weight of the soil (Ms) was divided by the known sample volume V, to determine Bulk Density ρb (Hillel, 1982).

$\rho b = Ms/V$ ……………………………………………………………………………(1)

Where ρb = dry Bulk Density (Mgm^{-3})

Ms = soil dry weight (g)

V = known sample volume in cm^{-3}

b) Total Porosity Determination

Total porosity determination by relationship between Bulk density and Porosity Density as described by Brady and Weil (1990).

$St = 1 – (Pb/Pp)$ ……………………………………………….…………………….. (2)

Where;

St = is the total porosity (%)

Pb = Dry Bulk Density (Mgm^{-3})

Pp = Particle density for most mineral soil is assumed to be 2.65 Mgm^{-3} (Blake and Hortge, 1986)

3.3.2.3 Pot arrangement

The pots were arranged in a completely randomized design (CRD) consisting of uncovered pots and pots covered by a plastic mulch. The aim of covering with plastic mulch was to avoid water evaporation from the soil sample and get the amount of water uptake by each tree species through transpiration process only. Perforations were made on the plastic mulch directly to the plant to allow it access sunlight. In uncovered pots the soil was left bare.

3.3.2.4 Management of experiment

A sample of composite soil was taken to the laboratory for analysis. A known weight of soil was prepared by adding essential nutrients to adequate level followed by mixing thoroughly. The essential nutrients, Nitrogen, Phosphorous and Potassium was added in order to make sure that soil fertility is not a limiting factor to plant growth. The fertilizer application rates used was 200 mg N/ kg, 200 mg P/kg and 40 mg K/kg. Phosphorous and Potassium sources were added in the soil by ‘broadcasting’ at the beginning of the experiment but nitrogen source was added in the soil in two splits. The first split was fourteen days after seed sowing and the second phase was done at the 60th day after seed sowing.

The soil was filled in the pots and water was added to the field capacity. Five seeds per each pot were sown. The total weight of a pot (pot + soil with water at field capacity + plant material) was recorded, which was 13.1 kilograms. This was the weight maintained throughout the experiment period. Fourteen days after germination, thinning was done by uprooting three seedlings and remaining with two healthier seedlings per pot. Irrigation was done once per day depending on the requirements of the plant and this was determined by weight loss of a pot.

3.4 Data Collection

3.4.1 Data collection from the field survey

Primary data were collected through interviews by using a designed questionnaire consisting of both closed and open-ended questions administered to household heads. Focus Group Discussions (FGDs) were also conducted to collect information from respondents while personal observations especially visits to some respondents farms were useful to triangulate and see the real situation of the farming practices in the area. A visit was done after an interview to a total of ten (10) farmers who cultivate at least one tree species.

3.4.1.1 Reconnaissance survey

Reconnaissance survey was carried out to make self-introduction to the community as a researcher as well as to introduce the aim of the present study. Through this exercise identification of various areas where study crops are cultivated and private biofuel company operating in the area was done. It is during this time when a researcher was in a position to get important data especially demographic data, including total households in the village. The researcher was able to familiarise with the background of the study area therefore be able to improve data collection procedures.

3.4.1.2 Household interviews

Primary data were partly collected through formal survey by interviewing heads of at selected households in each village. Data collected through this method included background information, farm size, size cultivated land or more of the trees in question, number of trees planted, soil/moisture condition and conservation measures used, propagation methods especially for *Jatropha curcas*, benefits obtained and respondent's views on *J. curcas, M. oleifera* and *E. saligna* cultivation in the area (Appendix 1). From their perception, respondents were also asked to rank *J. curcas, M. oleifera* and *E. saligna* in their order of increasing water consumption.

Plate 1: A researcher interviewing the respondent

3.4.1.3 Focus group discussion

A checklist containing sets of open-ended questions (Appendix 2) used for collecting information from key informants and Focus Group Discussions. A key informant is an individual who has a great depth of knowledge about issue in question, is accessible and willing to talk with the outsider. Key informants contacted in the present study were District agriculture (n=1) and Forestry officials (n=1) and PROKON Renewable energy staff (n=1). Focus Group Discussions were also conducted at Ward level in order to gather information that was not obtained in the interviews and key informant's discussions. The number of people who were purposively selected to join the group ranged from 8 – 10 whereby eight people at Machimboni Ward and ten people at Mamba ward. This number is also recommended by Chang and Zebeda, (2005) in Lusambo, (2009) who mentioned 7 – 10 people to be reasonable number for a focus group discussion. The group composed of Ward and Village leaders, Ward Extension Officers, farmers cultivating at least one of the study crops, famers who do not cultivate any of the study crops and representatives of the PROKON Renewable energy company. The interview was conducted in Kiswahili language where by group discussion was employed to encourage a collective response and to identify differences of opinion as well as area of consensus within the group. Secondary information was obtained from published and unpublished documents and reports on the Region, District, wards, villages and from libraries.

Plate 2: A researcher conducting focus group discussions with respondents

3.4.1.4 Researcher's direct observation

Direct observation was made through conducting a visit to the farms of various farmers in each ward in order to have general picture on the cultivation of *J. curcas, M. oleifera* and *E. saligna*. The main aspects that were focused include: availability of the study tree species, soil and environmental conservation measured practiced, farming systems, agro forestry technologies practiced and different uses of the study tree species. It also intended to make visual confirmation of the information obtained during interviews, for example on the soil conservation measures.

According to Mbwilo (2002), much information can be obtained simply by observing what goes on and some of the observed activities include conservation activities, farming practices and livestock keeping. Lema (2003) argued that, it is always essential to keep one's eyes when visiting the farm and to check what you are told against what you see.

During this process, the information was recorded in the special note books by the researcher and fieldwork assistants. In another way the information was recorded through taking pictures of farms showing various farming practices and land conservation measures and clarifying by taking notes concerning the obtained information.

3.4.2 Data collection from greenhouse experiment

3.4.2.1 Water consumption

Water consumption data was collected everyday from the Greenhouse and was estimated as the amount of water loss from the pot through evaporation and transpiration through the weight loss method (Klute, 1986), and adjusted for pot weight from the predetermined weight of a pot at field capacity (13.1 kg). The pots were rotated once every day in order to even-out the effect of light on the pots position.

3.4.2.2 Plant height

Plant height was determined by using 100 centimeters ruler to measure the plant from the soil level to the tip of the main branch. The average height was recorded because each pot had two plants. The measurement was done after every fourteen days (Appendix 3).

3.4.2.3 Collar diameter and number of leaves

The collar diameter of the plant was taken at 4 cm height from the soil surface. This was done by using a Micrometer Screw Gauge and the readings were recorded in the prepared data recording sheet (Appendix 3). The number of leaves per plant was determined by counting the leaves and taking the average number of leaves that was undergoing transpiration based on the two plants per pot.

3.4.2.4 Biomass and dry matter

After ninety (90) days of growth, fresh weight (biomass) of each plant was determined by cutting the plant (at 2 cm height from the soil surface), washing the roots thoroughly with water to remove soil particles and measuring the weights of stem, leaves and roots separately. The weight readings of the stems, leaves and roots were summed up to get the total weight of the plant. The plants were first air dried and then oven dried, at 75°C for 48 hours, at 105°C for 96 hours and at 105°C for 24 hours for leaves, stem and roots respectively to constant weight and dry matter per plant was determined and recorded (Appendix 4).

3.4.2.5 Water use efficiency determination

The cumulative water lost from each pot (through evaporation and transpiration) was determined by summing up the amounts of water added (in ml) to each pot throughout the experimental period. The value of water obtained was divided by two because each pot had two plants. Then, the volume of water (in ml) was divided by dry mass value (in g) to get Water Use Efficiency of each tree species by volume and by weight assuming that 1 cc of water is equivalent to one gram of water.

3.5 Data Analysis

3.5.1 Analysis of field survey data

Data collected from the primary sources using semi - structured questionnaires and checklists were summarized, coded and made ready for analysis. Some data were re-coded, for example the data obtained from 'open-ended' questions. Analysis of the field data was aided by the use of Statistical Package for Social Sciences (SPSS) version 16 and descriptive statistics were used to present the research findings. Content analysis method was used to analyse qualitative data in which components of verbal discussion and qualitative information from the open-ended questions was broken down into the smallest meaningful units of information or themes and tendencies. These helped the researcher in ascertaining values and attitudes of the respondents. In this way, views and perceptions of people concerning water consumption of *J. curcas, M. oleifera* and *E. saligna* were broken down into smallest meaningful units of information.

3.5.2 Analysis of data from the greenhouse experiment

MSTAT-C computer statistical package (Lund, 1991) was used to perform analysis of variance of the data obtained from the Greenhouse experiment. Mean separation was performed using Duncan's Multiple Range Test (DMRT). Means were ranked to determine the significant difference in water consumption, plant height, collar diameter, leaf number, total biomass and dry weight of the studied biofuel trees.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Field Survey

4.1.1 Socio-economic characteristics of the respondents

The respondent's gender and marital status, age and education level were the parameters used to describe household characteristics and their relationship with their perceptions concerning *J. curcas, M. oleifera* and *E. saligna* in terms of water consumption. These are considered as important factors in relation to natural resource utilization and conservation and may influence people on perceptions about a certain aspect of their environment.

A total of eighty one (81) respondents from six villages were involved in the questionnaire survey. Majority of the respondents who participated in the study were males (82.7%) while females were 17.3% (Table 3). The results show that 80.2% of all household respondents were male headed, 11.1% female headed. Others are either widowed (6.2%) or living separately (2.5%) due to various reasons.

Most respondents (56.8%) have primary education, while 11.1% and 1.2% have secondary and post secondary education respectively. The remaining (30.9%) have no formal education (Table 3). FGD revealed that only 15.8% of the participants had attended secondary and post secondary schools, the remaining (78.9%) had primary school education level and (5.3%) had informal education. Education is a tool that can make people manage their resources properly including water resources. Through education farmers may know the rationale for taking care of their environment from their point of view in various aspects such as farming practices and other socio-economic factors. According to Maro (1995), primary education system is reported to foster human creativity; therefore, it has been reported as having relationship with farmers' readiness to integrate innovations into traditional systems of land use and management.

Table 3: Socio-economic characteristics of respondents (n = 81)

Characteristics	Response	Percentage
Gender		
Male	67	82.7
Female	14	17.3
Education Level		
No formal school	25	30.9
Primary School	46	56.8
Secondary School	9	11.1
Post Secondary	1	1.2
Marital Status		
Single	9	11.1
Married	65	80.2
Widowed	5	6.2
Separated	2	2.5
Age (years)		
18 – 25	4	4.9
26 – 50	48	59.3
50+	29	35.8

The survey showed that large number of respondents had acquired primary education (Table 3). The FGDs revealed that only three participants had attended secondary school, one had informal education and the remaining had primary education. This helps the respondents to apply various environmental conservation measures in their farms; for example intercropping biofuel plants with other agricultural crops (agroforestry) and covering the farm soil with mulch to help conserving moisture.

About 59.3% of respondents were aged 26-50 years, others were 18 – 25 (35.8%) and 4.9% of them being over 50 years (Table 3). The age and experience of an individual may play an important role in indigenous knowledge and practices. Older farmers can contribute more effectively to the information on the type of crop to grow, including biofuel crops, and ways of conserving moisture and fertility in their farms, because they are more knowledgeable. The results revealed that majority of the respondents (59.3%) are between 26-50 years which is considered as a middle age class. The middle age classes are often early adopters of improved technologies of sustainable utilization of natural resources (Kiwale, 2002). The present study findings have revealed that, the composition of the respondents for both sexes tend to decrease in social and economic activities participation with increasing age, as also observed by URT-UNFPA (2003).

4.1.2 The Extent of *J. curcas, M. oleifera* and *E. saligna* cultivation in Mpanda District

The extent of cultivation of *J. curcas, M. oleifera* and *E. saligna* are presented in Tables 4 and 5. The total land size possessed by respondents in the study area ranges from 0.2 hectares to 20.23 hectares (Table 4). However, most of the people have land which ranges between 2.43 to 4.05 hectares (40.8%) and very few people have got large plots of land (Table 4).

Table 4: Proportion of the total land size possessed by respondents (n = 81)

Size of farm land (ha)	Percentage
0.20 – 2.02	27.0
2.43 – 4.05	40.8
4.25 – 6.07	13.7
6.48 – 8.09	6.1
8.17 – 10.11	2.4
10.52 – 12.14	2.5
12.34 - 14.16	1.2
14.57 – 16.18	2.5
16.39 – 18.21	0.0
18.62 – 20.23	3.7
Total	**100.0**

It was observed that 75.3% of the total respondents planted *J. curcas* alone as biofuel crop and no one had *E. saligna* alone (0%). Others have got *M. oleifera* plants alone (9.9%) or have planted both *J. curcas* and *M. oleifera* plants (11.1%). The rest cultivated a combination of more than one tree crop though generally, most of them grow *J. curcas* (Table 5).

Table 5: Percentage of respondents and type of tree they cultivate (n = 81)

Tree species	Percentage
J. curcas only	75.3
J. curcas, M. oleifera and *E. saligna*	1.2
E. saligna only	0.0
J. curcas and *M. oleifera*	11.1
M. oleifera and *E. saligna*	1.2
J. curcas and *E. saligna*	1.2
M. oleifera only	9.9
Total	**100**

Table 5 shows that although some farmers grew more than one tree species, *J. curcas* takes larger percentage of land (90.6%) than *M. oleifera* (9.1%) and *E. saligna* (0.3%). The proportion between total land size a person posses and the size of land used to grow study trees ranges between 0. 18 hectares (0.3%) for *E saligna* and 48.38 hectares for *J.curcas* which is 90.6% of the total land size of respondents. Generally, it was observed that the most extensively planted bio-fuel feedstock in Mpanda District was *J. curcas* (75.3%) followed by *M. oleifera* (22%) and *E. saligna* (2.7%) as shown in Fig. 2.

Table 6: Estimated land size used to grow study trees in Mpanda District (n =81)

Tree species	Respondents growing a crop*	Land size (ha)	Percentage
Jatropha curcas	72	48.38	90.6
Moringa oleifera	18	4.86	9.1
Eucalyptus saligna	3	0.18	0.3

* Some respondents grow more than one crop (crop mix).

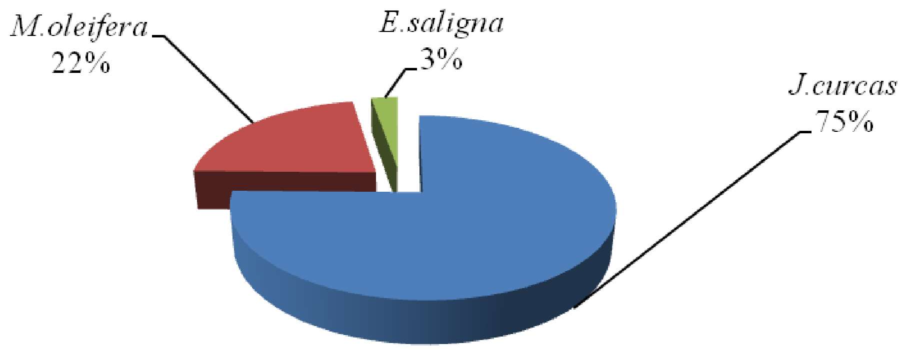

Figure 2: Proportion of the biofuel tree crops cultivation in Mpanda District

There was variation in age of study trees the respondents possessed. Most of them have got trees ranging from 15-50 months (1 to 4 years) whereby 49% of respondents had *J. curcas* of that age, 50% of respondents had *M. oleifera* of that age and 33% of respondents had *E. saligna* of that age. Other respondents had trees with more than 50 months (approximately more than 4 years) (Table 6).


(a) *J. curcas* trees around agricultural land (b) *J. curcas* farm at Kakese village


(c) Eucalyptus trees at Itenka 'B' village (d) People seating under Jatropha trees playing local game "bao" by using the Jatropha seeds


(e) and (f) *M. oleifera* trees in agricultural farms at Mpanda District

Plate 3: Land types under *J. curcas, M. oleifera* and *E. saligna* cultivation in Mpanda District

Table 7: Age of study trees planted in Mpanda District

Age (months)	*J. curcas* (%)	*M. oleifera* (%)	*E. saligna* (%)
< 5	37	11	0
5-14	4	11	0
15-50	49	50	33
> 50	10	28	67
Total	**100**	**100**	**100**

Jatropha curcas is the most cultivated tree species in Mpanda District than *M. oleifera* and *E. saligna* as biofuel feedstock. It has been observed that its cultivation has increased within the past 3 years because some farmers (37%) possessed *J. curcas* plants which are less than one year (Table 7). This was probably fostered by the installed *J. curcas*, and occasionally, *M. oleifera*, oil presses at the PROKON Renewable Energy company which started operations in the District in 2005 (Mkindi, 2008). Other reasons that have probably fostered *J. curcas* cultivation in large extent than *M. oleifera* and *E. saligna* were the benefits expected from *J. curcas* by farmers who are expecting to improve their livelihoods, create new jobs and having energy security (Sawe, 2007).

On the other hand, since *J. curcas* has been observed to be potential biofuel feedstock that do not compete with food crops in terms of arable land requirement (Gush, 2008; Blesgraaf, 2009; Sulle and Nelson, 2009), ability to withstand long drought periods (Henning, 2007) and being one of the most promising alternative sources of modern energy for rural areas (Sawe, 2007), increasing number of biofuel investors are attracted on its production in various parts of the country including Mpanda District. Rashid *et al.* (2010) and Kagiso (2008) pointed out that *J. curcas* oil is looked upon as one of the most appropriate renewable alternative sources of biodiesel in terms of availability and cost. It is foreseen that within the next decade or so, *J. curcas* will become a major source of renewable energy in the drier rural areas of (sub) tropical Asia, Africa and America (Henning, 2007).

Plate 4: Oil pressing machines and discussion at the PROKON Renewable Energy company Mpanda District

On the other hand, the main reason for the low extent of cultivation of *M. oleifera* (9.09%) in the District is the past experience encountered in 2000s where by the crop cultivation was highly promoted, and people positively responded to it due to a lot of promises they received from the Government (Nyanda, December 2010 – personal communication). The farmers found out that there is no market for *M. oleifera* seeds, as a result a lot of people uprooted the plant to continue cultivating other food crops; and others left few stands of the plant waiting for the market. This past experience has also affected the adoption of *J. curcas* to farmers because some of them are still not sure of the market.

The extent of cultivation of *E. saligna* is very low (0.34% of the total land possessed by respondents) because there is a lot of complaints among the community that Eucalyptus consumes a lot of water causing the land to become dry (Munishi, 2007). This ignorance of water use by Eucalyptus has resulted into most people not even trying to implement this investment in their lands.

The focus group discussion revealed that most people did not plant Eucalyptus instead they heard from other areas (especially Iringa and Urambo districts) saying that the plant uses a lot of water hence leads to drought. Some of them who had experience from a Eucalyptus woodlot earlier planted in Mamba primary school said that the plants caused the area to become dry, but there could be a lot of other factors behind drying of the soil, including poor management of the woodlots.

4.1.3 Peoples' opinions concerning water consumption by the study trees

Most respondents (49.4%) ranked *E. saligna* the first in terms of water consumption followed by *M. oleifera* and *J. curcas* though *M. oleifera* was ranked very close to *J. curcas* (Table 8). A small portion of people (4.9%) did not know which tree species consumes more water that the other.

Table 8: Ranking water consumption by *J. curcas, M. oleifera* and *E. saligna* in Mpanda District

Ranking	Percentage
E. saligna	49.4
M. oleifera	24.7
J. curcas	21.0
Don't know	4.9
Total	**100.0**

4.2 Greenhouse Experiment

The Greenhouse experiment revealed that there was variation in water consumption between the three tree species studied. *Moringa oleifera* consumed 1820 ml more than *J. curcas* and 5500 ml than *E. saligna* in uncovered pots and 80 ml higher than *J. curcas* and 2430 ml than *E. saligna* in covered pots. It is observed that there is no significant difference ($P < 0.05$) in water consumption between *M. oleifera* and *J. curcas* in both uncovered and covered pots (Table 9). In uncovered pots water was lost from the soil through two processes; firstly, evaporation process occurring directly from the soil surface and secondly water uptake by a plant, while in the covered pots water was mainly lost through plant uptake because evaporation process on the soil was highly reduced by cover. Thus, this is a reason of having more cumulative water consumption readings recorded in uncovered pots than in covered pots. When the soil is covered by plastic mulch, evaporation of moisture from the soil is reduced, optimum soil moisture is maintained, irrigation frequency and amounts generally can be reduced, and also as more uniform soil moisture is maintained there is less plant stress (Dickerson, 2002).

Plate 5: A Greenhouse experiment 8 weeks

Table 9: Water consumption and plant growth parameters for three biofuel plants

Species	Water consumption (ml)	Plant height (cm)	Collar Diameter (mm)	Leaf Number (No.)	Total Biomass (g)	Dry weight (g)
Uncovered pots						
J. curcas	13 580 ab	98 c	26.2 a	51 a	690.5 a	182.1 a
M. oleifera	15 400 a	178 a	16.3 c	42 ab	579.9 b	105.5 b
E. saligna	9 900 c	45 d	11.0 d	33 b	224.9 d	61.7 c
Covered pots						
J. curcas	12 200 b	80 c	20.2 b	33 b	456.9 c	103.3 b
M. oleifera	12 280 b	139 b	14.4 c	33 b	478.9 bc	105.2 b
E. saligna	9 850 c	50 d	11.5 d	35 b	195.3 d	63.6 c
CV (%)	9.39	10.71	8.78	11.66	13.12	17.23
SE	696.40	6.98	0.88	2.92	34.84	11.20

Means in the same column followed by the same letter(s) are not significantly different ($P < 0.05$) following separation by Duncan's Multiple Range Test.

There are other studies that have been done concerning water consumption by various types of plants including tree species but there are a lot of variation in results obtained between them due to different aspects like, the methodologies used, tree species used, study periods and the environmental conditions where the study was carried out. For example, a study done by Kheira and Atta (2009) in Egypt, revealed that throughout the growing season the average water consumption of *J. curcas* is 6 liters per week (almost 857 ml/dy), which means that *J. curcas* can survive and produce full yield with high quality seeds under minimum water requirements compared to other crops. Hubbard *et al.* (2004) studied water consumption by *E. saligna* and the results revealed that when no fertilizer application, *E. saligna* consumes an average of 302 mm/yr and when there is fertilizer application water consumed ranges between 401 mm/yr and 487 mm/yr.

The results have shown that although there is a slight difference in water consumption between *M. oleifera* and *J. curcas,* the difference is not significant ($p < 0.05$). This slight difference between *M. oleifera* and *J. curcas* can be caused by various factors including the physiological characteristics of each plant. For example, *M. oleifera* has got roots which are thickened so being adapted for water storage (BWS, 2009) thus there is certain amount of water that a plant store in the roots and other evaporated through evapotranspiration process; *J. curcas* has thicker epidermal layer on the stem but thinner epidermal layer in the leaves (Idu *et al.,* 2009). This feature contributes to limit excessive water evaporation on the shoot but only through leaves (Gonçalves *et al*., 2011). In addition, both of these plant species, *J. curcas* and *M. oleifera,* have similarity in most of environmental characteristics that favor their growth; for example being able to survive in environment with 20 - 35ºC temperature ranges, well drained soils, annual rainfall ranging between 250 – 1500 mm, soil pH of 5 – 9, (Palada and Changl, 2003; Amaglo, 2006; da Schio, 2010). Therefore, both *J. curcas* and *M. oleifera* are said to consume little water compared to other crops used as biofuel feedstocks such as sugarcane, oil palm and soy bean (WRC, 2008; Palada and Changl, 2003 in Rashid *et al*., 2008; Radovich, 2009; Eijck, 2007) hence not expected to affect the soil water budget. On the other hand, *E. saligna* survives in environmental conditions which are completely different from *J. curcas* and *M. oleifera.*

There is a different amount of water uptake by trees depending on their growth stage. Water consumed in very early growth stages (seedlings) is little compared to when the plant matures or reaches flowering and fruiting stages where consumption increases as the tree increases in growth reaching higher uptake before canopy closure which levels off thereafter (Munishi, 2007).

The differences in results obtained are probably due to difference in study periods, climatic condition where the studies were conducted and the methodologies used. The present study referred to young plants in a pot experiment while other studies were refereeing to long-term period of more than one year in the field. In addition, the difference between the results obtained from the field and results from the Greenhouse was due to difference in methodologies used and growth periods, especially for *E. saligna*. The respondents were referring to the effect of large eucalyptus trees having more than 4 years of age (Table 7) while the experiment reference was based on the young *E. saligna* trees (the seedlings of three months), also respondents results are based on speculation because most of them do not plant Eucalyptus while pot experiment was based on direct observations on Eucalyptus on tree seedlings planted from the seeds in a Greenhouse.

The plant height differed significantly ($P < 0.05$) between tree species. In uncovered soil *M. oleifera* had the highest height of growth 178 cm while *E. saligna* had the least height growth of 45 cm. In the covered soil *M. oleifera* had the fastest height growth while *E.saligna* grew the least in height (Table 9). The significant differences in height between tree species were caused by differences in their growth rates, habits and their statures. *Moringa oleifera* grew faster than the others due to its stature of being long, having bushy growth and also due to its habit of being extremely fast growing than *J. curcas* and *E. saligna*. It commonly reaches four meters in height within 10 months after the seed is planted (Foild *et al.,* 2001). *Eucalyptus saligna* grew the least in height because in the Greenhouse it was growing very slow compared to *J. curcas* and *M. oleifera* especially during the first two months.

Plate 6: *M. oleifera* with long stature compared to *J. curcas* (right bottom) and *E. saligna*

The maximum collar diameters reached by the plants at the end of the experiment differed significantly ($P < 0.05$) between tree species. The results showed that there was no significant difference in collar diameter growth for *M. oleifera* and *E. saligna* covered and uncovered pots. There was no significant difference in number of leaves ($P < 0.05$) between tree species in both uncovered and covered soils. However, plants in covered soil had relatively little number of leaves (42) compared to plants in uncovered soil (41).

The lowest number of leaves in an uncovered soil was 33 for *E. saligna* and 51 for *J. curcas* while the lowest number in covered soil was 34 for *E. saligna* and highest was 55 for *M. oleifera*. The combined mean number of leaves ranged between 49 for *M. oleifera* and 34 for *E. saligna* (Table 9). The number, the size and the shape of the leaves may have an effect on the amount of water uptake by a plant because the larger the size/area of the leaf, the larger the number of stomata and hence more water loss through evaporation process. A study by Nandy_Data *et al.* (2005) on the relationship between leaf micromorphology and photosynthesis conducted in India revealed that there is direct correlation between the abundance of stomata on a leaf and transpiration and stomatal conductance.

In the present study, there was a large variation in size and shapes of the leaves depending on the tree species. *Jatropha curcas* has green leaves which are large palmately lobed, simple, petioled and glabrous, with a blade broadly ovate in outline arranged alternately (Idu *et al.*, 2009). These leaves have got a length and width of 6 to 15 cm, with 5 to 7 shallow lobes (Henning, 2007). *Moringa oleifera* has tripinnate compound leaves with green elliptical leaflets of 1–2cm long (Radovich, 2009). *Eucalyptus saligna* has small needle-like simple leaves.

The number of leaves between *M. oleifera* and *J. curcas* are not significantly different, but there is a great variation in terms of leaf shapes, sizes and indexes in leaves of all three tree species. The leaf area of *J. curcas* is larger than that of *M. oleifera* and *E. saligna* and this leads to variations in the amount of water use by the species. There is a great possibility that a plant with larger leaf area index absorbs more water than the one with small leaf area index. The typical leaf areas of some eucalypt species are smaller than those of other forest species which suggests that the total interception by eucalypts may be comparatively low (Gash, 1979 in Munishi, 2007).

The increase in biomass was significantly higher in uncovered *J. curcas* compared to *M. oleifera* and *E. saligna* (Table 8). The biomass in uncovered *M. oleifera* (579.9 g), covered *M. oleifera* (478.9 g) and covered *J. curcas* (456.9 g) was not significantly different. The total biomass of *E. saligna* was significantly lower ($P < 0.05$) than that of *J. curcas* and that of *M. oleifera*. The overall biomass increase showed that the maximum biomass reached by *J. curcas* was higher (573.7 g) compared to that reached by *M. oleifera* (529.4 g) and *E. saligna* (210.1 g).

4.2.1 Water use efficiency (WUE)

The average water use efficiency of *J. curcas* was higher (220.63 l/kg) than that of *M. oleifera* (358.6 l/kg) and *E. saligna* (379.2 l/kg). This means that, in order to produce one kilogram of biomass, an average of 220 liters of water is needed by *J. curcas,* 358 liters for *M. oleifera* and 379 liters for *E. saligna*. This implies that, if the same WUE trend among these tree species continues up to the harvesting stage, *J. curcas* consumes water more efficiently than *M. oleifera* and *E. saligna*; and even than other agricultural crops like maize 1000 liters/kg, sunflower 2400 liters/kg, potatoes 1000 liters/kg (Davidson, 1989). The higher WUE in *J. curcas* is due to the fact that the same amount of water produces large biomass than in *M. oleifera* and *E. saligna*.

On the other hand, Lima *et al.* (1990) and Ranzini (1990) pointed out that *E. saligna* use water more efficiently than did the natural vegetation especially in terms of timber production. They argued that, most eucalyptus species need an average of 785 liters of water/kg of biomass produced as opposed to other agricultural crops like, cotton/coffee/banana 3200 liters/kg biomass produced. This amount of water is still however higher than that consumed by *J. curcas* and *M. oleifera* in order to produce a kilogram of biomass.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

(i) The study has shown that both Socio-economic study and the Greenhouse experiment revealed that *J. curcas* and *M. oleifera* which are oil seed bearing plants are not significantly different in water consumption. *Eucalyptus saligna* is less water use efficient compared to *J. curcas* and *M. oleifera.* This means, both parts of the study have shown the same trend of water consumption by *J. curcas, M. oleifera* and *Eucalyptus saligna* although in the socio-economic study people were mostly referring to large trees, particularly E. saligna, while the Greenhouse experiment refereed to trees at early growing trees (seedlings).

(ii) The extent of *J. curcas* cultivation is large because it is being cultivated more among small holder farmers and likely to increase as it is cultivated as a cash crop more extensively than *M. oleifera* and *E. saligna*. This has also been encouraged by the presence of an oil pressing machine at the PROKON Renewable Company in the District that buy *J. curcas* and *M. oleifera* seeds for pressing oil. The company also has been emphasizing people to cultivate *J.* curcas, so increase its extent of cultivation in the District. *Jatropha curcas* is more efficient in water consumption than *M. oleifera* and *E. saligna* because it uses less amount of water per unit biomass production (220 l/kg) compared to *M. oleifera* (358 l/kg) and *E. saligna* (379 l/kg). The same trend of results has been obtained from the perception of people who sees J. curcas being more water use efficient than the other two tree species.

5.2 Recommendations

The following recommendations are pertinent to be relevant as per results and discussions of the study:

(i) Since both socio-economic and greenhouse experiment has revealed *J. curcas* being more efficient in water consumption, I recommend it to be source of biofuel feedstock after undertaking other researches concerning, for example, its effects to water quality, biodiversity and the environment. It seems to have a promising future in regard to energy security and rural development if all of the challenges are well addressed.

(ii) *Eucalyptus saligna* has shown water use in-efficiency in terms of being used as biofuel feedstock. In terms of timber production *E. saligna* can be efficient in water use, but it has been observed that the costs and benefits of planting fast growing tree species including *E. saligna* need careful assessment based on detailed site specific studies considering both ecological and socio-economic needs. It can otherwise be planted in small holder forests and woodlots in order to be a source of forest produce to the community as alternative to natural forests / forests.

(iii) The impacts of biofuels production should well be addressed in every aspect environmentally, socially and economically before starting the implementation and these should involve stakeholders from local to national levels. This will help to avoid damage to the environment, social wellbeing and settle unnecessary land use conflicts among communities.

(iv) Since this study has set up the basis for future research, I recommend more to be done especially going further from greenhouse experiments to the field and study the proposed biofuel tree species on various aspects including pests and diseases, pest control, effect to water quality and soil characteristics. In order to come out with ideas that will direct the whole process of biofuel production in the Country and Worldwide.

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APPENDICES

Appendix 1: Household questionnaire for cultivation of selected biofuel crops (*J. curcas, M. oleifera* and *E. saligna*) in Mpanda District

Questionnaire No. ____________________

Village_________________ Ward________________ Division ___________________

Town _______________District _______________ Region ______________________

Date: __________ Time Start: _________

SECTION A: DEMOGRAPHIC INFORMATION

A1.Gender 1. Male [ ]

2. Female [ ]

A2. What is your age in years?

1. 18 – 25 [ ]
2. 26 – 50 [ ]
3. 50 and above [ ]

A3. What is your marital status?

1. Single [ ]
2. Married [ ]
3. Widowed [ ]
4. Other (specify) [ ]

A4. Education level?

1. No formal education [ ]
2. Primary School [ ]
3. Secondary School [ ]
4. Post Secondary [ ]

A5. What is the major source of household income?

1. Crop farming only [ ]
2. Livestock keeping only [ ]
3. Crop and Livestock keeping [ ]
4. Salary/wages [ ]
5. Business [ ]

A6. Estimate income from each of your income source per month

……………………………

S.No.	Source of Income	Estimated income/month (Tshs)
1.		
2.		
3.		
	TOTAL	

A7. Size of the household

Age group	Gender	
	Male	Female
0 – 9		
10 – 18		
19 – 50		
Over 50		

A8. What is the total area of your farm land? ………………….. (actares)

A9. Do you plant these trees in your farms?

1. *J. curcas* only [ ]
2. *J. curcas, M. oleifera* and *E. saligna* [ ]
3. *J. curcas* and *M. oleifera only* [ ]
4. *M. oleifera* and *E. saligna only* [ ]
5. *J. curcas* and *E. saligna only* [ ]
6. *M. oleifera only* [ ]
7. *E. saligna only* [ ]

A10. What estimated size of your land (ha) do you plant *J. curcas* ----------, *M. oleifera* ------ *E.saligna* ----------.

Land use pattern

Name of crop	A11. How many trees of this species do you have?	A12. What is the age of the trees you have? (months)	A13. Do you plant other cash and /or food crops? 1. No 2. Yes	A14. What is the size of land (ha) you planted other cash and/ or food crops? *(Please mention them in spaces provided)*	A15. What is the use of these trees in your farm? 1.Supporting other crops 2.Soil conservation 3.Cash crop 4.Other (please specify)
1) J. curcas					
2)M. oleifera					
3) E. saligna					
4)					
5)					

SECTION B: Local peoples' Perception about Water-use by Biofuel Crops (*J. curcas, M. oleifera* and *E. saligna***)**

B1. Have you experienced any effect of these tree crops in terms of water consumption?

1. No [ ]
2. Yes [ ]

B2. If yes, what are these effects?

J.curcas ……………,………………,……………,…………,……………..

M.oleifera …………,………………,……………,……………,…………..

E.saligna ……………,……………,………………,……………,…………

B3. Do you practice intercropping agricultural crops with one or more among the above mentioned three tree species?

1. No [ ]
2. Yes [ ]

B4. If Yes, what are the effects that you have encountered in terms of water consumption?

B5. What soil conservation measures do you practice in your farm?

1. Terracing [ ]
2. Intercropping [ ]
3. Organic manure application [ ]
4. Tree planting [ ]
5. Other (please, specify) [ ]

B6. Do you perform irrigation in your farms?

1. No [ ]
2. Yes [ ]

B7. If Yes, what crops do you mostly irrigate and why? …………………….

B8. Where do you get irrigation water from?

1. A stream/river flowing near to the farm [ ]
2. Short wells made in the farm land [ ]
3. Tape water [ ]
4. Other (please specify ……………………

B9. How far is your source of water for irrigation from your farm? How long (in Mins) do you take to the water source?

B10. If the answer in question no. B6 above is No, why? ……………………..

B11. How does *J. curcas* behave during water shortage period in the village?

………………………………………………………………………………

B12. Have you experienced water shortage condition in this village within the past three years?

1. No [ ]
2. Yes [ ]

B13. If Yes, what do you think could be the cause of this water shortage condition?

…………………………………………………………………………………….

B14. What are the methods of used for *J. curcas* propagation?

1. Seeds
2. Cuttings
3. Other (please specify)

B15. What benefits do you get from *J. curcas, M. oleifera* and *E. saligna*?

B16. Give brief comments on *J. curcas, M. oleifera* and *E. saligna* cultivation in this area.

B17. What is your position with regards to the cultivation of *J. curcas, M. oleifera* and *E. saligna.*

Time end: ________________

THANK YOU VERY MUCH FOR YOUR COOPERATION.

Appendix 2: Interview Checklist for the key informants and focus group discussions

1. How many farmers in this village are cultivating the following crops?

   J. curcas ……………........

   M. oleifera …………….

   E. saligna ....

   and what is the estimated size of land under cultivation of each?

2. What are the environment - related problems brought about by cultivation of *J. curcas, M. oleifera* and *E. saligna.*

3. How do farmers cope (Copping strategies) with the problems mentioned above?

4. What is the current condition of water in the village as compared to the time before the project (PROKON Renewable company)?

Appendix 3: Experiment Data Recording Sheet

Treatments	**Water used (ml)**	**Plant height (cm)**	**Collar diameter (mm)**	**Leaf Number (No.)**	**Total Biomass (g)**	**Dry weight (g)**
Uncovered *J.curcas*						
Uncovered *J.curcas*						
Uncovered *J.curcas*						
Uncovered *M.oleifera*						
Uncovered *M.oleifera*						
Uncovered *M.oleifera*						
Uncovered *E.saligna*						
Uncovered *E.saligna*						
Uncovered *E.saligna*						
Covered *J.curcas*						
Covered *J.curcas*						
Covered *M.oleifera*						
Covered *M.oleifera*						
Covered *M.oleifera*						
Covered *E.saligna*						
Covered *E.saligna*						
Covered *E.saligna*						
Covered *E.saligna*						

Appendix 4: Water Use Efficiency Determination

Tree species	**Cummulative Water used (ml) of each pot**	**Average water used (ml) per treatment**	**Average water used (ml) per species**	**Fresh weight (g) of each pot**	**Dry weight (g) of each pot**	**Average dry weight (g) per treatment**	**Average dry weight (g) per species**	**Average WUE per species (g/ml)**
Uncovered *J.curcas*	41,050	44,497	37,256	690.5	182.1	190.8	168.9	0.0045
Uncovered *J.curcas*	49,231			727.2	198.6			
Uncovered *J.curcas*	43,211			759	191.7			
Uncovered *M.oleifera*	44,700	45,515	39,397	579.9	105.5	110.1	109.9	0.0028
Uncovered *M.oleifera*	45,845			520.3	112.9			
Uncovered *M.oleifera*	46,000			513.6	112			
Uncovered *E.saligna*	33,700	33,750	29,436	224.9	67	82.1	77.6	0.0026
Uncovered *E.saligna*	33,800			209.3	93.1			
Uncovered *E.saligna*	33,750			212.4	86.3			
Covered J.curcas	29,842	30,014		456.9	103.3	146.9		
Covered J.curcas	30,150			694.3	193.2			
Covered J.curcas	30,050			617.7	144.3			
Covered *M.oleifera*	30,000	33,279		478.9	105.2	109.5		
Covered *M.oleifera*	31,756			589	99.9			
Covered *M.oleifera*	38,080			499.1	123.5			
Covered *E.saligna*	25,142	25,122		195.3	74.6	73.1		
Covered *E.saligna*	24,892			153.8	62			
Covered *E.saligna*	25,332			158.6	82.7			