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„The question of energy and food security on small scale farms in semiarid regions“

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Abstract

The overexploitation of the woods in Kenya is driving the scientific focus towards alternative resources. Therefore the aim of the study is to find out if it is possible for small scale farmers in Kenya to maintain food security, while becoming more autonomous through the self-production of energy. The energetic demand of the sample family of the study should be covered by two tree species called *Jatropha curcas* and *Ricinus communis*. Food crops and energy plants are planted in 3 different agricultural systems to ascertain which land use practice is the most consistently profitable.

The 1st land use practice, whereby monocultures are applied, is not able to cover the food, fodder or energetic demand. Neither the 2nd land use practice, where the trees are used as hedges for the agricultural area, is able to achieve one of the targets. The 3rd land use practice bears the potential to cover the food and fodder demand of the sample family. Energy security cannot be assured by the practices, but the applied tree species especially *Jatropha curcas* is conducive to cover the energy demand.

Keywords: food security, energy security, plant oil, agroforestry, hedges, semiarid region

Abstrakt

Die Überforstung der Wälder in Kenia richtet den wissenschaftlichen Fokus auf alternative Energieressourcen. Deswegen beschäftigt sich diese Studie mit der Möglichkeit für Kleinbauern die Nahrungsmittelsicherheit zu garantieren während Energie selbst produziert wird. Die Energienachfrage der Beispielfamilie soll durch zwei Baumspezien namens *Jatropha curcas* und *Ricinus communis* gedeckt werden. Nahrungsmittel und Energiepflanzen werden parallel in 3 verschiedenen landwirtschaftlichen Methoden angebaut, um das nachhaltig profitabelste Szenario zu ermitteln.

Die 1. Methode beinhaltet ausschließlich Monokulturen und kann die Nahrungsmittel-, Futter- oder Energienachfrage nicht decken. In der 2. Methode werden die Bäume als Zaun für die landwirtschaftliche Fläche eingesetzt. Dabei kann keines der Ziele der Studie erreicht werden. Die 3. Methode weist das Potential zur Deckung der Nahrungsmittel- und Futternachfrage der Beispielfamilie auf. Die Sicherstellung der Energieversorgung kann von keiner Methode garantiert werden, jedoch besonders *Jatropha curcas* könnte unterstützend zur Deckung des Energiebedarfs beitragen.

Schlagwörter: Nahrungssicherheit, Energiesicherheit, Pflanzenöl, Agroforstwirtschaft, Hecken, semiaride Gebiete

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1 Introduction

In the 1970s the discussion about the scarcity of fuelwood arose in developing countries. All around the world wood is a central energy source. Especially in poor regions the renewable resource is often overexploited. In Africa wood represents the most important energy supply. Good accessibility and low costs are the major reasons for the high consumption rate. In particular for low-income consumers in rural regions, wood is a fundamental option. In rural regions farmers cook and possibly heat on the basis of this renewable resource. In the majority of cases, combustion takes place inside the rural households. The flue gases are not transferred outside and the farmers suffer enormous health risks due to continuous inhalation. Lighting is often undertaken using kerosene lamps. Therefore two different sources of energy are permanently necessary to cover the daily energy demand of a small scale farm.

Deforestation has a ballooning effect in Kenya. The rapid population increase in the last few decades implicates a rising demand for land for agricultural uses (*Ngetich et al. 2009*). The emerging lack of land for cultivation puts pressure on forest areas.

Especially in these densely populated areas, supply is declining because of overexploitation. Thus, rural poor people often suffer from lack of energy. Especially the rising upsurge in the cost of fossil-derived fuels put fuelwood in the centre. Another major point of the extent of the wood demand are missing alternatives. There are trends to force new energy producing methods. The challenge is to allocate a renewable resource which compromises at least the same advantages that fuelwood does. The biggest advantages of timber are that in most cases people have perfect accessibility to this energy source. The allocation can be done all over the year by family members. That means that no extra costs for the working force accrue. In most cases prices are very low or not-existent. The direct exploitation has the advantage, that little storage space is sufficient.

The current situation of farmers, especially in poor regions like arid and semiarid lands (ASAL), is complicated. In climatically unfavourable parts, it is even harder to generate food and energy on a small scale farm. The field yields are limited, because of external effects like the fertility of soil and non-existent rainfall.

Rural power generation wastes a lot of energy because of inefficient existing technologies. In the process of energy production large parts of the generated heat are lost. The process suffers from low degrees of efficiency. The applied stoves are not conducive to an advancement of the situation.

Persistent discussions about food security put the acuteness of change in perspective. Local imbedded alternatives would have strong potential to improve the situation of small scale farmers. In this context, the energy production from plant oils represents a form of subsistence. On the one hand, this alternative would implicate the advantage to generate a renewable energy source and avoid the expanding deforestations. Farmers would be able to dissociate themselves from the fluctuating prices of the energy market. Energy could be produced directly on the smallholder areas. On the other hand, there are doubts about the sustainability of the new energy source. A controversial issue is that these new energy crops have significant pressure on food security. Farmers often rededicate their food fields to energy producing plants. In the first place, it seems interesting to generate an additional source of income. Instead of food crops, energy plants are adopted. Consequentially, farmers have to buy edibles on the international market. The food demand rises and hence their prices can augment without fearing decreasing sales volumes. The generated income from energy plants is often lower than the new costs for food affords (*IIASA 2009*).

Therefore the study is trying to set up various scenarios of agricultural, agroforestral and forestral land use practices. In doing so, small scale farmers could be facilitated in reducing the dependency on fuelwood. For that reason, the raw oil production from two relatively drought-resistant tree species will be presented. These plants could improve the energetic situation of small scale farmers in semiarid and arid regions. The aim of the study is to improve the energetic and nutritive situation of the farmers. These two concerns can only be achieved through a sophisticated land use practice which combines the cultivation of food crops with energy plants.

2 State of the Art

The following chapter serves to review the current state of art. The present state of knowledge will be used as basic data in the study.

2.1 Kenya

The Republic of Kenya is located in East Africa between 5°N and 5°S 34°W-42°E. The country on the equator boarders the Indian Ocean to the east and Lake Victoria to the west. Kenya has well-developed tourism because of its large and unique variety of wildlife reserves.

The highlands of Kenya cover an area of 85,000 km2. In this 15% of Kenya's total land area 8-10 million people are accommodated. That means 40-50% of the total population. The population of Kenya is about 36.5 m and is growing at a rate of 2.7%. Kenya has a land area of 569,140 km2, but only 6% is covered by forests. The development goal "Vision 2030" aims at Kenya achieving the status of a middle income country providing high quality life to all inhabitants (*UNEP 2009*).

2.1.1 Climate

Its proximity to the equator does not imply a tropical climate. The climatic conditions are effected by the high altitude. The annual precipitation ranges between 500-1500mm and reaches 900 mm in Nairobi. Kenya is typical for its variety of climate zones between the coastal region and the highlands (*UNEP 2009*).

2.1.2 Arid and Semiarid lands (ASAL) in Kenya

"Semi-arid lands occupy 17,7 % of the earth's surface and are home to about one billion people." (*Harrison and Pearce 2000*) In Kenya 87.000 km², which is 15 % of the country's surface is semi-arid. The arid area, amounting to 127,000 km², represents 22% of the land. The total amount of ASAL lands in Kenya add up to 37 % of the county's surface (*Singh 1989*).

ASAL regions are characterised by a bimodal rainfall regime (*Southgate and Hulme 2000*). There are "long rains" from March to May and "short rains" from October to December. Total annual precipitation in the ASAL areas is ≤ 900 mm. In semiarid lands rains vary between 450-900 mm and in arid lands between 300-550 mm per annum (*GTZ 2009*). Furthermore, farmers cannot rely on these rainfalls because of repeated failures. More than 70 % of the Kenya's population depends on crops and animal-based agriculture for the own consumption and sale (*IRI 2009*).

"Climate shocks such as drought and flooding lead not only to loss of life, but also long-term loss of livelihood through loss of productive assets, impaired health and destroyed infrastructure. The uncertainty associated with climate variability is a disincentive to investment and adoption of agricultural technologies and market opportunities, prompting the

risk-averse farmer to favour precautionary strategies that buffer against climatic extremes over activities that are more profitable on average." (IRI 2009)

Therefore it needs to be considered that the rainy seasons are very variable and cannot be well-defined. Long-term mean annual precipitation varies from 1200mm in the upper catchments of river Njoro to 800mm at Lake Nakuru (*UNEP 2009*).

In climatically unfavourable regions like the ASALs, preventative measures are executed by the population. These arrangements are set to avoid total crop failures in even drier periods. The prophylaxis implicates that the optimal yield amount cannot be utilised.

The increasing human population is another important factor. Especially Kenya in the last decades has established enormous overcrowded areas. For semiarid regions the increasing pressure on the land resource has fatal outcomes on the soil like reductions of fertility. Another crucial point is the inappropriate use of natural resources in the ASALs. The open access to the renewable resource wood contributes to a deliberated concept of utilisation. The harvest represents one problem of the usage, but also the efficiency of the energy production is a central issue to be highlighted. These aforementioned reasons result in land degradation, deforestation and in the last consequence food security is endangered (*Onduru 2009*).

The large extent of the fuelwood discussion results in a broad search for alternative solutions for farmers in these regions. The research interest focuses on drought resistant plants, because they have the ability to survive in paltry habitats. Results also show that arid and semiarid climates are applicable for special forms of agroforestry.

"Success of an agroforestry system in the semi-arid tropics therefore depends mainly on the combination of a cropping system with a perennial species which minimizes the competition for moisture." (Singh et al. 1989)

As water is mostly the limited resource in arid and semiarid regions, the consumption of water will be an important issue of the entire study. The need for water can be diminished through a wider planting which means reducing the population of tree species (*Singh et al. 1989*). Another possibility to reduce water stress is to plant trees and crops which do not compete with each other (*Muchiri 2002*).

2.2 Deforestation as the energy source

Half of worldwide energy consumption is based on biomass. The most commonly used fuel for cooking, lighting and heating is wood (*Ngetich et al. 2009*). Except in some regions where heating is not required because of warm climate conditions. In sub-Saharan Africa fuelwood energy accounts for about 80 % of energy used (*Jama et al. 2008*). Worldwide in the past decade 127 million ha of forests were cleared, whereas only 36 million ha were replanted. Africa has lost approximately 53 million ha of forest, which means almost 40 % of all fellings (*IIASA 2009*). More than 90 % of the total wood production is used as fuel. The fuelwood consumption is about five times higher than in Europe. Fuel scarcity is the consequence of the high consumption rate (*FAO 2003*).

Deforestation is often a consequence of lack of space. This problem derives from rapid population growth. Between 1980 and 2000 Africa's population grew from 469 million to 789 million (*FAO 2003*). Kenya has demonstrated an abnormally rapid population growth since the 1980´s. In the last 80 years the population rose from 2.9 to 37 million people. Human population often exceeds the estimated carrying capacity for fuelwood of 40 persons per km^2. Especially in semi-arid areas, the live tree biomass declined (*Lott 2000*).

Low income groups in developing countries, especially in rural parts, are extremely dependent on the energy production from wood (*FAO 2003*). In rural areas the main energy source is wood fuel accompanied by agricultural residues like maize cobs or maize straw (*Ngetich et al. 2009*). The adoption of residues is often a consequence of missing wood fuel. In the last year their energetic use was under discussion. The energy production of agricultural residues implies decreases of nutrients in an ecological valuation. Thus, the fertility of the soil can be reduced (*FAO 2003*).

The first reason for the usage is that wood as an accessible good can be dealt through the informal sector:

"A key feature of African economic transition is the growth of the informal sector in both rural and urban areas. Poor performance of the formal economy has increased dependency on a variety of informal sector activities, including collection and trade of fuelwood, charcoal

production, pit-sawing, illegal trade of timber and other products, and collection and trade of non-wood forest products." (FAO 2003)

The second factor is the autonomous collection of wood. The combustible can be easily obtained in high productivity zones (FAO 2003). There are a lot of critical points in the collection. The distances of the gathering site from the household can be a limiting factor. The collection time, load size and frequency depends on the displacement. Mostly women are in charge of gathering the fuelwood and carrying it home. The collection just for cooking activities takes on average 130 hours per year. Through the own wood production on the farm women could save 94 hours. The attainted time could be used for income generating activities (*Jama et al. 2008*). How frequent the collection takes place is also associated to the seasonal variation in availability. Who gathers the fuel is an important issue, because often woman as the household keeping person are engaged with this physical work (*FAO 2003*).

2.3 The question of food security

The increasing population needs more cultivated land. The expansion of crop cultivation is necessary to cover food demand (*IIASA 2009*). More cultivated land does not necessarily result in food security (*FAO 2009*). Food security is defined by the *FIVIMS 2009* as "A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (*FIVIMS 2009*). In 2007 globally some 923 million people were undernourished. Food insecurity is often attributed to poor performances of the agricultural sector. The failing access to the market remains unmentioned (*FAO 2009*). A food insecure person consumes less than 2100 kcal per day (*Shimelis/Bogale 2007*).

2.4 Impacts in Kenya

In Kenya 10 million people were afflicted with chronic hunger. The main reason for this persistent emergency affecting one third of the country's population are floods and droughts. Both external factors threaten lives and livelihoods of the poorest households, in particular in arid and semiarid lands (ASAL).

More than half of the country's population lives under the poverty line. The Kenyan economy has not experienced a significant upsurge in the last two decades. Instead the per capita income has declined and unemployment has risen. The nearly missing market and trade infrastructure hinders especially the rural population in their access to the market (*FAO 2009*).

2.5 The food crises

"The food price crisis in 2008 added a further 100 million to the world's undernourished." (FAO 2009) Among other things, the increased demand for biofuels, feedstocks and rising agricultural fuel and fertiliser prices were causes of the crisis. The increased demand for biofuels has been accelerated by governments. Rising support measures forced the farmers to invest in production of biofuels to cover the market demand. The trend entailed decreased food and feed production. The food supply declined with the consequence of increased food prices. Higher prices reduced food nutritive consumption in developing countries (*FAO 2003*).

2.6 Jatropha curcas Linnaeus

Jatropha has 186 species and belongs to the euphorbia family. *Jatropha curcas Linnaeus* shown in Figure 1 is one species also called the physic nut. The seeds of the nut yield a purgative oil. It is a bush or small tree which reaches a height of up to five metres. *Jatropha curcas* grows in the tropics and other warmer parts of the world. It is mainly represented in the Americas, but also native in Africa and Asia *(Govaerts et al. 2000).*

Figure 1: *Jatropha curcas*

(Source: Üllenberg 2007)

The modest plant is extremely resistant to drought and survives on 300 to 1000 mm rainfall (*World Agroforestry 2009*). The minimal annual precipitation represents 300 mm. Its survival can also be assured by less rainfall than about 200 mm, but then higher humidity is necessary. The physic nut prefers high temperatures and almost windless climate conditions.

"Most Jatropha spp. occur in the following seasonally dry areas: grassland-savannah and thorn forest scrub but, are completely lacking from the moist Amazon region. The current distribution of J. curcas shows that introduction has been most successful in drier regions of the tropics." (World Agroforestry 2009)

With little requirements on the habitat because of its vast root system, the plant can protect soils from erosion. Furthermore, the widely spread roots are useful for a sufficient nutrient supply in paltry areas. The roots loosen the soil and the flow rate can be improved (*Wiesenhütter 2003*).

"J. curcas is a highly adaptable species, but its strength as a crop comes from its ability to grow on poor, dry sites. It is very drought tolerant and can withstand slight frost." (World Agroforestry 2009)

Although *Jatropha curcas* has a high adaptability to soils, it prefers sandy ground. Few requirements enable the plant to grow in marginal habitats in the dry tropics.
The plant produces little fruits containing two or three oily seeds and can already be harvested in the first year. The first harvest yields depend on the water supply. In arid areas the first yield is carried out after 4 years. It takes 5 years to yield the full crop and the trees reach an anticipated average life of 50 years (*Münch 1989*).

Between the two rainy seasons, Jatropha has the attribute of losing all its leaves.
The absence of foliation in dry periods when eolian erosion is at the highest level could be a challenge. This disadvantage can be compensated through a drought-resistant under story (*Wiesenhütter 2003*).

2.6.1 Cultivation of *Jatropha curcas*

Best time to cultivate *Jatropha curcas* is before or at the start of the rainy season. Jatropha as a sole stand is planted in rows with distances between 1 and 5 metres depending on the soil. The most satisfactory widths are 2 to 3 metres. Hereby crop densities vary between 1,111 and 2,500 plants per ha (*Münch 1989*).

The plant also develops in mixed cultivations. Agroforestry systems are a good alternative to combine the oilseed plants with food crops. The planting density is much wider to avoid crop losses. In this study a width of 5 x 7 metres will be applied (*FAO 2009*).

The plants begin to output at 4 or 5 months. It is possible for the plant to reach full productivity within 3 years. The crops are harvested manually. The nuts can be collected repeatedly or at once when the whole harvest is mature. The trees blossom at the same time after both rainy seasons. Therefore the Jatropha plant has two major harvest times. Roughly speaking the harvests are done in July or August and in November or December (*Münch 1989*).

The oil content varies according to production conditions such as climate, soil, fertilisation and water supply (*BiomaGie 2007*). These contain 30 to 34 % of plantoil and can be pressed to extract the oil. Jatropha is inedible by humans and livestock and therefore a potential plant for biofuel production (*Togola 2001*).

"Components that contribute to physic nut oil yield per hectare are: number of pistillate flowers per inflorescence and subsequent number of capsules per shrub, number of seeds per capsule, 1000-seed weight, oil content of seeds (%) and plants per hectare." (Heller 1996)

To tap the full potential, researchers should delve into the relation between the 1000-seed weight and crude fat content. The other factors are hardly influenceable (*Heller 1996*).

2.6.2 Possible material uses of the *Jatropha curcas*

The *Jatropha curcas* plant serves for a lot of different ecological, material and energetic uses. In a sustainable waste management system, the material use is favoured. That assures that the resource stays in the life cycle as long as possible and CO^2 is stored over longer periods. If the material is not useful anymore, it can serve as a biofuel by complying the energetic use.

- Erosion protection and the combat of desertification

With few requirements on the habitat because of its vast root system, the plant can protect soils from erosion. Furthermore, the widely spread roots are useful for a sufficient nutrient supply in paltry areas. Hence, Jatropha could augment the economic efficiency of arid regions. The absence of foliation in dry periods when eolian erosion is at the highest level could be a problem. Often the leaves are not developed sufficiently to decrease the splash-effect. These disadvantages can be compensated through a drought-resistant under story. Mixed cultivation with, for example, agaves are a possible form of avoiding these problems (*Wiesenhütter 2003*).

- Living fence

Jatropha is generally toxic and bitter. It cannot be eaten by humans or livestock. It is not necessary to protect the trees from damage caused by game animals. That is the reason why it qualifies as living fences.

- Medical use

Local people use the seeds against constipation. The self-produced sap of Jatropha accelerates wound healing. The leaves used as tea are against malaria.

- Biological fertiliser

The press cake which is a by-product of the oil press is a good fertiliser. It can be sold on the local market or it is used directly on the farm. The aim is to export the by-product to neighbouring countries (*Henning 2002a*). The content of nitrate ranges between 3 and 4 %. The possibility of using Jatropha as a fertiliser is still under investigation (*Üllenberg 2007*). There are also authors who speak about toxic effects of the Jatropha press cake. Therefore it cannot be directly processed. In contrast, *Henning 2002a* speaks about the toxin as an insecticide.

- Soap production:

Especially women produce soap out of Jatropha oil. 23 % of the oil which remains from the fuel production can be inserted (*Wiesenhütter 2003*). The soap has many different medical properties and can be sold for a good price. *Henning 2002b* describes the soap production as an impressive profit. The production process consists of collecting the seeds, the oil extraction and the production of soap. No edible oil is integrated in the product. Every ingredient except coustic soda is available on the local market (*Henning 2002b*).

2.6.3 Possible energetic use of *Jatropha curcas*

The major product of the physic nut as an energy plant is oil. The by-products which remain from the harvest can be used as pellets. Also the press cake which remains as a by-product from the oil production can be processed and serve energetically (*BiomaGie 2007*).

The production of one litre of oil requires four kilograms of seeds (*Wiesenhütter 2003*). *Sieg 2006* confirms the data with the assumption that a yield of 2 t produces 500 l of Biodiesel. The extraction of raw oil is done by a press. This press can be manually operated or engine driven. Local farmers benefit from the possibility to produce the oil with the hand press, because the production can take place directly on the farm. The production volume of manual alternative is about 1 to 2 litres, whereas the electrical system produces 15 litres an hour (*Henning 2002b*).

Literature about the oil yield of *Jatropha curcas* is not consistent. Output data per *hectare* have a wide range. The study tries to apply the most applied data with consideration that the destination area is are semiarid regions.

Ratanjyot and Van Erand 2005 affirm the lastest output data and complement it with yields per tree of 0.35 to 0.375 gallons of oil per tree. That means every tree produces around 1.4 litres in rain-fed conditions. “At least 2-3 t of seeds/ha can be achieved in semi-arid areas.” (*World Agroforestry 2009*) The last specification is specific to semiarid areas and will be consulted in this study for the agroforestry scenarios. The average output in maturity of 2.5 t of seeds a year means an oil output of 625 l per ha, as Figure 2 highlights. A feasibility study of Jatropha yield in semiarid regions in Tanzania confirms the calculated data of 2.2 – 3.3 t of seeds per *hectare* (*Kempf 2007*).

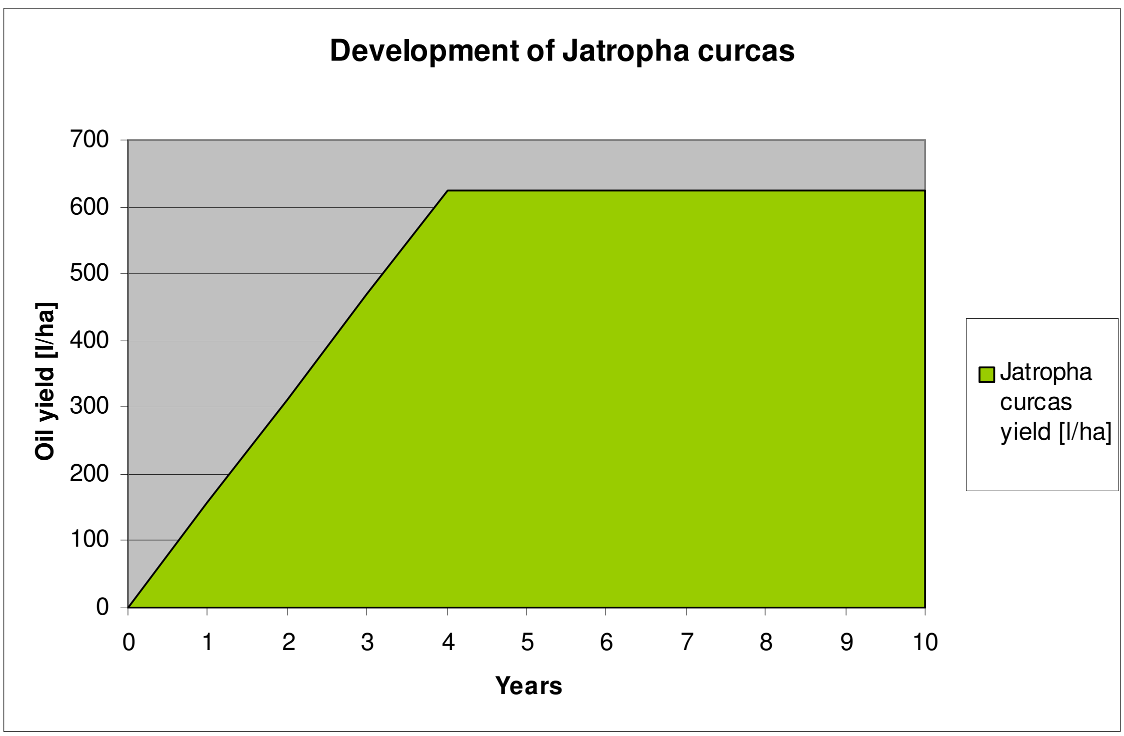


Figure 2: Oil yield development of *Jatropha curcas* in ten years

(Source: GTZ 2009, Green Africa Foundation 2009, own calculation)

The energetic value of *Jatropha curcas* oil is estimated at 37.8 MJ/kg (*Francis and Becker 2006*). The harvested amount of 625 l or 569 kg with a density of 0.91 kg/l means 19,843 MJ per year.

Jatropha finds direct utilisation as lamp oil. It is not suited to burn in kerosene lamps. Jatropha lamps can easily be self-made. The oil clearly burns more slowly than kerosene. Due to the low lamp black accumulation, it is most suited for interior light.

The oil serves as a fuel for fixed diesel motors through two different technical options. First, the oil can be transformed to biodiesel and used in conventional diesel motors with a pre-combustion chamber. Another possibility is to mix the Jatropha oil with diesel. In low application rates motors are not influenced. Third, automotive engines must be adapted to the plant oil. The usage of Jatropha in engines takes place at low temperatures. Results are an incomplete combustion with remaining residues. This by-product is very hard to remove. Therefore it is problematic to use Jatropha oil for cooking stoves. Residues tend to clog the accrual of oil *(Üllenberg 2007).*

In rural areas with little access to supply networks the Jatropha fuel could be a locally produced alternative to fossil fuels. Especially during the rainy season when transport systems are limited, the all-season available oil could serve the local community *(Luoma 2009).*

2.7 *Ricinus communis* Linnaeus

One species of Ricinus called *Ricinus communis* Linnaeus see Figure 3 belongs to the Euphorbiceae. It is probably native to northeast tropical Africa *(Govaerts et al. 2000)*. In this area the plant also called Castor grows wild. Now it is naturalised in many tropical and subtropical countries (*Purseglove 1968*).

Figure 3: ***Ricinus communis***

(Source: Botanikus 2009)

Castor requires warm climates with optimal temperatures between 20 and 25 degrees. The growth period takes 4.5 to 6 months. Original Ricinus is a tree with a height of approximately 10 metres (*Rehm/Espig 1996*).

Ecologically seen, the plant grows best in warm climates and is easily killed by frost. The preferred soils are rich, well-drained, sandy or clayey loams. It has a wide altitude range and needs low or medium rainfall (*Purseglove 1968*). With a deep root system it is quite resistant to drought. The roots are able to attain water from the below ground. The optimal rainfall ranges between 750 and 1000 mm, but special species can survive on 500 mm. The fruits are triple-lobed capsules, usually turning from green to brown (*Rehm/Espig 1996*).

2.7.1 Cultivation of *Ricinus communis*

The preparation of the seed-bed by destruction of the perennial weeds is essential. In mixed cultivation the seed-bed preparation is similar to other plants like cotton, soy beans or maize. Then the seeds are planted at a depth of 5 cm (*Rehm/Espig 1996*). *"In Africa 2-4 seeds are* *planted per hole, later thinned to one plant when 8-12 in. high; tall unbranching cvs are topped at 3 ft to encourage branching."* (*Purseglove 1968*)

In the first weeks Castor develops slowly. Weeds have to be controlled to guarantee initial growth (*Rehm/Espig 1996*). The trees are bed out in rows with an interval of one metre. For hand-picking the distances can even be narrower. Within the row the plant spaces differ between 20 and 25 cm (*Dove 2009*). The inter-row spacing can decrease to 60 cm to maintain the optimum plant density of 70,000 plants per ha (*Kumar et al. 1997*). The annual world average is 729 kg per ha. In dry regions a *hectare* produces 300 to 400 kilograms of seeds. To gather satisfactory yields in arid and semi arid regions, the growing season until the first harvest takes place should be 170 days (*Dove 2009*).

Castor beans are planted as Jatropha before or at the start of the rainy season. The plant is grown on drylands or in mixed cultivation with other crops. The cultivated species can often be harvested annually and it is cropped in semiarid and arid environments. The total harvest can be done at once because the cultivated seeds are held in capsules. On the contrary, wild plants split the woody pericarp to eject the seeds (*Purseglove 1968*). *"The African peasant farmer often prefers dehiscing types so that there is no need to tresh the seed.*" (*Purseglove 1968*) Dehiscing types are cut right before ejecting the seeds and afterwards dried (*Rehm/Espig 1996*).

2.7.2 Possible material uses for *Ricinus communis*

Castor oil has been used in the western world as medicine. The medical, purgative effect has lost its importance and found new applications in industries as:

- Quick-drying coating,
- Textile dyeing,
- Cosmetic articles,
- Lubricant with constant viscosity by high temperatures,
- Press-cake,
- Solid fuel with stem and testa.

Castor oil used as coating and dye does not turn yellow when it dries. Mixing castor oil with the colouring matter promises a clear coating and dye. In the cosmetics industry, it finds application as a dissolver for dyestuffs. The press-cake is toxic, but a nutrient-rich fertiliser (*Rehm/Espig 1996*).

2.7.3 Possible energetic uses for *Ricinus communis*

The seeds contain about 42-65 % of oil. The testa which is taken off before extracting forms 20 % of the seed weight (*Rehm/Espig 1996*). In the oil production about 45 – 50 % press cake remains.

The yield per *hectare* is about 1200 – 2000 litres of raw oil. The output depends on the climatic conditions like, for example, moisture. According to *Carlstein 2005* one *hectare* with good climatic conditions can produce 1320 litres of raw oil. In semiarid areas the *Brasilian Embassy 2007* reckons with 705 litres per *hectare*. Other calculations estimate the yield from 350 to 650 kg per *hectare* (*Dove 2009*).

Yields vary with planting dates. Early seeding dates lead to higher total bean yields (*Kumar et al. 1997*). In this context, field experiments in the study of *Kumar et al. 1997* add up to 1,155 t per ha. An average oil content of 53% would signify 320 litres of raw oil. In the result 47.5 % press cake are subtracted before the percentage of oil is calculated. The oil density is estimated at 0.96 kg/l and results in 307.2 kg per ha, as Figure 4 shows. The yield of seeds per tree is 0.72 kg. The calculated data is comparable with 0.5-0.836 kg/tree calculated by the GTZ 2009. The energetic value of Ricinus oil lies between 37.2 and 39.5 and reaches an average 38.35 MJ/kg (*Scholz 2005*).

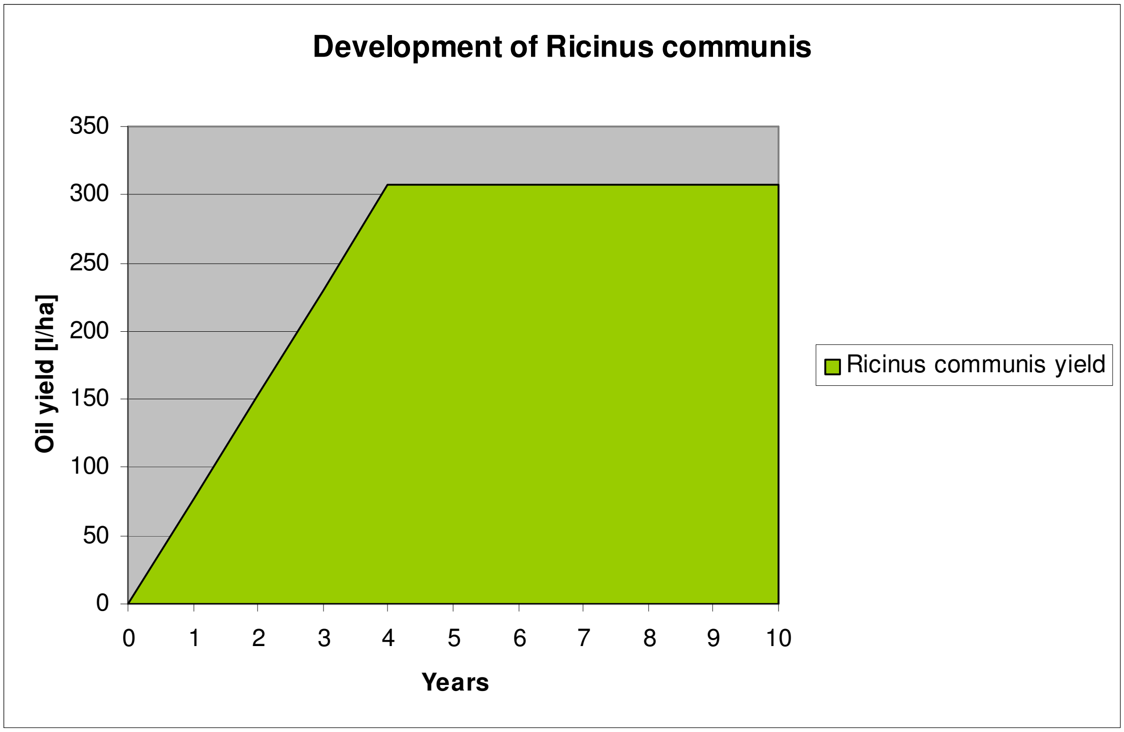


Figure 4: Oil yield development of *Ricinus communis* in ten years

(Source: GTZ 2009, Green Africa Foundation 2009, own calculation)

The oil finds utilisations in cooking, lighting and as a motor fuel. The press cake can be burned to generate energy. Both products can serve as cooking fuel. The oil can additionally be used in lamps and engines.

2.8 Livestock

Small scale farms in Kenya generally hold livestock. *Waithaka et al. 2002* argues that 77 % of the agricultural households in the district Vihinga in Kenya kept cattle. For farmers it is a central aspect to have dairy cattle. Often the poorest households do not possess livestock. *"This is consistent with the fact that farmers had food security as their primary household objective, with surpluses for sale."* (*Titonell et al. 2009*) Animal husbandry is linked to food security because of the direct and indirect products from the livestock. A cow generates 2.7 litres of milk per day. Calculated with an average lactation period of 300 days per annum the production signifies 985 litres per head (*Titonell et al. 2009*).

The cow dung can be collected and mixed with other farms waste to be converted into compost. Before the rainy season the compost is spread over the field. The rain facilitates the entry of the liquid fertiliser. If manpower is a limiting factor, the collection is mostly too expensive. The fresh cow dung and urine flow directly into the field. The direct way is not that effective, but still provides nutrients to the crops (*Giching/Maluvu 2003*).

The feed for a cattle is different in the wet and dry seasons. In the wet season, sufficient pasture is accessible and makes up 69 % of the dry matter (DM) intake. In the dry season about the half of this percentage is replaced by hay. The pasture ration and DM yield are dependent on the rainfall amount. The rest of the fodder are crop residues like leaves or maize cobs (*Salehu et al. 2005*)

Farmers in Kenya rarely meet the demands of the lactating cow. Therefore the interactions between crop and livestock must be optimised. The biggest problem of the decree of animal feed is the allocation of farm resources (*Mureithi 1998*). To meet the nutritional requirements of high yielding dairy cows is a challenge even in the rainy season.

Farmers are constrained to buying feeds off-farm. Small scale farmers profit from their form of cultivation. Especially in times of feed scarcity, other feedstuffs like crop residues, indigenous trees and weeds are applied (*Mwendia et al. 2007*).

"From the discussion it was clear that there was larger variety of feedstuffs offered to cattle under the semi-intensive system implying that the producers are a more opportunistic and feed whatever becomes available while under intensive system feeding was more organized and systematic" (Mwendia et al. 2007)

Following the international trend, poultry is kept under free-range systems. 90 % which means 20,8 million of the poultry stock are indigenous chickens. The birds are found in almost all rural households. They can survive on limited feed resources depending on the season. Hence the sub-Saharan chicken is characterised by low productivity (*Kingori et al. 2007*).

2.8.1 Napier grass

Napier grass is the most common feed resource in Kenya. Between 21-28 % of the farm land in central Kenya is dedicated to this indigenous grass (*Mwendia et al. 2007*). The cultivated area depends on the number of cattle and land availability. 0.4 ha per cow is recommended (*Mureithi 1998*): Primarily smallholder dairy farmers use the plant for their cattle. These farmers are often resource poor and require the use of high yielding forages (*Orodho 2006*).

Planting takes places during the rainy season on prepared seedbeds. Stem cuttings or root splits are planted in spacings from 60cm x 60cm to 90cm x 90cm depending on the moisture content. Especially in the tropics, yields are closely related to water supply. Gatherings are done all over the year so that feeding stuff remains available. Dry matter yields on average about 16 t per ha without fertilisers (*Mwendia et al. 2007*). The energy value varies between 13.4 and 14.6 MJ/kg (*Seye et al. 2005*). That signifies 3344 kcal/kg.
Especially women are in charge of the livestock and thus the fodder production. Planting, harvesting and weeding activities account for 70-80 % of the routine work (*Mwendia et al. 2007*).

Napier grass is suited to be intercropped with trees. Common mixed cultures like laucaena and napier grass are effective in Kenya: Crop-rotations with maize demonstrate better yields than continuous maize crops (*Mureithi 1998*).

2.9 Forms of Land use practices

In the thesis three different land use practices are the focus. Every practice is generally subdivided in two major parts:

- Agricultural area (Food + fodder)
- Forestral area (Energy)

On the agricultural area different food crops for the human consumption as well as for livestock are planted. The forestral area is managed in monoculture, hedges or agroforestry.
First land use practice: Monoculture
The planting density for the sample trees *Jatropha curcas* and Ricinus comunis is recommended at 2.5 x 2.5m in the sole stands (*GTZ 2009*). The sole stand results in 1600

trees per ha. In the field practice maize, beans, sweet potatoes and napier grass are planted as sample monocrop plants. These crops serve for human and livestock nutrition (*FAO 2009*).

2.9.1 Second land use practice: Hedges

To use the trees as hedges demonstrates a potential form of agriculture. The trees serve in this case as a windbreaker, fence and for material or energetic use. In the selection of the trees, the subsequent utilisation is significant (*FAO 2009*). *Jatropha curcas* and *Ricinus communis* grant protection to the crops from a lot of animals, because the plants are not suitable for consumption. The bushes or trees serve as natural fences because the fruits often contain toxins. (*Münch 1989*).

Climatically problematic conditions like water shortage can result in competition between the trees and the crop. Hence, there should be space or a laneway in-between. Narrow planting density of trees like 40 cm can lead to high mortality rates. Regular pruning is essential to reduce the competition in mixed stands. These human encroachments facilitate the symbiosis between the two plant systems. The continuous cuts minimise shadowing effects and can allocate more nutrients and water resources for the crop growth.

In the 4^{th} land use practice, both tree species are utilised as hedges to fence the sample farm. The trees are planted at a distance of 0.5 m. The planting density results in 1196 plants (*FAO 2009*).

2.9.2 Third land use practice: Agroforestry (Alley cropping)

Trees and shrubs have a positive impeding effect on soil erosion. The importance depends on the undertaken cuttings and browsings. Another important factor is the height above the ground. Tall trees offer little protection, while low shrubs are a very effective defence.

Perennial crops possess a nearly constant cover once established. The creation of the crown has a very important shading effect and takes about 3 years. These calculations result from the growing time of *Jatropha curcas* and *Ricinus communis*.

Annual crops, for instance maize or napier grass in this study, do not cover the soil in the planting phase. The protective effect increases during the early and late vegetative stage and reaches its top in the mature stage. The amount of erosion depends on the timing of the growth stage (*Kassam et al. 1992*).

"When estimating maximum LAI for intercrops, it is suggested that the LAI of the first (main) crop is not reduced, but that of the second and subsequent crops is reduced by 25%." (Kassam et al. 1992)

Plants use the available resources for growth. It can be reduced by limiting factors such as water in drylands. Hence, the competition is also influenced by the season. This rivalry is mostly higher between similar species. This effect is called the Gause's hypothesis and responsible for the success of mixed cropping systems. Complementarity in agroforestry means that the planted cultures influence each other positively. A special form is spatial complementarity where a deep-routed species es combined with a shallow species (*Lott 2000*).

Agroforestry systems tend to use the dispositve resources more efficiently than common cultivations. The crop is able to source its nutrients and water from the surface and upper soil layers, whereas the trees utilise the deeper ground (*Muchiri 2002*).

Alley cropping is a form of intercropping agroforestry in which trees or bushes are planted in hedgerows. In between the rows stripes of crops can be fitted. A characterisation of alley cropping is that the trees are already mature when the crops are sown. The trees or bushes are kept pruned to decrease the competition with the crops and to diminish shade. Therefore the plants are cut during the rainy season when the crops are sown.

A special form of the third land use practice is understorey agroforestry. This system concentrates on the crop yield production. These field revenues should not be diminished by the requirements of the trees. In agroforestry as a long rotation system it is important to farmers to assure the annual yields. The crop is the main income generating factor, at least in the first years (*Singh et al. 1989*).

Especially in semiarid regions where water is the limiting resource, it is important to plan the alley width exactly. *Singh et al. 1989* reports a consistent and considerable reduction of crop yield, which can range between 30 to 90 %. These results are based on less than 5 m distances between the hedgerows. Muchiri 2003 shows in his study that *Grevillea robusta* has negligible losses using an alley width of 10 m.

In ASALs the evaporation of plants is high. This effect can be alleviated by the shading effect of the perennial plants. The shadow which surrounds the tree or bush can also have negative influences. Often the crop yield in the stem surrounding is diminished (*Singh et al. 1989*).

"The effect of trees on crops can be predicted using traditional stand characteristics describing stand density such as stand basal area, number of trees per hectare, and percentage crown cover." (Muchiri 2002)

The ecological field theory assumes that the availability of resources has the strongest effect on trees. The availability is dependent on the distances and the dimensions of the tree. Every planted tree decreases the resources. The second tree has bigger implications on the first tree than the following ones. That means that the marginal costs of the first tree decrease with every further planted tree (*Muchiri 2002*).

2.9.3 System productivity

System productivity is reached when the agroforestry model (trees and crop) exceeds the same yield as the sole stand. An important variable is the land equivalent ratio (LER). It demonstrates the amount of land needed in sole stands to produce an equivalent yield like in agroforestry (*Lott 2000*).

2.10 Human, energy and livestock consumption

The analysis of eight different agricultural scenarios requires exact information about the size of households. The number of persons living and working on the small scale farm is basis data. As the literature presents, the presumption of a six member family is realistic (*Titonell et al. 2009*). The human and livestock calorie consumption calculates first in kilocalories (kcal) per person a day. In the results, the consumption data will be quoted in megajoules (MJ) per household to avoid additional complexity.

The assumed household size of a six member family relies on the study of *Ngetich et al. 2009*. The average family is represented through predefined standardised units of measurements. Members aged between 15 and 59 years are counted as adults. Adults are separated into female with an adult equivalent (AE) of 0.88 and males with 1.0. Older persons are also separated in female with 0.72 and male with 0.8 AE. Girls account between 0.4-1.0 and boys between 0.4-1.2 AE (*Shimelis/Bogale 2007*).

	Female	Male	Family
2 x Adult	0.88	1.0	1.88
1 x Old person	0.72	0.8	0.76
3 x Children	0.4 - 1.0	0.4 - 1.2	2.25
AE of 6 member family			**4.89**

Table 1: Calculation of adult equivalents (AE) of a six member family

(Source: Titonell et al. 2009, own calculation)

The family structure consists of 2 adults (parents), 1 old person and 3 children, as Table 1 points out. The adult equivalents for the parents are calculated with a female (0.88 AE) and a male (1.0 AE) person. The old person is counted with the average between 0.72 AE and 0.8 AE which is 0.76 AE. The standard child is 0.75 AE, evaluated by the average between 0.4 AE and 1.1 AE. The adult equivalent for the household represents 4.89.
The average livestock in the study is calculated with a cow, four goats and ten chickens.

2.10.1 Human consumption

The researched data on calorie consumption is based on two different studies. In the study *Titonell et al. 2009*, the calorie consumption per adult equivalent is 2110 kcal per day. This data is collected in rural households with 6 members in Kenya. The second analysis *Shimelis and Bogale 2007* calculates with 2100 kcal per person in Ethiopia. Both authors assume that the data are the minimum acceptable weighted average food requirement per person a day. Households with less than 2100 kcal metabolism are defined as food insecure (*Shimelis/Bogale 2007*).
The thesis calculates with an energy consumption of 2110 kcal because of the actuality and the geographic accuracy of the information.

Daily calorie consumption (MJ)		**Daily calorie consumption**	
per household (6 persons)	per AE	per person/kcal	**per AE/kcal**
53	11	2110	**2589**

Table 2: Calculation of daily calorie consumption in kcal per adult equivalent.

(Source: Titonell et al. 2009, own calculation)

In the calculation of *Tittonell et al. 2009* the 6 member family needs 53 megajoules (MJ) per day. The required energy per AE represents approximately 2589 Kcal a day.

The four major food groups in Kenya are cereals, vegetables and fruits, starchy roots and milk and eggs, as listed in Table 2. Meat is also produced at the sample farm. In this study the sample farm is only able to produce these aliments. The sample crops are presented by maize as cereal, beans as vegetable and sweet potatoes as starchy roots. The cow and goats are responsible for the milk and meat production. The chickens serve the farm with meat and eggs.

Human energy demand by food group				
	Consumption g/day per person	**percent of intake**	**Calories (MJ) per family**	**Consumption kg/year per family**
Maize	326	27.1	5243.6	713.9
Vegetables, Fruits	255	21.2	4101.6	558.5
Sweet potatoes	152	12.6	2444.9	332.9
Milk and eggs	235	19.6	3779.9	514.7
Oilcrops, nuts	48	4.0	772.1	105.1
Sweeteners	61	5.1	981.2	133.6
Meat	46	3.8	739.9	100.7
Vegetable oils	20	1.7	321.7	43.8
Fish, seafood	14	1.2	225.2	30.7
Animal fats	2	0.2	32.2	4.4
Other	43	3.6	691.6	94.2
Total	1202	100.0	**19333.8**	**2632.4**

Table 3: Current energy demand by food group of the 6-member family.

(Source: FAO 2009, own calculation).

The annual food consumption per person is 770,150 kcal, which results in about 949,500 kcal per adult equivalent. The total calorie consumption of the sample family is calculated with 19,333.8 MJ per year. 27.1 % of the human consumption is covered by maize. The cereal is the most important nutritive source. The sample family consumes 2,632.4 kg food per year. Maize, vegetables, sweet potatoes, milk and eggs, meat and animal fats can be produced on the farm. The self-produced calories (SPC) amount to 16,342.1 or 84.5 % of the food demand. The remaining percentage of 15.5% is purchased from the market.

2.10.2 Livestock consumption

For small holder farmers it is essential to hold specific livestock. Their products are used to cover their own calorific consumption and for sale. All calories produced on the farm are calculated in self-produced calories (SPC%) per season. *Freyer 2009* calculates with a local cow weight of 250 kg as shown in Table 3. The daily dry matter intake (DM) is 2.5 % of the live weight and amounts to 6.25 t per annum. This percentage of DM is applied in the entire study. The milk production of a cow is calculated with 985 litre per year. An average goat, according to *Galina et al. 1995*, produces 385 litre milk a year. The weight of a goat is about 55 kg. The sample farm with 4 goats requires 5.5 t DM and produces 1,540 litres of milk a year. The DM is calculated at 2 t per annum. The live weight of an indigenous chicken according to *Haitook 2006* is 1300 g per bird. Every animal has a dry matter intake of 78 g per day. The total amount of 10 chickens have a DMI of about 0.3 t per year (*Kingori et al. 2007*). The aggregated amount per year results in 500 eggs on the sample farm. This calculation is based on the data of *Kitalyi 1997*.

	Amount	Live weight (kg)	Total live weight (kg)	Dry matter intake in tonnes (DM)
Cattle	1	250	250	6.25
Goat	4	55	220	5.50
Chicken	10	1.3	13	0.30

Table 4: Calculation of total live weight and DM of the total livestock

(Source: Freyer 2009 oral communication, Bett 2009 oral communication, own calculation)

As Table 4 points out, the total livestock consumption of the sample farm is about 12 t DM. In the results the rainy and dry season are considered. Pasture is the main feed resource in the rainy season. Hay is only applied in the dry season. Crop residues remain constant during the whole year.

	Pasture (kg)	Hay (kg)	Crop residues (kg)	Mash (kg)	Total (kg)
Cattle	3125	1042	2083		6250
Goat	2750	917	1833		5500
Chicken				300	300
Livestock fodder	5875	1958	3917		12030

Table 5: Fodder calculation per livestock and total livestock consumption.

(Source: Bett 2009 oral communication, own calculation)

The calculation shows that 7.8 t napier grass are consumed per annum by the sample farm. Hay is attained from napier grass. Crop residues and mash are not extra calculated in the study. This kind of fodder remains on the sample farm and does not have to be produced separately.

2.10.3 Energy consumption

"A household energy survey is a means of gathering statistically representative information on residential fuel demand and use so as to help precisely define household energy issues and aid in formulating appropriate strategies." (Leitmann 1989)

As already mentioned, deforestation and degradations of soils are important challenges in Kenya. The energy supply of households in Africa is basically guaranteed by biomass like wood or agricultural residues. In urban areas charcoal and in rural areas fuel wood is the most important energy source (*Schlenzig 1998*). *"Overall, biomass is the largest single source of energy, meeting about 75% of final energy demand, and over 93% of rural household energy needs." (Njenga 2001)*

Another challenge in Kenya is the high resource consumption. In rural areas the annual fuel wood usage is even higher than in urban regions. This data results from the low energy efficiency of the present cooking systems. Smallholders tend to use the usual three stone stove with 12 % efficiency. The allocation of energy could improve significantly by a change of technology. In urban regions of Kenya the stoves reach are twice as efficient (*Schlenzig 1998*).

"Over the years, it has been found that improved stoves are more difficult to introduce into rural areas because stoves cost money and the traditional three-stone cooking system does not. Rural people are generally very poor, and women and children usually collect their fuel wood without a financial cost." (Njenga 2001)

Therefore the energy consumption of the cooking system in rural areas is unconcerned in Kenya. The working time for collecting the fuel wood is not considered. Other stoves like the Kenya Ceramic Jiko could augment the efficiency to 25 %. The new system is widespread in urban areas. The successful dispersion is based on the related costs which are connected to the extent of energy consumption. Therefore technical and innovative aspects find more approval in urban regions.

The consumption rate of fuelwood in the cities is decreasing. Due to a higher output of final energy referring to the used amount, charcoal is gaining in importance.
For the urban areas the energetic efficiency of the charcoal production is around 18 %. Using charcoal instead of fuel wood means higher inputs of material for the same net energy output, which means that the utilisation of charcoal instead of fuel wood does not contribute to saving resources (*Schlenzig 1998*).

Annual energy consumption			
kg oe per person	Kcal per AE	MJ per AE	**MJ per family**
106	1300613	5442	**26610**

Table 6: Calculation of daily energy consumption of the sample small scale farm

(Source: UNData 2009, own calculation)

The per capita oil equivalent per annum accounts for 106 kg (*UNData 2009*). To adapt the energy consumption to the calorie consumption the same household with 6 members and 4.89 adult equivalents is consulted. An AE requires approximately 5,442 MJ a day. The annual energy consumption of the sample family is 26,610 MJ see Table 6.

2.10.4 Current status of energy consumption

At the moment woody biomass is the main energy source. Therefore it is interesting to compare energy production out of wood and oil. Instead of oil the biomass production is now the focus. The average consumption of firewood is 1.23 kg per person per day (*Ngetich et al. 2009*). This data is based on a family with 5-6 members. Other references like *Nyang 1999*, *Mugo 1999* and *Kituyu 2001* confirm the applied fuelwood consumption rate *(Jama et al. 2008*).

The standard tree for the biomass production in the study is *Grevillea robusta*. This species is planted in various planting arrangements in Kenya. It grows in sole stands or in combination with other plants as commonly maize fields (*Lott 2000*). Often farmers believe that *Grevillea robusta* does not compete with other agricultural crops because of its light crown and deep rooting character. Thus, it can be planted in drier regions because the roots are able to exploit 80 % of the water consumption from the deeper ground. These water reserves can not be considered in the case of the crops. As *Lott 2000* shows, in the first four years there is just little competition between the crop and the trees. Afterwards the trees need the below ground water as well as the rain water. The crop growth is handicapped and yields are extremely diminished.

"Performance ratios never approach unity for both the tree and crop components during the same season, demonstrating that there was always competition for the same resource pool irrespective of crop species or tree size." (Lott 2000)

The results signify that for maize water is the most important and limiting resource. *Grevillea robusta* is not able to establish good trunk and above-ground biomass growth in the first two years. The diminished development cannot be recovered fully in the following years (*Lott 2000*).

According to *Muchiri 2000*, agroforestry systems with ample plantings of *Grevillea robusta* have little influence on the amount of maize yield. This data was collected in a field study lasting for 30 years. The adult trees had no significant effect on the development of maize.

In the first land use practices the tree species are planted in sole stands. The *World Agroforestry Center 2009* recommends a planting density for *Grevillea robusta* of 800-1200 trees per ha. The study operates with an average data of 1000 plants.

The second land use practice operates with the same planting density as *Jatropha curcas* and *Ricinus communis*.

In the last system, agroforestry, the yields are not highly influenced because the right density of trees is applied. That is the reason why only 204 stems of *Grevillea robusta* are planted per *hectare*. After every treatment 30 trees are replanted to maintain the tree volume at a nearly constant level (*Muchiri 2002*).

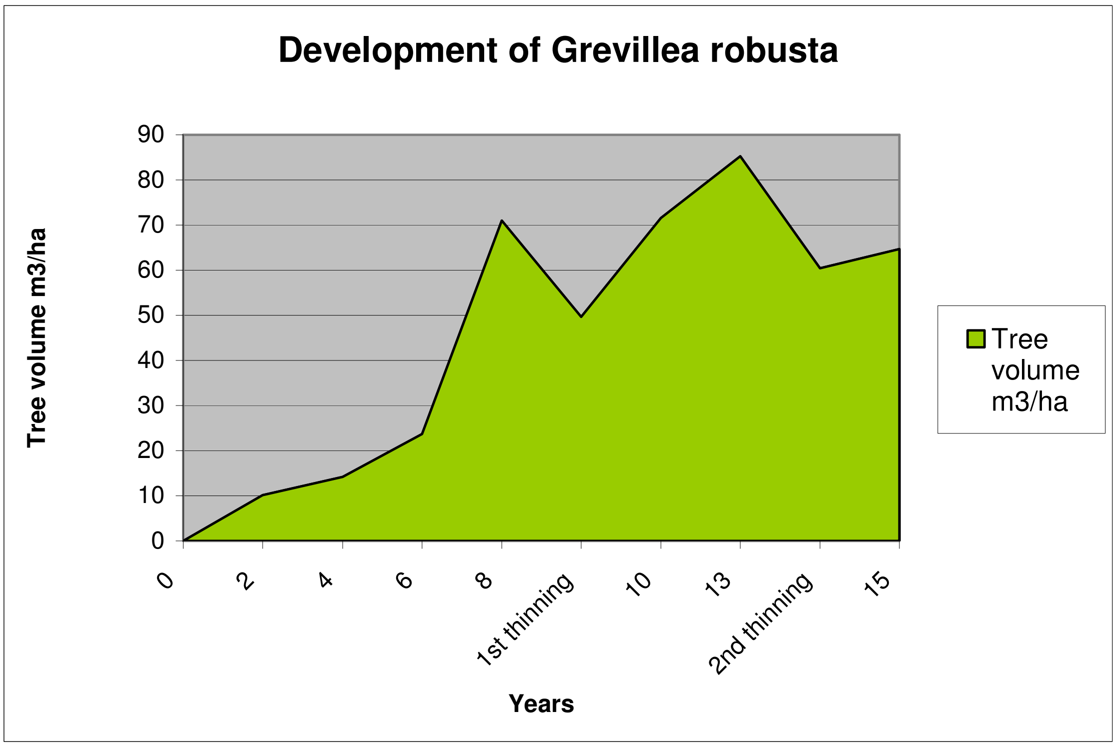


Figure 5: Development of tree volume (*Grevillea robusta*) in a agroforestry yield with maize in the Central Highland of Kenya

(Source: Muchiri 2002, own calculation)

2.11 Raw Oil, Press cake and Biodiesel production

The economic consideration of the *Jatropha curcas* and *Ricinus communis* production is complex. The yields and costs for maintenance are dependent on many factors as mentioned in chapter 2.6 and 2.7.

2.11.1 Hand presses

The oil of Jatropha and Ricinus can be extracted by hand presses. Usually a Bielenberg press as is applied *(Wiemers et al. 1989)*.

Figure 6: Bielenberg press

(Source: Üllenberg 2007)

2.11.2 Hand pressing process

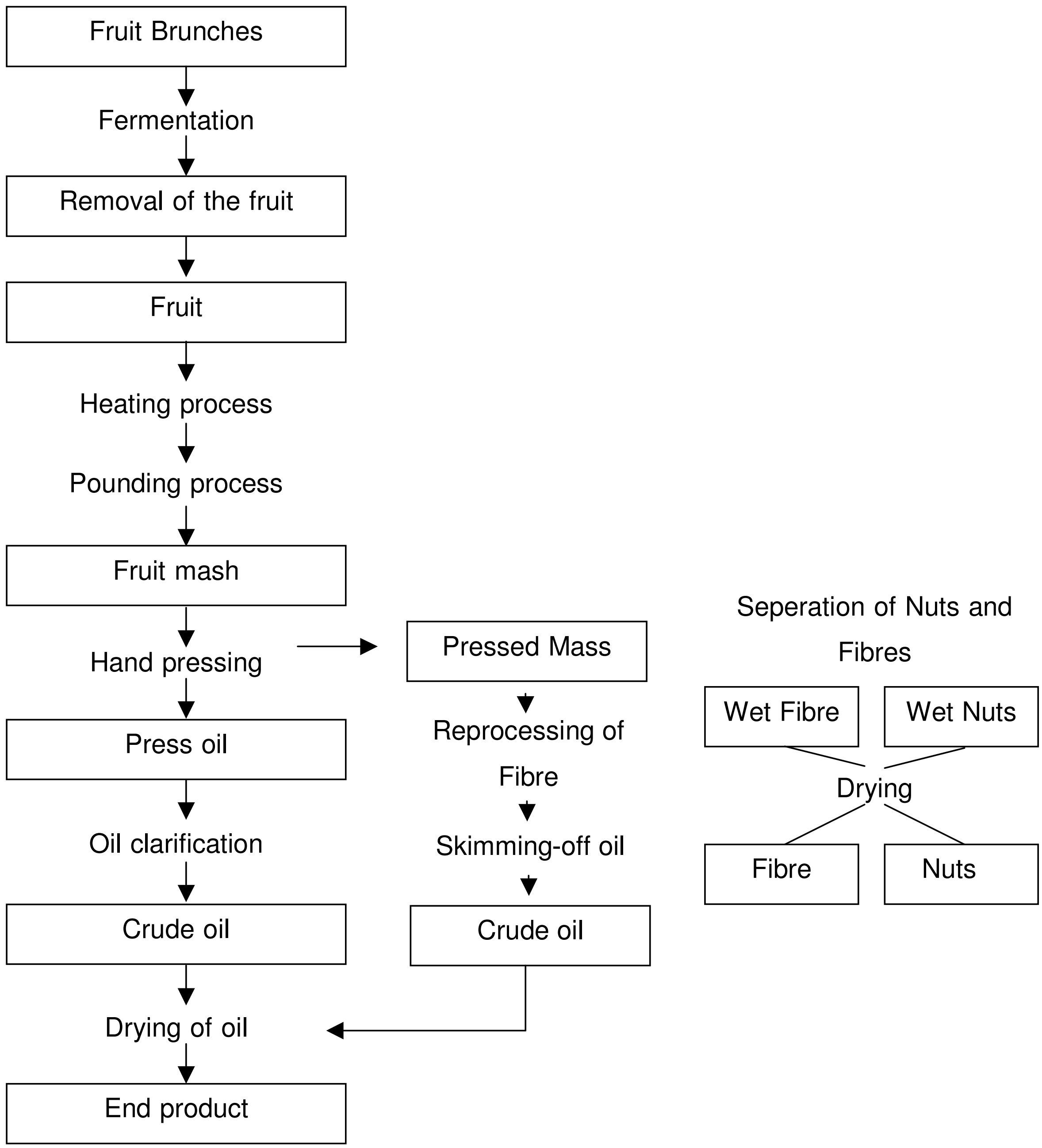


Figure 7: Usual Process of Oil Fruit with Hand Press

(SOURCE: WIEMERS ET AL. 1989)

As Figure 7 shows, the working process starts with the fermentation of the fruit bunches. This enables the removal of the fruits *(Wiemers et al. 1989)*. The oil output can be increased from 25 % to 30 % by warming up the material *(Üllenberg 2007)*. The preparation for oil extraction consists of heating the seeds on a black underground in the sunlight for several hours. A labour-intensive step is pounding the fruits. To facilitate this step, the heating of the fruits helps to remove the pulp from the nuts. The pounding process can cause an augmentation in the oil production up to 47 % of the seed *(Üllenberg 2007)*. Now the fruit mash is put in the hand press. The products are press oil and pressed mass. The clarification process transforms press oil to crude oil which is dried to the final product red oil *(Wiemers et al. 1989)*. The sedimentation is the easiest way to get the oil clear. It takes up to one week until the sediment is reduced to 20-25 % of the volume of the crude oil. Boiling the oil with 20 % of water accelerates the process. The process continues until the water is evaporated and after several hours the oil becomes clear *(Üllenberg 2007)*. The pressed mass is separated in nuts and fibre. Both by-products have to be dried because of their high moisture content. Parts of the fibre are reprocessed and crude oil is skimmed *(Wiemers et al. 1989)*.

With the Bielenberg press Jatropha oil can be pressed. The machine is commonly used for other materials, but minor changes can facilitate the production process. About 5 kg of raw material are processed per hour. The raw oil contingent ranges between 17 and 18 %. The press costs about 180 € *(Üllenberg 2007)*.

2.11.3 Community based production (Investment, Profit)

In the community based production where higher yields could be generated the possibility to produce biodiesel should be considered. The production is a complicated process. The oil is mixed and heated up to 60°C with 10 % methanol. Fatty acid methyl ester (FAME) also called biodiesel needs a strictly controlled proceeding with special technical equipment. The acquisition is quite expensive and amortises with a production of 100,000 t a year (*Üllenberg 2007*). This amount of biodiesel signifies the fourfold of field material like kernels. One sample farm with a *hectare* of land turns out about 320 litres of Ricinus oil or 625 litres of Jatropha oil per year (*GTZ 2009*). The community would therefore need about 160 participating small scale farmers. That is no realistic possibility for Kenya, because the project region is ample. The transport of the raw material demonstrates a big effort. The organisation of the production time of 160 farmers on a single machine would be problematic.

3 Conceptual framework

The conceptual framework implements the research objective and questions.

3.1 Objective

The main objective of the study is to figure out which of the three systems (monoculture, hedges, agroforestry) forms the most effective for the local people. The aim is to identify the potential of these systems to guarantee food and energy security to small scale farmers. Self-supply of food and energy makes farmers more independent from the market. The sale of the produced surpluses diversifies their source of income.

The aim of the study is to find out if it is possible for small scale farmers in Kenya to attain food security, while becoming more autonomous through the self-production of energy resources.
The expected results are theoretically calculated and qualitative data. The data will show which system represents the most effective and safest way for self-supply and sale. The results will be compared with the output of a common agricultural and agroforestry land use practices to show yield distinctions. In the last comparison the three newly applied systems will be opposed to the common used system. This survey demonstrates the advantages and disadvantages of the new species as well as of the planting systems.

The ecological and economical consequences of both will be highlighted. Afterwards the results will be discussed by using social indicators to check the sustainability of the study.

3.2 Research question

In semiarid regions it is possible for small scale farmers to reach energy security without endangering their food security.

- Which land use practice can assure food security to the small scale farmers?
- It is possible to attain food and energy security on the sample area?

- Are there any surplus products to diversify the source of income?

4 Methodology

In the study a model is developed, which aims to cover the required food and energy demand of a 6 member family on a small scale farm in semiarid regions. Therefore it was necessary to find out the yield data of the applied crops and tree species. The yields are measured for semiarid regions to ascertain the exact harvests for the small scale farm. The study operates with three different agricultural land use practices to find out which one is the most suitable for small scale farmers in Kenya. For this reason eight different scenarios were developed to vary the dimensions of the cultivated areas. The calculated yields point out which scenario bears the most potential to cover in first concern, the food, and the second concern, the energy demand.

Before the model was constituted, *Ricinus communis* and *Jatropha curcas* were tested in the laboratory of the **ofi** (Austrian Research Institute for Chemistry and Technology). A detailed analysis of the energetic potential was undertaken.

4.1 Data analysis

In the study both research plants *Ricinus communis* and *Jatropha curcas* were tested. The main goal of the tests was to determinate the fuel parameters of the raw materials. The most important parameter is the calorific or heating value, because both tree species should be applied energetically. The energetic potential is dependent on this output data of the sample material.

Ricinus communis was presented through two different species of the plant in the sampling. The White Ricinus and the Black Ricinus were tested separately. Therefore the two sample materials are divided in three test samples (1-3).

4.1.1 Sample materials

The following samples were tested in the study:

- Sample 1: *Ricinus communis* (Black Ricinus) see Figure 8, one plastic bag with approximately 0.5 kg of crushed nuts.

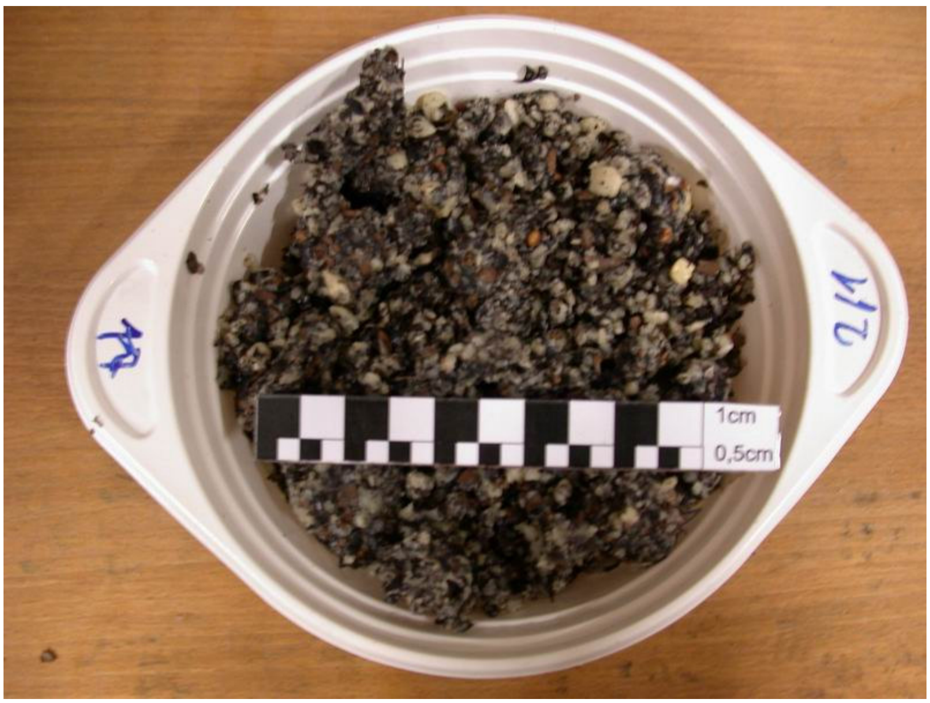


Figure 8: *Ricinus communis* (Black ricinus)

- Sample 2: *Ricinus communis* (White Ricinus) see Figure 9, one plastic bag with approximately 0.5 kg of crushed nuts.

Figure 9: ***Ricinus communis*** **(White ricinus)**

- Sample 3: *Jatropha curcas* (Figure 10), one plastic bag with approximately 0.5 kg of crushed nuts.

Figure 10: ***Jatropha curcas***

4.1.2 Material description

The test material was sent from Kenya directly to the University of Natural Resources and Applied Life Science. The sampling started at the **ofi** in October 2009. The samples were airtight packed in plastic bags to avoid variations in the moisture content and other external influences. Hence the samples were sent from Kenya to the university of natural resources and applied life science in Vienna. At the Austrian research centre the material was first examined by a visual control, but no improper optical observable contaminations e.g. stones, soil were recognised.

4.1.3 Sample preparation

The samples were grinded and homogenised to <0.5mm using a cutting mill, Fritsch, Pulverisette P 19, Apparatus no. 2050. The prepared material was pressed to pellets as Figure 11 shows and hence used for the ash and heating value determination.

Figure 11: Pressing of the grinded material into pellets.

4.1.4 Water content

For the determination of the moisture content the samples were dried in an oven at a temperature of 110°C for several days. To achieve significant data for the moisture content a double determination was applied.

The determination of the moisture content is carried out according to DIN 52183. The water content is calculated by the moisture of the sample material.

Applied equipment:

- Analytical balance, apparatus number 2200
- Drying oven, apparatus number 2186

4.1.5 Fuel analysis

The following specified fuel parameters were to be determined for the biomass samples:

- moisture content
- ash content
- calorific value
- chlorine and sulphur content

4.1.6 Ash content

For the determination as Figure 12 highlights about 1 g sample material was weight in and heated up to 815 °C. After 2 hours at an end temperature of 815°C the samples were cooled down in an desiccator and the loss of weight was determined.

Figure 12: Pot of porcelaine with the remaining ash.

The determination of the ash content is carried according to DIN 51719.
Applied equipment:

- Analytical balance, apparatus number 2200
- Muffle furnace (Figure 13), apparatus number 2187

Figure 13: Determination of the ash content in the muffle furnace.

4.1.7 Calorific value/heating value

The determination of the heating value is carried according to DIN 51900, part 1 and 3. Applied equipment:

- Analytical balance, apparatus number 2200
- Bomb calorimeter IKA C 5000, measuring principle: adiabatic, apparatus number: 1715.

4.1.8 Sulphur and chlorine content

The determination of the sulphur and chlorine content was performed by a combustion decomposition in the bomb calorimeter with 30 bar oxygen partial pressure carried out according to ASTM D 2361 or ASTM D-3177. The emissions were collected in a receiving solution and the concentration was determined with ion chromatography according to ÖNORM EN ISO 10304.

Applied equipment:

- Catalytic ascertained bomb for calorimeter IKA C 5000, apparatus number: 1715
- Ion chromatography (DIONEX DX-320 with suppression and eluat generator), apparatus number 1780.

4.1.9 Test

Testing took place in October 2009. The tests were carried out in the individual technical departments within the scope of competence of the authorised signatories according to the ***ofi*** QM manual. The applied tests are represented in Table 7.

Parameter	**Operating procedure**	**Test conditions**	**Test apparatus (*ofi* – equipment #)**
Moisture content(*)	CEN TS 14772-2	drying temperature: 105℃	Analytical balance, # 2200 Drying oven, # 2186
Ash content (*)	CEN TS 14775	ashing temperature: 815℃	Analytical balance, # 2200 Muffle furnace, # 2187
Calorific value (*)	CEN TS 14918 (equal to DIN 51900)		Analytical balance, # 2200 Bomb calorimeter IKA C 5000, # 1715
Sulphur- and Chlorine content (*)	CEN TS 15289; quantification: Ion chromatography ÖNORM EN ISO 10304		Bomb: IKA C 5000, # 1715; ion chromatography (DIONEX DX-320), # 1780

Table 7: Applied tests: Moisture content, ash content, calorific value, nitrogen content, Sulphur- and chlorine content (*).

(*Source: Ofi 2009*)

(*) accredited method

4.2 Models

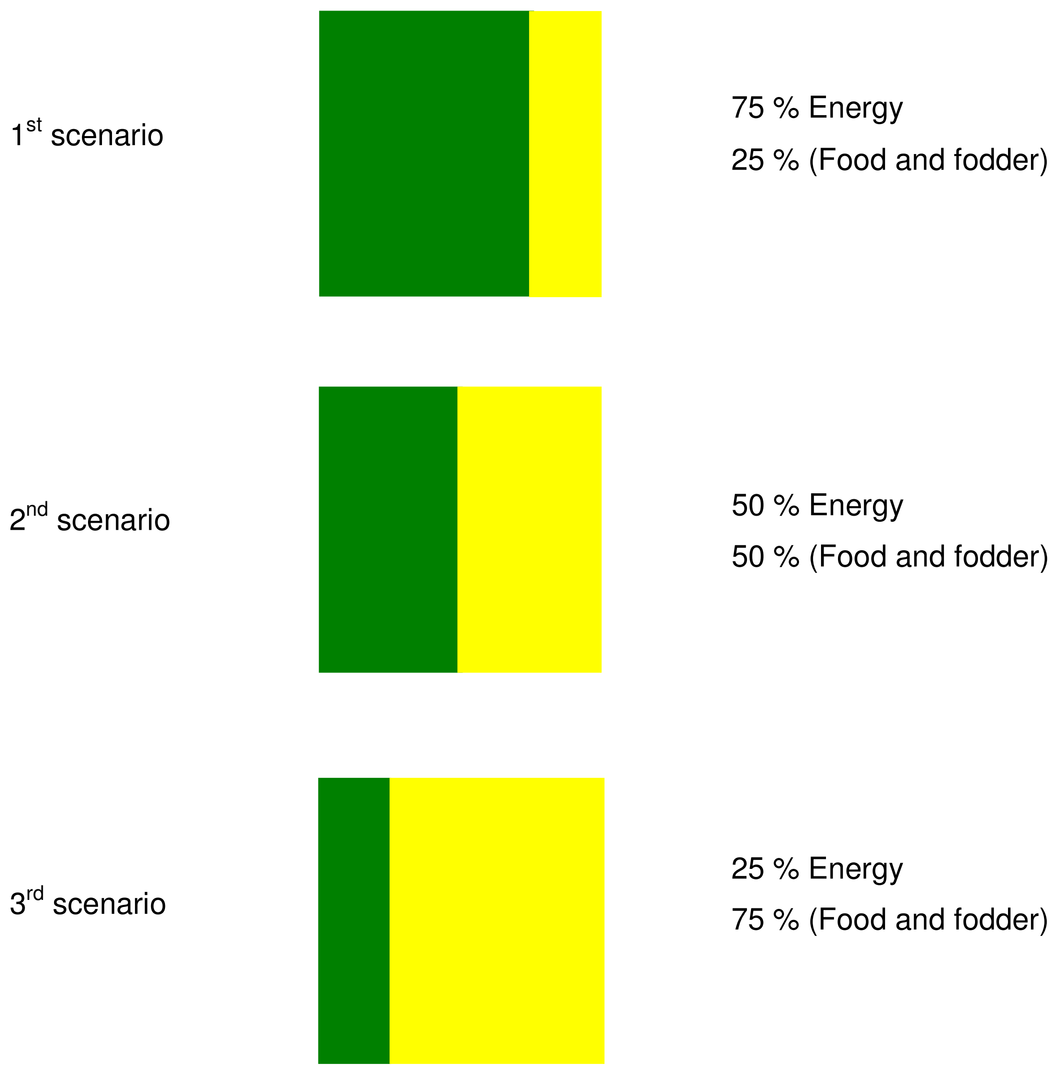
The first land use practice divides the researched area in an agricultural and forestry field. These fields are cultivated on the one hand with different crops and on the other with the analysed trees: *Jatropha curcas* or *Ricinus communis*.

In the 2^{nd} practice a hedge model is selected, where the two tree species fence the agricultural area. In the middle of the small scale farm the crops will be arranged in monocultures. This practice consists just of a single scenario analysis.

The last practice equals the first one in the segmentation of the area. The forestry field is now used for an agroforestry practice, where food, fodder and energy crops grow on the same area. The agricultural area remains and will be calculated with the same data as in the 1^{st} monoculture practice.

4.3 1st land use practice: Monoculture

The 1st land use practice is conducted in three scenarios which vary in the percentage of cultivated fields. In the 1st scenario the percentage of the crops is just 25 %, in the second 50 % and in the third 75 % of the sample small scale farm. According to that, the net area of the analysed plant declines from 1.125 to 0.375 ha. The agricultural area is used to plant different crops for the human (food) and livestock (fodder) consumption. The energy demand should be covered by the analysed trees.

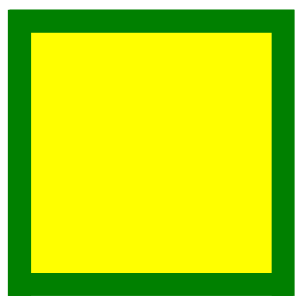


Monoculture is applied in the study to highlight the most common form of land use practice. This practice serves as a direct comparison to the agroforestry models. The field yields of both practices will be compared.

4.4 2nd land use practice: Hedges

The 2nd land use practice describes only one scenario in which the analysed plant is used as a hedge (living fence) for the agricultural area. In the 2nd practice a system of the tree species is established which fences the farming area. In the middle part of the small scale farm different crops will be arranged.

4th scenario



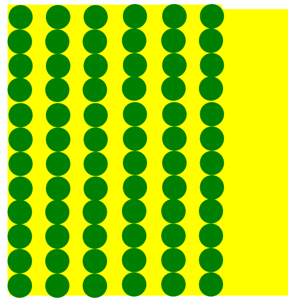
20 % Energy

80 % (Food and fodder)

4.5 3rd land use practice: Agroforestry

The last land use practice is schematically nearly similar to the first one. The study area is also divided in food and fodder and energy production. The analysed energy trees are now farmed in an agroforestry system. Scenarios 5 to 7 are calculated with the same percentages of 25, 50 and 75 % like the first three models. In addition, the last scenario will be developed to present a small scale farm with 100 % agroforestry.

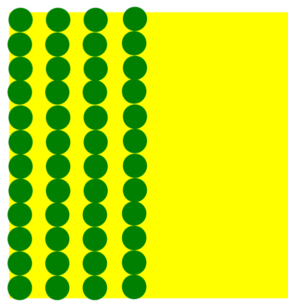
5th scenario



75 % (Food + fodder) and energy

25 % (Food and fodder)

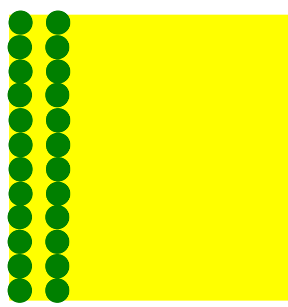
6th scenario



50 % (Food + fodder) and energy

50 % (Food and fodder)

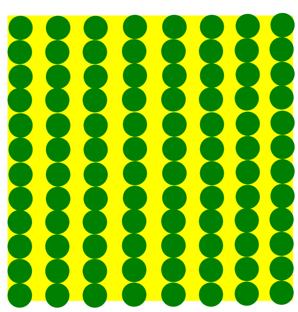
7th scenario



25 % (Food + fodder) and energy

75 % (Food and fodder)

8th scenario



100 % (Food and fodder) and energy

All scenarios will be compared with a common land use practice in Kenya. As a usual tree for fuelwood production in Kenya, *Grevillea robusta* is chosen, while the crops remain. The yields of the crops in the three different land use practices (agriculture, hedges, agroforestry) are calculated with the same productivity as in the scenarios whereby *Jatropha curcas* and *Ricinus communis* are applied.

Therefore three different result variants have been developed. The first and second variant ought to highlight the results of *Ricinus communis* and *Jatropha curcas*. The third variant illustrates the results of *Grevillea robusta*. This method serves to bring out the differences of the required area for food, fodder and energy in the eight different scenarios.

5 Results

In the subchapter 5.1 the analyzed data are registered and afterwards interpreted. In subchapter 5.2 the system definition and the general basic assumption are summarised. The following subchapter specifies more detailed information to enable an exact study. In the subchapters 5.5 to 5.10 the data of the three applied land use practices (monoculture, hedges and agroforestry) will be presented. All applied scenarios are calculated annually.

5.1 Test results

The results in this test report compiled in Table 8 have been obtained under the specific conditions of the individual tests. As a rule, they are not the only criteria for assessing the biofuel in question and its suitability for a specific purpose of application.

		***Ricinus communis* (Black ricinus)**	***Ricinus communis* (White ricinus)**	***Jatropha curcas***
moisture content	[%]	5,9	6,3	8,9
ash content (db)	[%]	3,1	3,5	4,8
net calorific value (db)*	[MJ/kg]	28,3	30,2	27,3
net calorific value (ar)*	[MJ/kg]	27,9	28,2	24,7
Sulphur content (db)	[%]	0,027	0,017	0,072
Chlorine content (db)	[%]	0,190	0,141	0,139

Table 8: Results for the determination of fuel parameter

(Source: Ofi 2009)

*…the correction of the hydrogen content was not implemented in the results.

5.2 Interpretation of the test results

The moisture content of both tree species can be interpreted as low. Compared with other solid biofuels like wood chips the applied material is ranked in the under field.

The ash content of all analysed biofuels is higher than of wood without bark. Compared with non-woody biomass e.g. olive-, fruit residues and straw the ash content is similar. The ash content is important when the material is burned in bigger or industrial stoves, because the residue has to be removed and processed. The ash constitutes a fertilizer and can be spread out at the farming area. High ash contents are normally not desired in the combustion process, because the stoves or combustion units have to be continuously extricated from this residue. In smaller stoves high ash contents worsen the combustion process, because the heat transmission is inhibited. In industrial combustion units the slagging caused by ashes with negative chemical composition is an additional problem. In comparison *Jatropha curcas* shows the lowest ash content.

The net calorific value is mentioned in (db) which means ”dry basis” and in (ar) which stands for “as received”. Both tree species exhibit a superior heating value. The value is synonymous to that of brown coal. The heating materials are without any previous treatments able to outyield these excellent data. White Ricinus shows the best results with 30,2 MJ per kg. In Europe the energy production out of wood increases, although the heating value of this biomass is with 18 MJ per kg significant lower.

The sulphur and chlorine content are high. Both data significate that the stoves have to be more resistant against corrosion (*Ofi 2009*).

5.3 System definition

The system consists of a small scale farm with an area of 1,5 ha. On this farming area food crops, animal feed and energy trees are yielded. For the scenario analysis the crop-livestock systems are simplified. The system defines some measurement categories as fixed. Other categories e.g. the segmentation of the cultivation area, food and fodder crop yields, tree yields are in every scenario different. The following main characteristics of the sample farm are in every scenario equal:

- 6-member family: 1 old person, 2 adults and 3 children
- Field tree species: *Jatropha curcas*, *Ricinus communis*
- Common tree: *Grevillea robusta*
- Livestock: 1 Cattle, 4 Goats, 10 Chickens
- Food and fodder crops: Maize, beans, sweet potatoes and napier grass

The total calorie consumption of the family per year is 4.620.900 kcal or 19.333,8 MJ a year (*FAO 2009*). The energy consumption represents 26.610 MJ per annum (*UNData 2009*). To get good overview the following calculation will be based on MJ.

Figure 14 represents the food and fodder planting composition of the sample small scale farm in the 1^{st} and 2^{nd} land use practice. The most important crops in this study are napier grass and beans, because they have the highest area demand. The proportion of beans is extended, because all vegetables are decimated to this crop. This assumption was undertaken to facilitate the model. The maize yield is calculated with 28% of the agricultural area. The sweet potatoes also called starchy roots are incorporated with 2% of the area (*FAO 2009*).

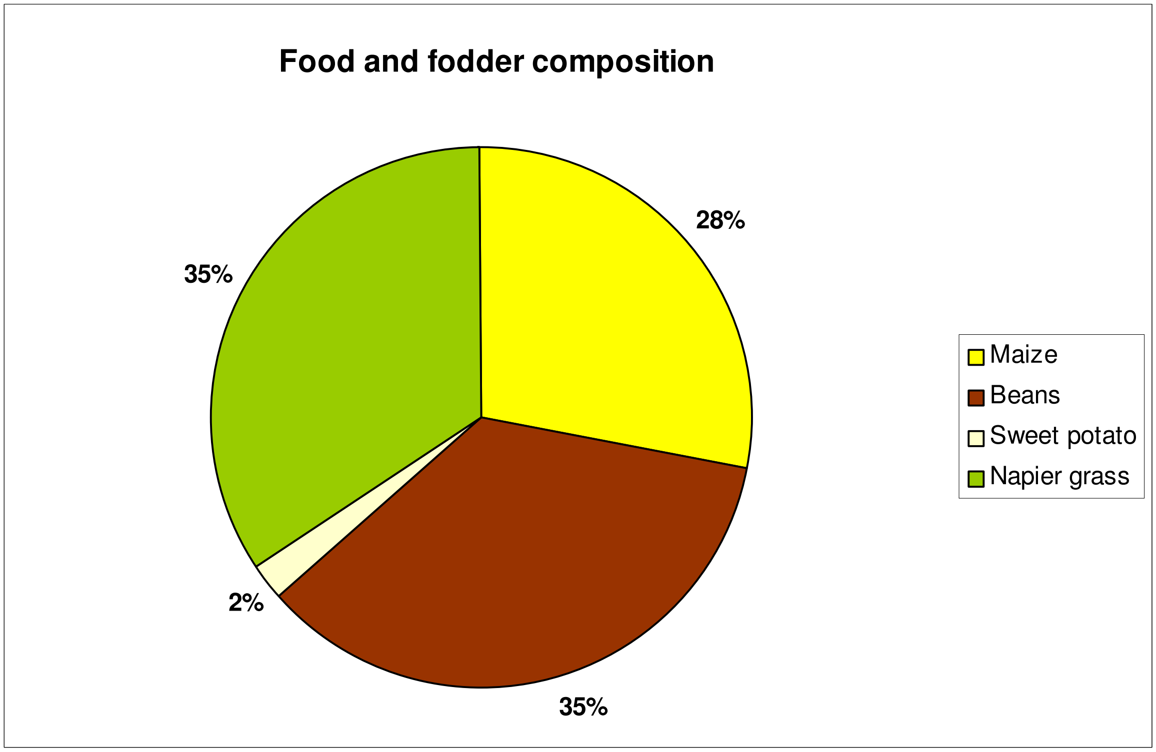


Figure 14: Food and fodder composition in the 1st and 2nd land use practice on the sample small scale farm for all scenarios

(Source: FAO 2009, own calculation)

In agroforestry and 3rd land use practice the small scale farm is redivided as the agricultural land use practice points out in Figure 14. A difference is that maize and beans are intercropped in this practice. Therefore the net area of the maize/bean intercrop is calculated with 51 %. Napier grass makes up 48 % and sweet potatoes have only a share of 1 %.

Table 9 serves to get a general idea of the food, fodder and energy yield per hectare. The food and fodder production is divided in the agricultural and the agroforestry land use practice. The yield decline from the 1st to the 3rd land use practice is calculated with an average of 11 % of the yields achieved in monocultural land use systems to simplify the model (*Muchiri 2002*). In the agroforestry land use system the yields of maize and beans are equal, because of intercropping. To facilitate the following calculations the yield was shared. The evaluation of the energy is done in litres and m^3 per hectare. The animal products are calculated in kg.

Crop	Yield [kg,l,m3/ha]
(Food + fodder agriculture)	
Maize	2500
Beans	1077
Sweet potato	9800
Napier grass	16000
(Food + fodder agroforest)	
Maize (intercrop)	1143
Beans (intercrop)	1143
Sweet potato	8722
Napier grass	14200
Animal products	
Meat	101
Milk and eggs	2775
Energy (1st land use practice: monoculture)	
Ricinus communis	307
Jatropha curcas	625
Grevillea robusta	15,567
Energy (2nd land use practice: hedges)	
Ricinus communis	187
Jatropha curcas	381
Grevillea robusta	15,178
Energy (3rd land use practice: agroforest)	
Ricinus communis	59
Jatropha curcas	120
Grevillea robusta	4,764

Table 9: Food, fodder and energy yields on the small scale farm

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

5.4 Description of the graphical cultivation plan

The different colours mark the tree species and crops. The lines consisting of small circles present the rows of trees in the agroforestry system.

Jatropha curcas, Ricinus communis, Grevillea robusta agroforestry

Beans

Napier grass

Maize

Maize + Beans, intercrop

Sweet potatoes

The energy production provides an insight into three different variants, whereby in the first and second one oil serves as the energy source while fuelwood is applied in the last variant.

- Variant 1: *Jatropha curcas*
- Variant 2: *Ricinus communis*
- Variant 3: *Grevillea robusta*

5.5 Basic scenario

As already in subchapter 2.10.1 the own food and fodder production on the small scale farm can reach 84,5 % of the total consumption of the sample family. The basic scenario gives a review over the basic needs and the required area on the small scale farm. This area is calculated with the yields of the monoculture land use practice listed in subchapter 5.3.
The basic scenario serves in this study to compare the output data of the eight land use practices with the basic food and fodder needs of the sample family.

Basic scenario			
Crop	(Food + fodder) yield [kg, l/ha]	(Food + fodder) amount [kg]	(Food + fodder) area [ha]
Maize	2500	700	0,28
Bean	1000	540	0,54
Sweet Potato	9800	294	0,03
Napier grass	16000	7840	0,49
Animal products			
Meat	67		
Milk and eggs	1850	515	0
Total	31217	9374	1,34

Table 10: Basic scenario of the food and fodder consumption of the small scale farm.

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

5.6 1st land use practice: Monoculture

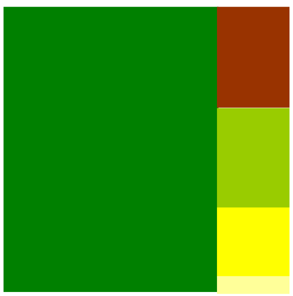
The applied data results from a previous study of *Muchiri 2002*. In this study as the normal maize yield prediction without any trees are 4600 kg per ha. In agroforestry systems the expectation vary between 4000 and 4500 kg per ha. The percentual difference between the average intercropped maize yield and the sole stand yield is 11%. These yields were achieved in the Central Highlands of Kenya with a bimodal, annual mean rainfall of 1000 to 1600mm (*Muchiri 2002*).

This study realized in ASAL regions will operate with an average yield of 2,5 t in sole stands (*Freyer 2009 oral communication*). *Ayoola/Makinda 2009* affirms the assumption of 2,5 t per ha if cow dung and municipal waste is used as fertilizer. The maize demand per family requires 0,28 ha. The average bean yield is estimated with 1 t per ha. Therefore 0,54 ha are necessary to cover the vegetable demand. The sweet potato yield per ha is estimated with 9,8 t, which means an area of 0,03 ha is necessary to cover the family demand. The napier grass yield is estimated with 16 t per ha (*Mwendia et al. 2007*). Average yields of 16 t per ha would significate that an area of 0,49 ha is required to cover the livestock consumption. The

Jatropha curcas yield per ha is more than the double of the *Ricinus communis* yield and results in 625 while Castor offers 307 litres per *hectar*e (*FAO 2009*).

5.6.1 1st scenario

In the 1st scenario the food and fodder production is minimised to 25 %, which signifies an area of 0,375 ha of the 1,5 ha sample farm. The crops are calculated with the percentage resulting from Figure 14. The energy production makes up the remaining 75 %.



75 % Energy:

75 %	Variant 1
75 %	Variant 2
75 %	Variant 3

25 % (Food + Fodder):

8,75 %	Napier grass
8,75 %	Beans
7 %	Maize
0,5 %	Sweet potatoes

1st scenario 25% (food + fodder)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg,l/farm]	Lacking or surplus area [ha/farm]
Maize	2500	0,4	264	-736	-0,29
Beans	1077	0,5	142	-396	-0,37
Sweet potato	9800	0,03	78	-216	-0,02
Napier grass	16000	0,5	2071	-5769	-0,36
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,5			**-1,05**

Table 11: 25% (food + fodder) monoculture.

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

1st scenario (75% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [l,m3/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					-1,0
Ricinus communis	307	345	1,5	-13356	-1,1
Variante 1					**-2,2**
Food + fodder area [ha]					-1,0
Jatropha curcas	625	703	0,8	-2424	-0,1
Variante 2					**-1,1**
Food + fodder area [ha]					-1,0
Grevillea robusta	11,675	13,135	0,1	289071	1,1
Variante 3					**0,1**

Table 12: 75% energy and total balance monoculture.

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

The first model see Table 11 shows the highest deficit of all scenarios in the food and fodder production. This certainty is based on the fact that 25% of the total farm area of 1,5 ha are used for agriculture. The first goal food security is definitely not reached by this model.

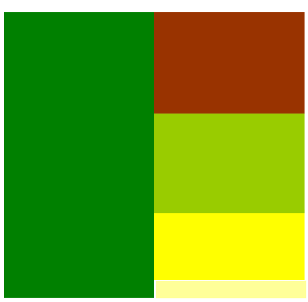
On the energy side the model shown in Table 12 builds the most effective one. In this scenario 1,125 ha are harvested with the energy plants. Variant 1 would need the double of the momentaneous area to cover the energy demand of the sample family.

Variant 2 nearly reaches the point of energy security and the lacking area can be neglected. About 703 litres of oil can be produced on this area. The missing amount consists of 64 litres.

The last energetic variant results in a surplus area of 0,1 ha. This positive data is caused by the high yield of *Grevillea robusta* used as fuelwood. The food and fodder production remains in all variants the same, but the sufficient energy production needs in this farming variant 1,2 ha less than Jatropha and 2,2 ha less than Ricinus.

5.6.2 2nd scenario

In the 2nd scenario the area of food and fodder production is equal to the area used for energy production. Both are calculated with 0,75 ha.



50 % Energy:

50 %	Variant 1
50 %	Variant 2
50 %	Variant 3

50 % (Food + Fodder):

17,5 %	Napier grass
17,5 %	Beans
14 %	Maize
1 %	Sweet potatoes

2nd scenario 50% (food + fodder)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg,l/farm]	Lacking or surplus area [ha/farm]
Maize	2500	0,4	528	-472	-0,189
Beans	1077	0,5	284	-254	-0,236
Sweet potato	9800	0,03	155	-139	-0,014
Napier grass	16000	0,5	4141	-3699	-0,231
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,5			**-0,670**

Table 13: 50% (food + fodder) monoculture.

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

2nd scenario (50% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [kg,l/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					-0,7
Ricinus communis	307	230	1,5	-17774	-1,5
Variante 1					**-2,2**
Food + fodder area [ha]					-0,7
Jatropha curcas	625	469	0,8	-10486	-0,4
Variante 2					**-1,1**
Food + fodder area [ha]					-0,7
Grevillea robusta	15,567	11,675	0,1	162799	0,6
Variante 3					**0,0**

Table 14: 50% energy and total balance monoculture

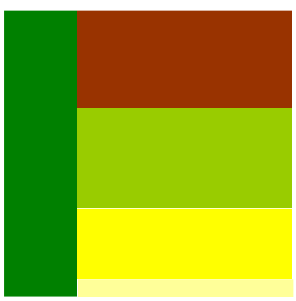
(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

The 2nd scenario see Table 13 produces more food and fodder, but it still misses the target of food security. The lacking area of the sample family for the crops amounts in 0,67 ha and would result in 1,34 ha as the basic scenario see Table 10 highlights.

The energy production shown in Table 14 is not as good as in the first scenario because the forestry area is reduced to 0,75 ha. Variant 3 is still able to reach energy security and the 1,5 ha farm provides enough space for the food and energy production. The surplus area which is planted with energy plants could serve for the food production. This variant of the 3rd scenario is exactly reaching both aims of the study.

5.6.3 3rd scenario

The food and fodder production is in the 3rd scenario the highest of the 1st land use practice and represented by 1,125 ha. The area for energy production is therefore with 0,375 ha marginal.



25 % Energy:

25 %	Variant 1
25 %	Variant 2
25 %	Variant 3

75 % (Food + Fodder):

26,25 %	Napier grass
26,25 %	Beans
21 %	Maize
1,5 %	Sweet potatoes

3rd scenario 75% (food + fodder)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg,l/farm]	Lacking or surplus area [ha/farm]
Maize	2500	0,4	792	-208	-0,083
Beans	1077	0,5	427	-112	-0,104
Sweet potato	9800	0,03	233	-61	-0,006
Napier grass	16000	0,5	6211	-1629	-0,102
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,5			**-0,295**

Table 15: 75% (food + fodder) monoculture

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

3rd scenario (25% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [kg,l/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					-0,3
Ricinus communis	307	115	1,5	-22192	-1,9
Variante 1					**-2,2**
Food + fodder area [ha]					-0,3
Jatropha curcas	625	234	0,8	-18548	-0,8
Variante 2					**-1,1**
Food + fodder area [ha]					-0,3
Grevillea robusta	15,567	5,838	0,1	68094	0,3
Variante 3					**0,0**

Table 16: 25% energy and total balance monoculture

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

The third scenario (see Table 15) approaches the first goal of the study to nourish a 6 member family, but still fails in assuring food security. The sample farm would require around 0,3 ha extra area.

The coverage of the energy demand shown in Table 16 is in this scenario of the 1st land use practice the worst one. This fact is based on the small amount of 0,375 ha, which is used for the planting of the sample tree species.

5.7 Interpretation of the 1st land use practice

The agricultural land use practice consists of monocultures. As Table 11, Table 13 and Table 15 show all three scenarios miss the capacity to cover the food demand. The food production falls below the human consumption rate. That means that food security cannot be assured through the agricultural land use practice. The livestock consumption calculated on the basis of napier grass fails in each scenario.

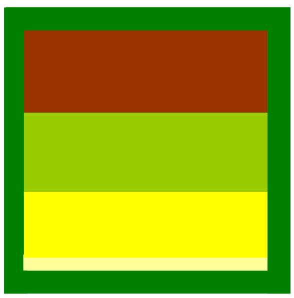
The energy demand of the sample family is not covered by the 1st land use practice. Generally *Jatropha curcas* holds more development potential than *Ricinus communis*. The oil yields of the two applied tree species for oil production show a very big difference. *Jatropha curcas*, used in the 2nd variant, outputs nearly the double amount of *Ricinus communis*. In the high planting density system, which is applied in the 1st land use practice the output data are far apart from each other. In the 1st scenario the energy requirements can nearly be achieved with an percentage 75 % forestry in the 2nd variant. The other two scenarios are far out of the recovery of the energy demand. A noticeable development is that the total balance of all three scenarios show the same lacking or surplus area.

5.8 2nd land use practice: Hedges

The following practice bears a single scenario, whereby the trees are planted around the agricultural area like a hedge. The 4th scenario works with a planting interval for the trees of 0,5 m. That adds up to 975 stems per ha (*FAO 2009*). The centre of the farm serves the food and fodder production, where the crops grow in sole stands. This signifies that the same field yields as in the 1st monoculture practice are applied.

5.8.1 4th scenario

In the 4th scenario the highest monocultural yields of food and fodder accumulate. The total area for the nutrient purpose accounts for 1,2 ha. The energy production is compared to the amount of area high, because the trees are in the hedge system cropped in a more frequent interval.



20 % Energy:

20 %	Variant 1
20 %	Variant 2
20 %	Variant 3

80 % (Food + Fodder)

28 %	Napier grass
28 %	Beans
22,4 %	Maize
1,6 %	Sweet potatoes

4th scenario 80% (food + fodder)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg,l/farm]	Lacking or surplus area [ha/farm]
Maize	2500	0,4	986	-14	-0,006
Beans	1077	0,5	531	-8	-0,007
Sweet potato	9800	0,03	289	-5	0,000
Napier grass	16000	0,5	7730	-110	-0,007
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,5			**-0,020**

Table 17: 80% (food + fodder) hedges

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

4th scenario (20% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [kg,l/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					-0,02
Ricinus communis	187	56	2,5	-19431	-2,71
Variant 1					**-2,73**
Food + fodder area [ha]					-0,02
Jatropha curcas	381	114	1,2	-13509	-0,94
Variant 2					**-0,96**
Food + fodder area [ha]					-0,02
Grevillea robusta	15,567	4,670	0,1	219621	0,89
Variant 3					**0,87**

Table 18: 20% energy and total balance hedges

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

The 2nd land use practice (see Table 17, Table 18) shows high food and fodder yields. All the applied crops still present a little deficit, but compared with the produced amount this lack is insignificant. There is also the possibility to cover the lacking food and fodder through the reduction of the energetic used area.

Variant 1 is able to produce 56 litres of Ricinus oil while variant 2 reaches an Jatropha oil output of 114 litres (*FAO 2009*). The last data signifies that the energy demand cannot be covered meanwhile the food security is guaranteed. The 4th scenario is a potential model to reach food security and to get more independent from other energetic resources. Variant 3 generates an surplus area of 0,87 ha per farm.

5.9 Interpretation of the 2nd land use practice

The 4th scenario has a good potential to cover the food and livestock demand. The energy surpluses are considerable negative. Both tree species do not have the potential in this practice to guarantee energy security to the sample farm.

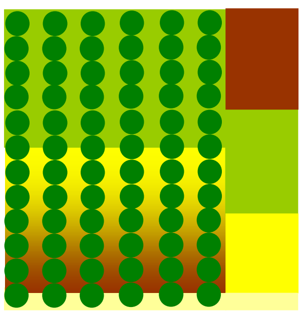
5.10 3rd land use practice: Agroforestry

In the 3rd practice the maize is intercropped with beans and the sample trees. The intercropped maize/bean yield reaches 2286 kg dm per ha in the study of *Tittonell et al. 2009*.

The sweet potato yield of 8,7 t per ha in the agroforestry scenarios is calculated like in *Muchiri 2002* with a decrease of 11 % compared with the yields of sole stands. An area of 0,04 ha is required for the sweet potato production. The same calculation was undertaken to ascertain the napier grass yield of 14,2 t per ha in the agroforestry system. The yield decreases are marginal, because the right planting density of trees diminishes the competition between crops and trees. A planting density of 7m x 7m spacing is suggested in agroforestry systems (*FAO 2009*).

5.10.1 5th scenario

The sample area is in all scenarios assumed with 1,5 ha. The percentages of the 3rd are similar to those of the 1st practice. Energy and food and fodder can be cropped on the same area in the agroforestry system. That means that the food and energy production are listed separately to achieve exact data. Therefore the sum of the percentages exceeds 100%. In this scenario the agricultural used area is 0,375, while the agroforest reaches 1,125 ha.



75 % (Food + Fodder agroforest):

36 %	Napier grass
38,25 %	Maize + Beans
0,75 %	Sweet potatoes

75 % Energy (agroforest):

75 %	Variant 1
75 %	Variant 2
75 %	Variant 3

25 % (Food + Fodder):

8,75 %	Napier grass
8,75 %	Beans
7 %	Maize
0,5 %	Sweet potatoes

5th scenario 75% (food + fodder agroforest), 25% (food + fodder monoculture)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg,l/farm]	Lacking or surplus area [ha/farm]
Food + fodder (agriculture)					
Maize	2500	0,1	264	86	0,034
Beans	1077	0,1	142	3	0,001
Sweet potato	9800	0,01	78	-6	-0,001
Napier grass	16000	0,1	2071	112	0,011
Food + fodder (agroforest)					
Maize (intercrop)	1143	0,5	656	-208	-0,182
Beans (intercrop)	1143	0,4	656	-91	-0,080
Sweet potato	8722	0,03	98	-152	0,003
Napier grass	14200	0,4	7690	1815	0,405
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,6			**0,147**

Table 19: 75% (food + fodder agroforest) and 25% (food + fodder monoculture) Agroforestry

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

5th scenario (75% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [kg,l/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					0,1
Ricinus communis	59	66	17,7	-24920	-16,6
Variant 1					**-16,4**
Food + fodder area [ha]					0,1
Jatropha curcas	120	165	8,8	-23520	-7,8
Variant 2					**-7,7**
Food + fodder area [ha]					0,1
Grevillea robusta	4,764	5,359	0,5	31349	0,6
Variant 3					**0,8**

Table 20: 75% energy and total balance Agroforestry

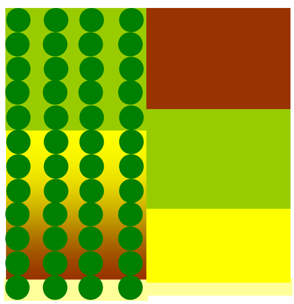
(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

Table 19 highlights that the 5th scenario is a potential one to cover the food demand. In this model the maize and the bean yield fall below the border of food security. The sweet potatoes and especially the napier grass yield exceed significantly the required amount. This surplus area could be rededicated to the missing crops. The cover of the maize demand needs 0,182 ha and the beans 0,080 ha of additional agricultural used land. The food security could be easily reached in this example.

The question of energy security (see Table 20) is far-off reaching the required amount. To yield the sufficient amount of *Ricinus communis* an additional area of 16,4 ha would be necessary. These high requirements highlight the problems of this model. The low planting density guarantees the yields of food and fodder purposes, but constrains the energetic production on a very low limit.

5.10.2 6th scenario

The farming area is exactly divided into food and energy production. As usual in the agroforestry land use practice the energetic used area is coexistently cultivated with food crops. The splitted area for both uses add up to 0,75 ha.



50 % (Food + Fodder agroforest):

24 %	Napier grass
25,5 %	Maize + Beans
0,5 %	Sweet potatoes

50 % Energy (agroforest):

50 %	Variant 1
50 %	Variant 2
50 %	Variant 3

50 % (Food + Fodder):

17,5 %	Napier grass
17,5 %	Beans
14 %	Maize
1 %	Sweet potatoes

6th scenario 50% (food + fodder agroforest), 50% (food + fodder monoculture)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg,l/farm]	Lacking or surplus area [ha/farm]
Food + fodder (agriculture)					
Maize	2500	0,1	528	171	0,068
Beans	1077	0,3	284	5	0,005
Sweet potato	9800	0,02	155	-11	-0,001
Napier grass	16000	0,2	4141	225	0,014
Food + fodder (agroforest)					
Maize (intercrop)	1143	0,3	437	-138	-0,121
Beans (intercrop)	1143	0,2	437	-61	-0,053
Sweet potato	8722	0,02	65	-101	0,002
Napier grass	14200	0,3	5126	1210	0,270
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,5			**0,098**

Table 21: 50% (food + fodder agroforest) and 50 % (food + fodder monoculture) Agroforestry

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

6th scenario (50% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [kg,l/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					0,1
Ricinus communis	59	44	17,7	-25483	-17,0
Variant 1					**-16,9**
Food + fodder area [ha]					0,1
Jatropha curcas	120	90	8,8	-24554	-8,2
Variant 2					**-8,1**
Food + fodder area [ha]					0,1
Grevillea robusta	4,764	3,573	0,5	12029	0,2
Variant 3					**0,3**

Table 22: 50% energy and total balance Agroforestry

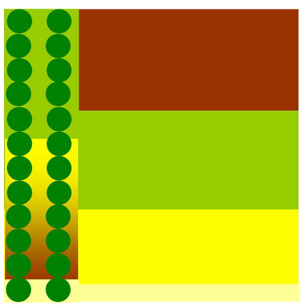
(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

As Table 21 demonstrates the food and fodder security of the 6th scenario fails just in a single crop with an insignificant lacking area. The lacking amount of sweet potatoes are 11 kg per farm. The surplus maize area could also be used to cover the lacking yields. To optimize the 6th scenario an extra agricultural area of 0,001 ha would be necessary. The maize field would be minimized to 0,067 ha. Food and fodder security could be reached by restructuring the percentual fragmentation of the fields. In this model the surplus food and fodder area reaches nearly 1 ha.

The energy demand (see Table 22) is like in the 5th scenario not close-by fulfilling the second aim of the study to reach energy security.

5.10.3 7th scenario

In this scenario the energy production is limited to 0,375 ha. Additional this area is also used for agroforest food and fodder purposes. The remaining area of 1,125 is dedicated to monocultural food and fodder production.



25 % Food + Fodder (agroforest):

12,75 %	Napier grass
12 %	Maize + Beans
0,25 %	Sweet potatoes

25 % Energy (agroforest):

25 %	Variant 1
25 %	Variant 2
25 %	Variant 3

75 % (Food + Fodder):

26,25 %	Maize
26,25 %	Beans
21 %	Napier grass
1,5 %	Sweet potatoes

7th scenario 25% (food + fodder agroforest), 75% (food + fodder monoculture)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg,l/farm]	Lacking or surplus area [ha/farm]
Food + fodder (agriculture)					
Maize	2500	0,2	771	235	0,094
Beans	1077	0,4	448	29	0,027
Sweet potato	9800	0,03	227	-23	-0,002
Napier grass	16000	0,4	6041	166	0,010
Food + fodder (agroforest)					
Maize (intercrop)	1143	0,2	219	-69	-0,061
Beans (intercrop)	1143	0,1	219	-30	-0,027
Sweet potato	8722	0,01	33	-51	0,001
Napier grass	14200	0,1	2563	605	0,135
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,4			**0,049**

Table 23: 25% (food + fodder agrofrest) and 75% (food + fodder monoculture) Agroforestry

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

7th scenario (25% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [kg,l/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					0,05
Ricinus communis	59	22	17,7	-26047	-17,3
Variant 1					**-17,3**
Food + fodder area [ha]					0,05
Jatropha curcas	120	45	8,8	-25582	-8,5
Variant 2					**-8,4**
Food + fodder area [ha]					0,05
Grevillea robusta	4,764	1,786	0,5	-7290	-0,1
Variant 3					**-0,1**

Table 24: 25% energy and total balance Agroforestry

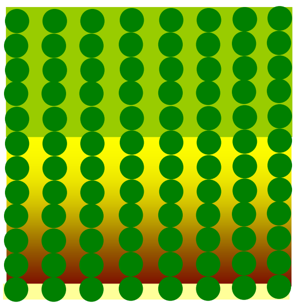
(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

The 7th scenario is almost similar to the other 2 scenarios. The food and fodder production highlighted in Table 23 is like in the other agricultural land use practices sufficient for the sample family. The sweet potatoes are the only crop, which cannot be fully produced with the in this scenario applied fragmentation of the farm. Therefore it would be necessary to harvest more sweet potatoes instead of other crops which offer a surplus.

The energy yields are in this scenario see Table 24 the lowest in the study. This assumption is based on the low planting density in the 3rd land use practice. The area used for energy production is 0,375 ha, which signifies 25% of the small scale farm. On this area 77 trees are planted, which produce an oil output in variant 1 of 59 l and in variant 2 of 120 l. Not even *Grevillea robusta* is able to cover the energy demand.

5.10.4 8th scenario

In the last scenario agroforestry constitutes the single applied system. The total area of 1m ha is planted with mixed cultures divided in the tree species and food and fodder crops.



100% (Food + Fodder):

48 % Napier grass

51 % Maize + Beans

1 % Sweet potatoes

100% Energy:

100 % Variant 1

100 % Variant 2

100 % Variant 3

8th scenario 100% (food + fodder)					
Crop	Yield [kg,l,m3/ha]	Demand area [ha]	Yield [kg,l/farm]	Food/energy surplus [kg/farm]	Lacking or surplus area [ha/farm]
Maize (intercrop)	1143	0,4	874	374	0,164
Beans (intercrop)	1143	0,4	874	374	0,164
Sweet potato	8722	0,04	131	-408	-0,012
Napier grass	14200	0,6	10253	9959	0,525
Animal products					
Meat			101	0	
Milk and eggs			2775	2260	
Food + fodder area [ha]		1,4			**0,841**

Table 25: 100% (food + fodder) Agroforestry

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

8th scenario (100% energy + total balance)					
Crop	Yield [l,m3/ha]	Yield [kg,l/farm]	Demand covering area [ha]	Food/energy surplus [MJ]	Lacking or surplus area [ha/farm]
Food + fodder area [ha]					0,8
Ricinus communis	59	88	17,7	-24357	-16,2
Variant 1					**-15,4**
Food + fodder area [ha]					0,8
Jatropha curcas	120	179	8,8	-15687	-5,2
Variant 2					**-4,4**
Food + fodder area [ha]					0,8
Grevillea robusta	4,764	7,145	0,5	50669	1,0
Variant 3					**1,8**

Table 26: 100% energy and total balance Agroforestry

(Source: Bett 2009 oral communication, FAO 2009, Fleischer et al. 1999, Freyer 2009 oral communication, Muchiri et al. 2002, Mwendia et al. 2007, Titonell et al. 2009, own calculation)

The variant 2 of the last scenario see Table 25 and Table 26 shows the potential to reach food and energy security on the small scale farm. Sweet potatoes do not achieve the covering point. Maize/bean and napier grass can easily spare some space for the sweet potato production, because the food and fodder area outranges the required area. The energy production is not fully achieved by the 100 % agroforestry model. This lackage could be corrected by a closer planting density. Another possibility is to rededicate a small piece of land to forestry. The yield of Jatropha as monoculture reaches more than the fivefold of agroforestry land use practice. Therefore an area of about 0,06 ha would be sufficient to cover the entire energy demand of the sample family. There is an obvious difference between the two applied tree species.

The main goal of achieving food security by increasing the sweet potato area would significate that there are 0,841 ha available to plant more *Jatropha curcas* in sole stands. On this area 1302 stems could grow to reach an oil yield of 19.536 l. Hence the energy security would also be assured by the 100 % agroforestry scenario.

5.11 Interpretation of the 3rd land use practice

The food production of the 3rd practice is considerably more effective than that of the first one. In the agroforestry area trees and crops can produce food and energy coexistent. The result shows that the agroforestry area serves the crop production and could augment food security in the semiarid regions.

Energy security can not be assured by *Ricinus communis* or *Jatropha curcas*. Jatropha has a stronger potential because the field yields are much higher. The yield is more than the twofold of *Ricinus communis*. The differences between variant 1 and 2 are anyway quite similar. This assumption is based on the low oil yields in the 3rd land use practice. Both tree species could be used additionally to other energy sources e.g. fuelwood to cover the energy demand of the sample family.

5.12 Oil versus fuelwood production

Grevillea robusta has a calorific value of 25,76 KJ per gram (Singh/Gopi 2003). The tree yields a medium-weight hard wood with a density of 540-720 kg per m^3. The average density results in 630 kg per m^3. Every m^3 of *Grevillea* robusta has an energetic value of 16.222,8 MJ *(World Agroforestry Center 2009*). The average thinning is calculated with 30 % of the developed biomass. The first wood is removed after 8 years to take advantage of the accelerated period of growth. As Figure 5 highlights the first thinning in an agroforestry system results in 21,30 m^3 and the second in 24,78 m^3. Which means that an area of 1 ha would generate approximately 51.519 MJ a year. The energy supply for the sample family of the total research area of 1,5 ha would result in 77.279 MJ per annum.

The cultivation of *Grevillea robusta* instead of *Jatropha curcas* or *Ricinus communis* exemplifies the productivity of the system. The fuelwood species has the potential to cover the own consumption of the sample family. In all models with the exception of the 7th scenario the plant exceeds the energy demand. This exception results from a low agroforestry area of 25 %. The wide spacing just allows to plant 306 trees on the 1,5 ha small scale farm. In the 7th scenario 51 stems would have to secure the covering of 26.610 MJ. *Grevillea robusta* is in his worst performance still more successful as the analyzed trees. The aim of the study of energy security cannot be fulfilled in the 7th scenario.

All the other models have the potential to allocate the required fuelwood. The 1st land use practice including all three scenarios is the most effective. The 1st scenario with 75 % forestry area makes a surplus of 289.071,37 MJ available. For the energy production this data is the most successful of the study. The hedge and the other agroforestry scenarios are able to meet the energy demands of the sample family.

The food and fodder production is consequential to the similar crop yields identic to the *Jatropha curcas* and *Ricinus communis* model. The *Grevillea robusta* model bears the potential to devote more area to agriculture.

6 Discussion

The literature research of this study results in some key assumptions which are recommendable to consider in further investigations in this field. The most important result, which is already applied in the work, is that the models have to be simplified to prevent their failure. Unnecessary complexity can form a barrier to reach simple and precise information. Therefore an exact consideration of the basic assumptions is fundamental.

The potential of the small scale farm is calculated with opportunity costs for the planted area of 0. That signifies that no other use would take place instead of *Jatropha curcas* and *Ricinus communis*. In the 3rd land use practice the yields of the crops are diminished by the agroforestry land use practice. This loss is not connected to the opportunity costs.

To build up a realistic model for small scale farmers the tree species as well as the crops are planted in year 0. That signifies that the yields of the trees are in the first years very low. The development of the trees is based on the literature research. It seems very important to refer the study to the first ten years of growth. This time period is the most difficult for the farmers to reach adequate yields. To develop a realistic model this basic assumption is unavoidable.

The technical equipment for the practical realisation of the cultivation is quite simple. The planting, maintenance and harvest is done by manual work. The working force in the harvest time is the biggest cost factor, but the labour can be done solely by the sample family members. The harvest of 2 kg nuts would take one hour. Therefore no new investments are necessary. The planting and maintenance costs have to be implicated. In the literature two cents per kg seem to be quite realistic (*Wiesenhütter 2003*). The yields have to be pressed to extract the oil. Therefore the study suggests a Bielenberg press, which should be available for small scale farmers. The machine has a purchase value of approximately 180 €.

The calculation of the energetic potential of the two tree species should be based on the present status of energy production. The three stone stove is the current used equipment at small scale farms. Therefore further investigations could calculate with an efficiency of 12% *(Schlenzig 1998*). The equipment for the combustion of the material is not fully developed. It is not sure if the three stone stove can be applied for the new form of energy production. The change of stoves would implement another investment for the small scale farmers. This modification could also be used as chance to improve the efficiency of the furnaces.

7 Conclusions

The consideration of the eight different scenarios adds up to the result that food and fodder security can be assured by four scenarios. The 3^{rd} land use practice which is the agroforestry one has definitely higher potential to cover the food and fodder demand of the sample small scale farm in semiarid areas. Hence the main goal of the study to guarantee sufficient food is reached by the 5^{th}, 6^{th}, 7^{th} and 8^{th} scenario. The last scenario is far-off the most successful one. Therefore the recommendation following this study is that small scale farms should develop a 100% agroforestry system. The energy production cannot be fulfilled but the oil could serve to decrease the fuelwood consumption. A good alternative could be that the Jatropha and Ricinus oil is used for lightening. The lamps could easily be handmade and as already mentioned the oil has a better specific burn-up than for example kerosene.

That means that the energetic use of *Jatropha curcas* and *Ricinus communis* builds an extra resource in the local energy production. On small scale farms it is not able to displace fuelwood. As seen in the variant 3 of each scenario fuelwood like in this study *Grevillea robusta* could also be planted on small scale farms. The wood yields show high outputs and could serve to reach energy security. This study results in the fact that food security can be reached meanwhile the oil for lightening can be produced. Hence the small scale farmers would be able to produce their lamp oil directly on the farm, which would significate more independency. The fuelwood production necessitates further investigation. It seems that the energy production on the 1,5 ha farm could suffice to reach security. The possible food, fodder and energy security would advance the security of the small scale farmers. This fact explains that further investigations should be engaged in this research field.

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