Sugarcane and agroforestry farming in western Kenya

A comparative study of different farming systems in the Nyando district

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Front-page picture: Rows of sesbania (*Sesbania sesban L.*) intercropped with food crops in an agroforestry system, Kopere, Kenya. Photo: Ida Lindell

Keywords: agroforestry, carbon, farming systems, Kenya, manure, nitrogen, sugarcane

Preface

This Bachelor's dissertation, worth 15 credits (Swedish hp), is the result of a collaboration between the Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU) and the non-governmental organisation Vi Agroforestry. Professor Ingrid Öborn and PhD student Ylva Nyberg supervised the work, which was made possible by a SIDA-funded scholarship, Minor Field Study.

We would like to express our particular thanks to Ylva Nyberg for the great supervision, especially in Kenya, and to Ingrid Öborn for her help during planning and completing the work. We would also like to thank Elijah Errustus Dibogo for his great engagement in finding suitable farmers for the study and his help with local knowledge. Special thanks also to all the farmers and their families for the information they shared with us and their hospitality during our visits. We are grateful to the ICRAF laboratories in Kisumu and Nairobi where the soil analyses were carried out. During our study we met a number of people in the Vi Agroforestry office in Kisumu, in the village of Kopere and members of the WESAME network, whom we would also like to thank for making our visit even more educational and enjoyable.

Abstract

In the past 50 years, the demand for food, fuel, timber, fibre and fresh water has increased in East Africa. Because of this, the high growth rate of the population and the economic dependence on agriculture, large areas in Kenya have been deforested. One way to reconstruct the ecosystem and compensate for the loss of resources is to design farming systems that can help safeguard these demands, *e.g.* agroforestry systems. This study, which was carried out in the West Songhor district, Western Kenya in January-March 2010, compares the impacts on the soil and on the household situation of two different farming systems (sugarcane farming and agroforestry) from an environmental, ecological, social and economic perspective. To investigate these factors, 21 farms were visited for semi-structured interviews and topsoil samples were taken for bulk density determination and carbon and nitrogen analysis. This was followed by in-depth interviews with eight of the farmers, in which a seasonal calendar and field gate nitrogen balance were constructed to obtain information about the situation on the farm during the previous year (2009). In addition, soil pits were dug on these six farms, a soil profile description was carried out and bulk density samples were taken from different horizons. All 21 farms studied were located around the same village, Kopere. The results showed an improvement in soil under agroforestry, as indicated by increased carbon and nitrogen concentrations in the topsoil and decreased bulk density in the agroforestry systems. The agroforestry systems without manure had a significant difference in the carbon and nitrogen concentrations compared to the sugarcane systems. For the household situation, the differences between the two farming systems depended greatly on the utilisation rate of resources generated by these farming systems. The agroforestry system generated many more products, such as firewood, timber, fruits and seedlings, than the sugarcane system. These products helped improve the livelihoods of households practising agroforestry in terms of income distribution throughout the year, but overall income was lower than with the pure sugarcane system. Overall, the most important factor as regards differences between these two farming systems studied proved to be knowledge of how to implement the system and how to utilise and conserve available resources.

Contents

1 Introduction

In the past 50 years, demand for food, fuel, timber, fibre and fresh water has increased in East Africa (Swallow *et al.*, 2009). In the same period, the population in Kenya has grown rapidly, by 2.7% a year (Regeringskansliet, 2010; The World Factbook, 2010). About 45% of the total area in Kenya is agricultural land and 8% is arable land (Nationmaster, 2010). This makes agriculture the main occupation, and the agricultural sector contributes about 21% to Gross Domestic Product (World Factbook, 2010). Because of the increased demands, the high growth rate of the population and the economic dependence on agriculture, large areas in Kenya have been deforested (Vi Agroforestry, 2009) and replaced by major cash crops such as sugarcane, coffee and tea. Tea provides the largest export income after tourism (Nationsencyclopedia, 2010). Smallholder farmers mainly produce crops for domestic use, such as maize, beans, fruits and vegetables (Nationmaster, 2010).

One of the most common cash crops in Kenya is sugarcane, but the sugar industry is not functioning very effectively. There are six different sugar companies, of which only one, West Kenya Sugar, is entirely privately owned. Another, Mumias Sugar, is partly private but the government is still the majority shareholder (Kenya Sugar Board, 2010; Mbendi, 2010). The other four factories are entirely owned by the government. In total, the factories produce between 400,000 and 500,000 tons of sugar every year from their own plantations and from 'outgrowers' (more or less contracted farmers). However, the farmers are usually paid late and get little general information about managing their sugarcane crop.

In the area where this study was made, deforestation had been carried out in some places to make way for cultivation of cash crops, a practice that poses a threat to the ecological systems in the region.

One way to reconstruct the ecosystem after deforestation and to compensate for the loss of resources is to design farming systems that satisfy the increased demands of the population. Agroforestry is an example of a system that increases the supply of *e.g.* fuel, timber and fibre, while at the same time increasing the productivity of the soil. In agroforestry trees and shrubs are planted together with the main crop in an intercropping system, which is beneficial for the crop and also for the household (Lwakuba *et al.*, 2003). This kind of mosaic ecosystem also has qualities as a filter for flows of dissolved particles from mass flows of water, air and even organisms (van Noordwijk *et al.*, 2004). The trees and shrubs in such systems can also provide the main crop with nutrients, since many of the commonly used woody species can biologically fix nitrogen.

Agroforestry systems tend to give a large diversity of products on the farm. Lwakuba *et al.* (2003) showed that a more diverse system improved the productivity of the soil and gave opportunities to sell some excessive products and obtain extra income. Resource-poor households in the region, where most of the production is for domestic use, have little or no savings and thus limited opportunities to spend money on farm inputs, restricting the resources available for crop production (David, 1996).

Sugarcane farming and agroforestry systems have different management practices that also influence the conservation of organic matter in the soil. In the area studied in this project, the sugarcane crop is burned before harvest. This results in more than 70% of the organic matter and nutrients in the sugarcane trash being lost to the atmosphere (Robertson and Thorburn, 2007).

Sugarcane is a very important crop in the area but the farming system generates problems for the farmer in the form of delayed or low payment. To reduce the dependence on unreliable payments from sugar factories and to increase the self-sufficiency of smallholders, there is a need for an alternative to the traditional sugarcane system. This study investigated the suitability of agroforestry systems for that purpose in terms of farm income and environmental sustainability.

1.1 Objectives and hypotheses

The overall objective of this study was to compare sugarcane systems and agroforestry systems, in particular their impact on carbon and nitrogen concentrations in the soil and on social and economic conditions, *e.g.* food security and monetary flows in farming households.

Four different farming systems were examined in this study: two sugarcane systems, one of which was combined with some agroforestry and one which had no agroforestry, and two agroforestry systems, one with manure applied to the fields and one without. The four systems were compared in terms of economic values, production opportunities and nitrogen flows in order to assess their overall sustainability (including ecological, economic and social aspects).

Five starting hypotheses were formulated:

1. Agroforestry affects the soil in a similar way to a perennial crop, *e.g.* sugarcane. The roots increase the carbon content in the soil and help decrease the density of the soil structure. Agroforestry systems that use animal manure have better soil structure and higher carbon content owing to increased amount of organic matter in the manure.

2. Agroforestry systems are able to store more carbon in above and below ground biomass and have higher soil organic matter content than sugarcane systems.

3. Different systems affect the nitrogen content of the soil in different ways. Agroforestry systems, especially with manure application, have higher nitrogen content in the soil since more organic matter is recycled in the systems. Agroforestry systems also have a more balanced flow of nitrogen to fields compared with sugarcane systems, where more nitrogen is exported from the farm in the harvested crop.

4. Agroforestry systems are more time-consuming because of management of the trees in addition to the crops.

5. Different systems affect household finances in different ways. Since agroforestry systems have a wider range of products and a longer harvesting period than sugarcane systems, income is more evenly distributed throughout the year. Agroforestry systems (particularly with manure applied) also improve the food security of households in terms of number of meals per day and food diversity.

The study will be divided into three parts; one part is the literature study, one part will be field work and one part will be laboratory work. The literature study is reported in the following section.

2 Background

2.1 Sugarcane farming

Sugarcane is a perennial crop that is often harvested up to four times, once every 18 months, before re-planting (interviews in Kopere, Kenya, Jan-Feb 2010). Since the canes stay in the field for about five to six years, it is important to prepare the land properly. If the soil is deep-ploughed, crop performance is improved even further. Re-planting is often very expensive compared with regrowth (ratoon) of the crop, so it is important to get satisfactory establishment of the new crop. If managed correctly, the ratoon crop has more tillers than the newly planted crop (Sugarcane crops, 2010).

The sugarcanes are generally burned before harvesting, although it is becoming increasingly common to harvest the canes while they are still green (Proserpine, 2010). This practice is also being introduced in the Muhoroni district (interviews in Kopere, 2010).

The sugarcane crop requires quite a large amount of water, with 1100-1500 mm of rain considered to be the optimal amount provided it comes at the right time. However sugarcanes are sensitive to water-logging and hence they grow best in free-draining soils. The optimum temperature is between 25 and 34 °C, while outside this range the growth rate decreases. During the ripening period, the optimum temperature is between 12 and 14 °C (Sugarcane crops, 2010).

High soil porosity favours germination, which needs good aeration for root respiration. To improve aeration of the roots, the crop can be grown in ridges, which can be re-made two or three times by moving the soil into the row of canes. The associated disturbance of the soil, together with the competition from the canes, also decreases the weed pressure (Sugarcane crops, 2010).

Although sugarcane is a very demanding crop as regards nutrients, it sequesters carbon in the soil. Suman *et al.*, (2009) reported that during a five-year period in the Indian sub-tropics, the amount of carbon in the soil increased by 2.3-17.1 tons ha^{-1} under sugarcane, even though a large biomass yield was removed at every harvest. The majority of the carbon added to the soil originates from the root biomass, which is about 30% of the shoot biomass. The root biomass is estimated to bind 3.7 tons carbon ha^{-1} annually (Suman *et al.*, 2009).

2.2 Agroforestry

2.2.1 Definition

Agroforestry systems are defined in many different ways, but most commonly as land-use systems where woody perennials (*e.g.* trees, shrubs or bushes) are arranged, spatially or temporally, in the same field as agricultural crops. This can be practised both with and without manure applied. The different components in the farming system should interact as regards economic and ecological aspects (Nair, 1993; Sinclair, 1999). Consequently, the term agroforestry does not refer to a fixed arrangement of plants, but a land-use system where the woody perennials can be grown together with the crop or temporally during periods of *e.g.* fallow (Lwakuba *et al.*, 2003).

In the following text the trees and/or shrubs in agroforestry systems are referred to as trees, which thereby include all types of woody perennials included in agroforestry systems.

2.2.2 Practising agroforestry

An agroforestry system can be arranged in many different ways with a number of different components. Different systems are often categorised on the basis of structure (temporal or spatial arrangement), function (*e.g.* windbreak, soil fertility, and soil conservation), socioeconomics (management and commercial objective) and ecology (environmental conditions and ecological sustainability) (Nair, 1993).

How the trees and crops are arranged depends on the conditions in the area and the intended outcome of the system (Figure 1). In hilly landscapes the trees can be arranged in hedgerows along the contours, which slows down the speed of rainwater runoff and thereby increases infiltration and decreases soil erosion. In this type of landscape the trees can also be used to stabilise terraces. In flat areas the trees can be arranged in rows, around the fields or within a temporal arrangement in fallow systems (Nair, 1993; Lwakuba *et al.*, 2003). Walker *et al.* (2008) showed in a model that the effectiveness of an agroforestry system to a large extent depends on the design of the system practised. They also showed that to maximise the gains of such systems, the design has to be adapted to environmental factors such as access to water and nutrients.

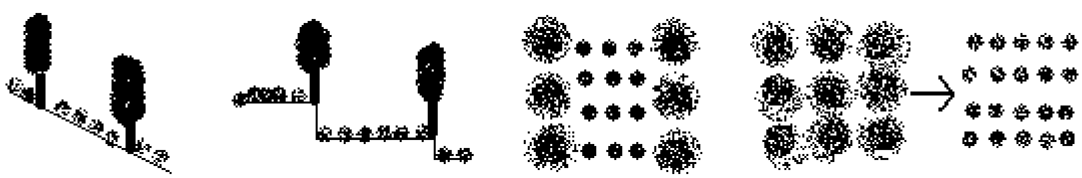

Figure 1. Examples of different arrangements of trees and crops in agroforestry systems.

2.2.1 Tree species

A large number of tree species with different qualities can be used in agroforestry systems. When designing an agroforestry system it is important to consider what purpose the trees should serve and what crops should be grown together with the trees. Some tree species can host diseases and pests that might also affect certain crops, so the system must be designed with this in mind (Lwakuba *et al.*, 2003). Three commonly used intercropped tree species in Western Kenya according to Nyberg (pers. comm., 2010) are described below.

Sesbania *(Sesbania sesban L.)*

Sesbania is a nitrogen-fixing tree that can be used for firewood, construction, fodder and for soil conservation. However, it should not be grown in the same field as crops sensitive to nematodes, such as bananas or potatoes (Maundu and Tengnäs, 2005). Sesbania can store 10.1 ton C ha^{-1} above and below ground in a 12-month old fallow and 23.5 ton C ha^{-1} in a 22-month old fallow (Verchot *et al.*, 2007). The density of sesbania is 500 kg m^{-3} (World Agroforestry Centre, 2010).

Tithonia *(Tithonia diversifolia L.)*
Tithonia is a shrub used for example as fodder, medicine and a soil improver. Since the leaves contain high amounts of nutrients, such as phosphorus, they can be applied to the soil as green manure. This treatment can double crop yield (Maundu and Tengnäs, 2005).

Yellow oleander *(Thevetia peruviana L.)*
Yellow oleander prefers sandy soils but can tolerate most conditions. All parts of the tree are poisonous and can therefore not be used as fodder, although the seeds can be used as medicine. It is commonly used as hedges, i.e. as live fencing (Maundu and Tengnäs, 2005).

2.2.2 Interactions in agroforestry systems

The interactions between the trees and crops in an agroforestry system can have both positive and negative impacts on the growth of the plants in the system (Figure 2). The benefits from the intercropping include conservation of soil and moisture, improved soil fertility because of nutrient recycling, nitrogen supply, reduction of weeds and pests and improved microclimate (van Noordwijk *et al.*, 2000; Lwakuba *et al.*, 2003). If the interactions between the crops and trees can improve the amount of nitrogen and organic matter in the soil, this might increase the productivity of the soil, since these are factors that commonly limit agricultural production in East Africa (Vi Agroforestry, 2010).

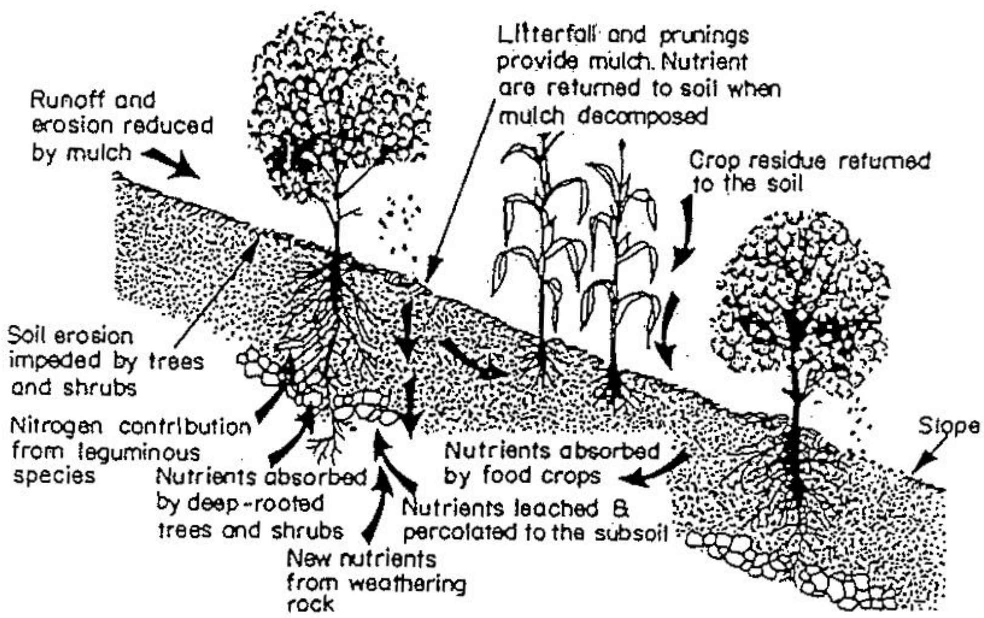

Figure 2. Positive interactions in an agroforestry system. Source: Nair *et al.* (2003).

There are also negative interactions, since the trees shade the crops and the roots compete for the same resources of water and nutrients (van Noordwijk *et al.*, 2000; Lwakuba *et al.*, 2003) (Figure 3). For example, the soil fertility effect from certain species of trees or shrubs on maize is positive, while the competition effect has a negative impact on the crop (van Noordwijk *et al.*, 2000; Seleshi *et al.*, 2008). Rao *et al.* (1998) determined that the overall relationship between crops and trees in an agroforestry system depends on how the different components in the system compete for resources from different parts of the ecosystem, the efficiency of nutrient recycling in the system and the relationship between the crop products that could be produced with the resources used by the trees. Choice of species, spacing and management of the system are some of the most important factors in maximising the positive interactions and minimising the negative.

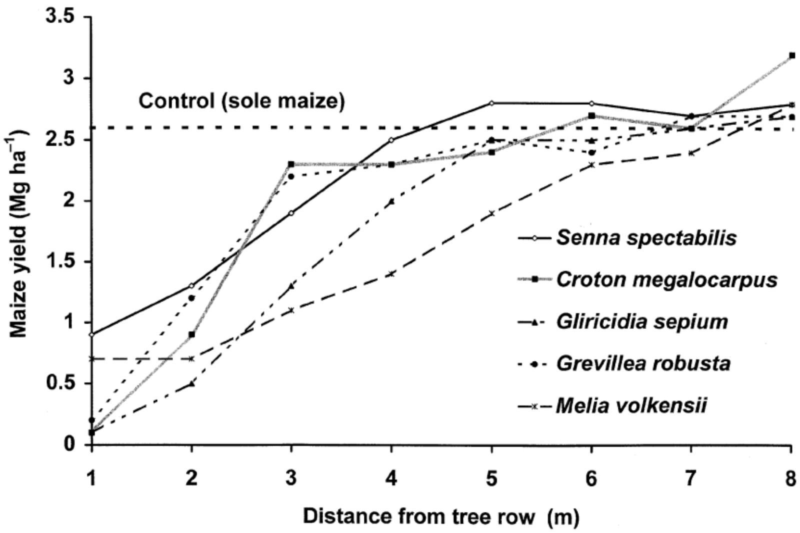

Figure 3. Relationship between yield and distance from hedgerows of trees. Source: Rao *et al.* (1998).

Nutrients

The trees used in these kinds of systems are often symbionts with nitrogen-fixing bacteria and can thereby increase the amount of nitrogen available for the trees and crops. *Sesbania sesban* can fix 100-250 kg N ha^{-1} $year^{-1}$ (Pye-Smith, 2008), while *Leucaena leucocephala*, another common species in agroforestry systems, can fix 100-500 kg N ha^{-1} $year^{-1}$ (Gachene and Gathiru, 2003). These species can substantially increase the fertility of the soil in two to three years (Ong, 1996).

The intercropping system means that the roots have to compete for nutrients and other resources in the soil (Lwakuba *et al.*, 2003). However, some researchers claim that since most of the trees and shrubs used in these systems have deep roots, they use nutrients that the crop would not be able to assimilate in any case. The effect of this is that the trees or shrubs transport nutrients up from deeper layers in the soil and after leaf decomposition these nutrients are made available to crops with shallower root systems (Nair, 1993; van Noordwijk *et al.*, 2000). The deeper roots can also act as a network where nutrients that leach down to deeper layers can be absorbed (van Noordwijk *et al.*, 2000).

Soil and water

The trees and shrubs in an agroforestry system increase the amount of organic matter in the soil, partly from decomposed old roots but mainly from leaf litter. This litter results in an increased amount of organic matter, nutrients and mulch being added to the soil (Gachene and Gathiru, 2003). If the litter has a low C/N ratio is rapidly decomposed and increases the nutrient levels in the soil. If the quality of the litter is lower, with high C/N ratio, the decomposition process is much slower (van Noordwijk *et al.*, 2000). The mulch prevents the soil from drying out and supports the soil organisms. With a high amount of mulch, the soil also has a lower bulk density and thereby higher porosity and hydraulic conductivity (Eriksson *et al.*, 2005).

A study by Ong (1996) showed that an agroforestry system is more efficient in terms of using the available soil moisture than annual crops alone, as the mulch and the deep tree roots reduce evaporation and thereby conserve the humidity in the soil. However, the same study showed that high tree density in agroforestry systems may not be sustainable in terms of water availability, since the evapotranspiration may exceed the rainfall.

Van Noordwijk *et al.* (2000) showed that shading by trees reduces the intensity of incoming light available to the other crop. This helps conserve the moisture in the soil, but also reduces the rate of photosynthesis because of the lower radiation.

Trees or shrubs as intercrops are beneficial for conservation of the soil, *e.g.* they reduce soil erosion and increase the humidity (Ong, 1996). The trend in modern agriculture is to simplify and specialise production on the farm, which often brings a less diverse cropping system (Vandermeer *et al.*, 1998). This factor, combined with large herds of grazing animals (Hoang Fagerström *et al.*, 2005), makes the land very susceptible to soil erosion, since there are few plants and roots to stabilise the soil (Vi Agroforestry *et al.*, 2009). Soil erosion decreases the soil fertility since the fertile topsoil layer is blown or flushed away (World Agroforestry Center, 2010). This degradation of soil is severe to very severe in western parts of Kenya, according to FAO (2010a). One way of dealing with soil erosion is to replant trees (Lwakuba *et al.*, 2003; Hoang Fagerström *et al.*, 2005) in order to restore some of the ecosystem. Soil erosion is reduced when trees are planted in hedgerows since these slow down the surface flow of water. The effects of raindrop impact are also reduced, since the mulch from the trees decreases splash and sheet erosion by raindrops. Wind erosion may also be decreased as an effect of planting trees as an intercrop (Ong, 1996; Hoang Fagerström *et al.*, 2005).

Pests and weeds

An agroforestry system is a more diverse system that can host a larger amount of species than a monoculture. This makes the system favourable for pests and weeds, while it can also include more species with inhibiting qualities. Thus, the interaction between the trees and shrubs and the crop can be either positive or negative when it comes to pests and weeds (Lwakuba *et al.*, 2003; Noordwijk *et al.*, 2000).

The trees and shrubs may also provide shelter for birds, which can be beneficial in catching pest insects. However, the birds can also be a problem, *e.g.* grain losses may increase when birds shelter near crop fields (Lwakuba *et al.*, 2003).

According to Rao *et al.* (1998) and Lwakuba *et al.* (2003), another problem may arise when the agroforestry species themselves turn into weeds by uncontrolled spread. This problem is most likely to occur when profusely seeding tree species are used (Rao *et al.*, 1998).

Rao *et al.* (1998) noted that the major effect from trees grown in hedgerows in an agroforestry system compared with an annual system is the reduction in weeds. They concluded that this reduction in weeds probably depends on increased amounts of mulch from the tree litter, shading and competition with weeds for growth resources and potential allelopathy from the tree species. However, all these factors depend on the tree species and how frequently the hedgerows occur in the fields. Less space between the hedgerows suppresses the weeds more efficiently, but too little space leads to decreased yield. According to Rao *et al.* (1998), the primary objective should always be improvement of yield.

Economic, health and food situation
Trees as an intercrop may play a large role in a farming system with low income, since 10-25% of the household income can come from the trees and shrubs (Hoang Fagerström *et al.*, 2005). Additional products generated by the trees and shrubs are *e.g.* firewood, timber, fodder, fruits, medicines and seedlings (*e.g.* Lwakuba *et al.*, 2003; Hoang Fagerström *et al.*, 2005). Hoang Fagerström *et al.* (2005) concluded that agroforestry systems that provide the household with products for sale and consumption are the most promising tree-based systems in terms of food security.

David (1996) reports that the incomes of smallholder farmers are largely dependent on the seasons and the seasonal cycles in the farming system. During periods when the store is empty and no crops are ready for harvest, cash-flow is low and does not rise again until after harvest, when food products are available both for marketing and household consumption. Trees are important in a farming system regarding financial returns in a longer time perspective compared with food crops, while they also give more secure productivity compared with food crops, which have very fluctuating yields. Trees can also be cut irrespective of season, making it easier to meet urgent expenses (David, 1996).

A more diverse farming system will not only diversify the sources of incomes but also improve the nutritional situation for the household (Shelemew, 2005). There are two major ways of improving the food and nutrition situation through agroforestry: increased availability of vegetables and fruits produced from the trees; and improved yields of food crops as a result of organic matter or manure from trees or from animals fed products from the trees (Babu and Rhoe, 2002) (Figure 4).

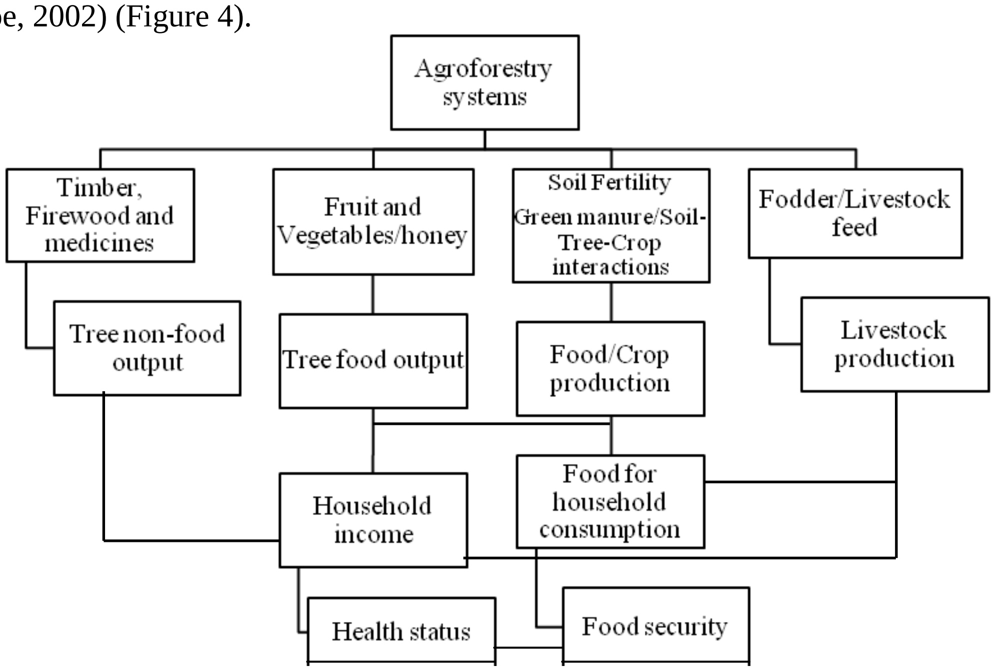

Figure 4. Links between agroforestry and food security and health status. Sources: Babu and Rhoe (2002), Pye-Smith (2008).

Better food security and improved income also give rise to a better health situation, owing both to improved nutrition and to the higher income making it possible to access healthcare (Babu and Rhoe, 2002; Pye-Smith, 2008) (Figure 4).

2.2.3 Agroforestry systems and climate fluctuations

Climate fluctuations indirectly affect soil conditions, such as infiltration, erosion control and nutrient availability, because of changes in precipitation (Verchot *et al.*, 2007).

Agriculture plays a large role in emissions of greenhouse gases and hence as a contributor to climate change. A number of farming practices can also contribute to a reduction in the amount of carbon dioxide in the atmosphere and store it in long-term pools, *e.g.* trees in agroforestry systems (Verchot *et al.*, 2007; Nair *et al.*, 2009). Agroforestry systems have higher potential to store carbon in aboveground and belowground biomass than pasture or field crops (Nair *et al.*, 2009). Agroforestry can contain a total of up to 50-75 ton C ha^{-1}, while row crop systems only contain <10 ton C ha^{-1}. The benefit of agroforestry as a carbon dioxide sink is mainly because of the high carbon density, although the benefit becomes even greater since the system is suitable for large areas of land. However, an agroforestry system may have a negative impact in terms of some greenhouse gases, since emissions of nitrogen oxides from nitrogen-fixing trees are about ten times higher than those from a system with unfertilised maize (Verchot *et al.*, 2007). The nitrogen oxide emissions from fertilised maize are estimated to represent 0.08-0.44% of the nitrogen applied (Watanabe *et al.*, 2000). However, according to Verchot *et al.* (2007), the nitrogen oxide emissions from agroforestry are very low compared with the carbon that the system can store.

Albrecht and Kandji (2003) described some problems in determining the exact value of the sequestered carbon in agroforestry systems. If a hedge is planted around a field, the trees can contribute to the field by litter but the actual carbon sequestered is rather low because of the small area covered. Rao *et al.* (1998) found that boundary plantings have an effect extending about 10 m on each side of the hedge. Therefore the density of the trees is important.

Agriculture in general is very exposed to climate fluctuations, since many enterprises are greatly dependent on the climate (Verchot *et al.*, 2007). There is currently a trend for more specialised farming systems (Vandermeer *et al.*, 1998). For smallholder farms in the tropics, mainly dependent on subsistence agriculture, this means a more vulnerable situation to climate change. This is because the resources are few, which makes adaptation to change even harder. Agroforestry is one possible way of decreasing farmers' vulnerability to climate fluctuations, since such systems can help improve the nutrient status and water balance in the soil compared with a system with only cereals (Verchot *et al.*, 2007).

3 Materials and methods

3.1 Study area

This study was carried out between January and March 2010 in the area of west Songhor, Nyando district, in a village called Kopere (altitude: about 1260 m above sea level), located 50 km east of Kisumu (00°03'S, 35°08'E; Figure 5). The village is situated in a valley containing the Nyando river. The main village is located on the valley slope and is bisected by the main road connecting Awasi with Eldoret. This road also separates the more sloping land from the flatter land in the valley base.

Figure 5. Map of Kisumu, Kenya, located on the shores of Lake Victoria (Kenya Travel Guide, 2010; The World Atlas, 2010; Google maps, 2010).

Climate data for Kisumu were used in this study (Figure 6). Kisumu is located 1 146 m above sea level by Lake Victoria in western Kenya. There are two rainy seasons in the area, one heavy in March to May and one lighter in November and December. The mean monthly temperature is in the range 17-29 °C but the minimum and maximum temperature can vary from 12 to 37 °C (BBC, 2010) (Figure 6).

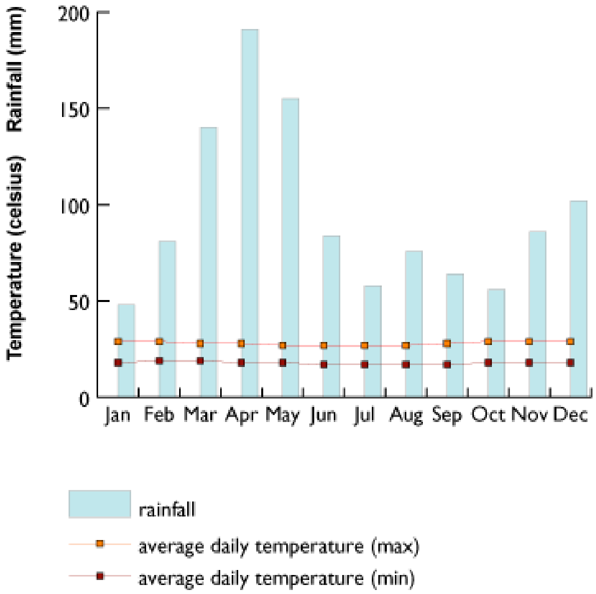

Figure 6. Precipitation and average temperature in Kisumu (BBC, 2010).

Kopere is located in one of three sugar belts in Kenya and is about 10 km from the Chemilil sugar factory (Kenya Sugar Board, 2010; Mbendi, 2010). Tradition and proximity to the sugar factory have made most of the farmers dependent on sugarcane farming.

3.1.1 Vi Agroforestry and WESAME

Vi Agroforestry is a non-governmental organisation founded in Sweden in 1983. The aim of the organisation is to increase the number of trees and improve the situation for small-scale farmers in the Lake Victoria basin. The organisation works with spreading knowledge about agroforestry and diversified farming systems that are adapted to the market situation. The capacity building is done through employing field advisors connected to local farmers' organisations (Vi-skogen, 2010).

One of the areas where Vi Agroforestry is working is West Songhor. This area has long been dependent on sugarcane farming because of its proximity to Chemelil Sugar Company. To diversify the farming systems and the incomes of farmers in the area, the farmers' organisation West Songhor Area Marketing Enterprise (WESAME) was founded in 2007 after capacity building by Vi Agroforestry. WESAME introduced agroforestry as a farming system to make the farmers less dependent on sugarcane and to allow them to market their produce to a larger range of customers (interviews in Kopere, Kenya, Jan-Feb 2010). Vi Agroforestry contributes knowledge to the members of the group via a field officer, but much of the work is done by the group members themselves.

WESAME is also collaborating with the Kenya National Federation of Agricultural Producers (KENFAP), which makes it possible to sell some of their excess produce in bulk through this channel (KENFAP, 2010),. This collaboration improves the possibility of getting a good price for the products (interviews in Kopere, Kenya, Jan-Feb 2010).

3.2 Field work

The main techniques used in the field work were interviews and soil sampling as tools for a comparison between the farming systems. The interviews were intended to provide social and economic information on the households. This was combined with carbon, nitrogen and bulk density analysis of the soil to examine the impact on the soil of the different systems. The approach thus integrated ecological and socio-economic aspects to get a broader picture of the effects from the different systems.

The farmers included in the study were selected after discussions with WESAME. Twenty-one farms were selected and grouped into four systems. Three of the groups were connected to WESAME and were practising agroforestry (Table 1). However these three groups differed in type of cash crops grown and in intensity of the agroforestry system. The first group (1) had agroforestry and used manure (8 farmers), the second group (2) had agroforestry but without manure (4 farmers) and the third group (3) relied mainly on sugarcane but had also some fields where agroforestry was practised (6 farmers). The farmers in the fourth group (4) were not connected to WESAME and had no agroforestry (5 farmers) and they are referred to here as ‘Sugarcane-non agroforestry’. All farmers, irrespective of farming system, had some vegetables and food crops for household use. In order to get as similar conditions as possible regarding soil, climate and social aspects, all the farmers selected were within walking distance of Kopere. However, the varying landscape in the valley made the soil and water conditions on the farms quite dissimilar.

In the beginning of the study, five farmers from each system were selected, but after the field work and observations made during this work, there were some changes between the groups in order to gather the farmers into more accurate groups (Table 1).

One of the farmers (Farmer 4) without animals also had agroforestry with manure on some fields and sugarcane farming on some other fields, and hence three systems could be sampled on the same farm where all the fields were maintained with the same basic conditions.

Table 1. Composition of farms with forms of agroforestry (AF) and sugarcane (SC) included in the study. A semi-structured interview was held on each farm, and the rest of the information was collected as indicated in the table. For all systems except Sugarcane-non agroforestry (SC-non AF), soil samples for elemental analysis and bulk density were taken in the topsoil. Farm 4 had all systems except SC-non AF and was therefore sampled three times, on one field per system

	Farm acreage (ha)	AF with manure (1)	AF without manure (2)	SC (3)	SC-non AF (4)	Interviews	Soil samples (0-15 cm)	Seasonal calendar	Field gate nutrient balance	Soil profile pit
Farmer 1	2.0	*				*	*	*	*	*
Farmer 2	4.9	*				*	*			
Farmer 3	0.6	*				*	*			
Farmer 4	4.9	*	*	*		*	*	*	***	***
Farmer 5	1.6	*				*	*			
Farmer 6	2.0	*				*	*			
Farmer 7	2.0	*				*	*			
Farmer 8	1.2	*				*	*			
Farmer 9	0.8		*			*	*			
Farmer 10	0.4		*			*	*	*	*	*
Farmer 11	0.8		*			*	*	*	*	*
Farmer 12	1.6			*		*	*			
Farmer 13	11.7			*		*	*	*	*	*
Farmer 14	5.1			*		*	*			
Farmer 15	0.8			*		*	*			
Farmer 16	3.2			*		*	*	*	*	*
Farmer 17	4.9				*	*				
Farmer 18	3.2				*	*		*		
Farmer 19	4.0				*	*				
Farmer 20	2.0				*	*		*		
Farmer 21	4.8				*	*				

Most of the farmers in the village spoke English, but local interpreters were present during all interviews in case of need.

3.2.1 Interviews

The field work was carried out as two types of interviews and two sessions of soil sampling. Both types of interviews were held with one of the people responsible for the farm and were carried out by two persons (the authors), one interviewing and one taking notes. The first type of interview was carried out with all farmers, using a semi-structured interview technique (FAO, 2010b). Information about general life on the farms was gathered using a questionnaire (Appendix I). The interview questions were built on the sustainable livelihood framework system including *e.g.* social, natural and financial capital (IFAD, 2009). Information about how to perform the interviews was taken from Mikkelsen (2005).

For the second type of interview, two farmers from each of the four systems were revisited for more detailed data collection using a seasonal calendar (Table 1; Appendix II). For the farmers connected to WESAME (six farmers) a field gate nitrogen balance was also drawn up (Table 1; Appendix III). Both these methods are examples of participatory rural appraisal (PRA) tools (Chambers, 1994a), which are based on local knowledge as well as information from outside the community (Chambers, 1994b). In the seasonal calendar the farmers described the practices on the farm for each month in 2009 within 14 different categories. For the field gate nutrient balance they had to declare the flows of products to and from one field of their farm. The same field was also included in the soil analyses. The answers from the field gate nutrient balance were used to calculate the nitrogen flows to and from the field.

For the seasonal calendar, food security and workload were graded on a scale from 1 to 5. For the food situation, 1 to 3 indicates the number of meals eaten per day and 4 and 5 the diversity of these meals. The workload was graded on the same scale, where the numbers represent the amount of time spent on the farm and the heaviness of the work.

3.2.2 Soil and manure sampling

Soil sampling was carried out in two steps. First, topsoil samples (0-15 cm) were taken for chemical analyses. Between 12-20 sub-samples was taken across the field (Figure 7), using a small spade, and mixed to a composite sample of about one litre. The number of sub-samples depended on the size of the field. In addition, two samples for bulk density determination were taken in the topsoil at two different locations in the same field using metal cylinders (279 cm^3). On the farms which were revisited, soil profile pits (approximately 1 m deep) were dug and the pedogenic horizons were identified. Within the profile pit, samples for bulk density were taken in all horizons. The depth of sampling on the different farms varied, since sampling followed the pedogenic horizons (Appendix IV).

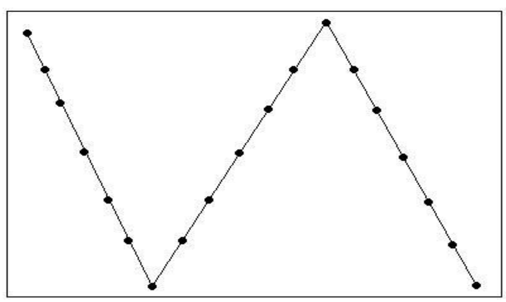

Figure 7. Schedule used for topsoil sampling (0-15 cm) for carbon and nitrogen elemental analysis. Each dot represents one sub-sample and the square represents the sampled field.

In addition to the soil sampling, five samples of manure and compost and three samples of plant species often used as organic fertiliser were collected. The plants commonly used by the interviewed farmers were Sesbania, Thevetia and Tithonia.

When calculating the flows of nitrogen inputs of seeds, fertiliser and organic fertiliser were used and the outputs were based on the harvest. In order to calculate the nitrogen balance, the following assumptions were made. The fertilisers were calculated from the diammonium phosphate (DAP) values except for the second sugarcane, farm 13, where half the amount of fertiliser was applied as urea. The nitrogen content in organic fertiliser was taken as the mean of the five organic fertilisers analysed. For the crops and seeds, the nitrogen concentration of maize and sweet potatoes was estimated based on literature data on the protein content (Livsmedelssverige, 2010). A protein index produced by the Swedish Food Administration

(Livsmedelsverket, 2010) was used for the agroforestry systems, while information on the sugarcane crop was taken from Mutuo *et al.* (2005).

In order to calculate the carbon stock in the trees, the height and circumference at chest height were measured and the number of trees was counted. Tree volume was then calculated assuming that trees were cylindrical (Wekesa, pers. comm., 2010). The volume values obtained were converted into weight using a density value for each tree species obtained from the world wood density database (World Agroforestry Center, 2010). Since density data were not available for some tree species, values for similar species or mean values were used. Thus *Sesbania sesban* was estimated to have the same density as *Sesbania rostrata*, while for *Carica papaya* and *Oleum ricini* an estimated value for density was used. The carbon content of trees was then estimated to be 50% of the weight (Kürsten and Burschel, 1993). The total carbon per hectare in the field was calculated using the carbon content of the boundary trees and trees within the field.

To calculate the carbon stock in the trees, an belowground:aboveground ratio of 0.29 for a 22-month fallow was used (Table 2), which is the value for *Sesbania sesban* (Boye, 2000). The *Sesbania sesban* value was used because this is the most common agroforestry tree in the study area. In the fields with hedges, a mean of tree radius was estimated after measurements on 10-15 trees.

The number of trees per metre hedge was estimated to be 12 on all farms, and then the total carbon per metre was calculated using the mean height and the stem volume per metre. The total carbon sequestered in aboveground tree parts was then multiplied by 1.29 (Table 2) to give the total aboveground and belowground carbon.

Table 2. Relationship between biomass fractions for different tree species and ages. Source Boye (2000)

Fallow tree	Above-ground (Mg ha^{-1})	Below-ground (Mg ha^{-1})	Root/Stem
12-month-old fallow			
Sesbania sesban	14.2	7.3	0.51
22-month-old fallow			
Sesbania sesban	36.9	10.8	0.29
Grevillea robusta	32.6	17.7	0.54

3.3 Laboratory work

The topsoil samples were analysed for carbon and nitrogen and the C/N ratio was calculated. As well as these parameters, the bulk density was measured for the topsoil (2 samples per farm) and for each horizon in the profile pits. These measurements were carried out at the ICRAF laboratory in Kisumu, where the samples were dried at 105 °C for 48 hours before weighing. All other analyses were carried out at the ICRAF laboratory in Nairobi.

For the analysis of nitrogen and carbon in the topsoil, the samples were air-dried for one to two weeks, ground and sieved using a 2 mm sieve (fine soil). The fine soil (<2 mm) was analysed by near infrared (NIR) spectrophotometry (Shepherd and Walsh, 2003) and mid-infrared (MIR) spectrophotometry (Weullow, pers. comm., 2010). The compost was treated in the same way as the topsoil samples, while the plant samples were dried at 60 °C for two days before being ground into max. 0.5 mm particles. The carbon and nitrogen concentrations were determined by elemental analyser (EA1112), which gasified 20 mg portions of soil samples placed in small foil containers and measured the thermo-conductivity with a TCD detector. The chemicals used in the quartz tube of the machine were reduced copper, which absorbs oxygen, and silver-cobalt oxide and chrome oxide, which absorb halogens. These chemicals make it possible to get a clean reading for the sample. The carbon and nitrogen values obtained were then used to calculate the C/N-ratio.

For analysing the data collected above, the statistical programs R (2010) and Minitab (2010) was used for box-plots, analyses of variance and significance tests ($P<0.05$).

4 Results

4.1 Farming systems

When they could afford to, farmers with agroforestry systems reported that they bought commercial fertiliser. A rather large proportion of the farmland was used to grow food crops, which were consumed in the household or sold at the market, although some of the farmers in this group also had some land with sugarcane.

The farmers in the sugarcane group reported that they mainly grew sugarcane, but in addition to this they had gained some knowledge of agroforestry, which they practised on some of their land where food crops were grown. The food crops were mainly for the household, but on some of the farms the excess was sold at the local market.

The farmers who had sugarcane-non agroforestry mainly relied on the sugarcane crop for their incomes. Those farmers also had some land for food crops, but in general they bought more food than farmers with the other three systems.

4.2 Soil

4.2.1 Farmers' perceptions

The interviews revealed that ten out of 16 farmers (63%) had noticed an improvement in the soil since they started with agroforestry (Table 1). Of these ten, four reported a larger improvement close to the agroforestry trees in terms of softer and darker soil and higher yields. According to the interviewees, these features are associated with *e.g.* more organic matter from trees, manure and household waste applied to the fields, more frequent tillage and knowledge about how to use trees in the farming system.

4.2.2 Soil carbon and nitrogen concentration

The results from the carbon and nitrogen analyses of the topsoil are shown in Figure 8 and Figure 9 and presented in Appendix V. For both carbon and nitrogen, the samples from the sugarcane systems seemed to have more constant levels compared with those from the agroforestry systems, where the variation between individual soil samples was greater (give range of values). According to the analyses, the concentrations of carbon and nitrogen were significantly ($p<0.05$) higher in the agroforestry system without application of manure (median: 1.81% C, 1.12% N) and than in the sugarcane system (median: 1.21% C, 0.08% N). The agroforestry systems with manure did not differ significantly from those without.

Calculation of the C/N ratio for the different systems revealed a tendency for the sugarcane systems to have a less variable C/N ratio between fields than the agroforestry systems (median: 15.73 compared with 13.93 and 15.29). There was a tendency for higher C/N ratio in the sugarcane systems (15.73) than in the agroforestry system without manure (15.29), but the differences were not significant (Figure 10; Appendix V).

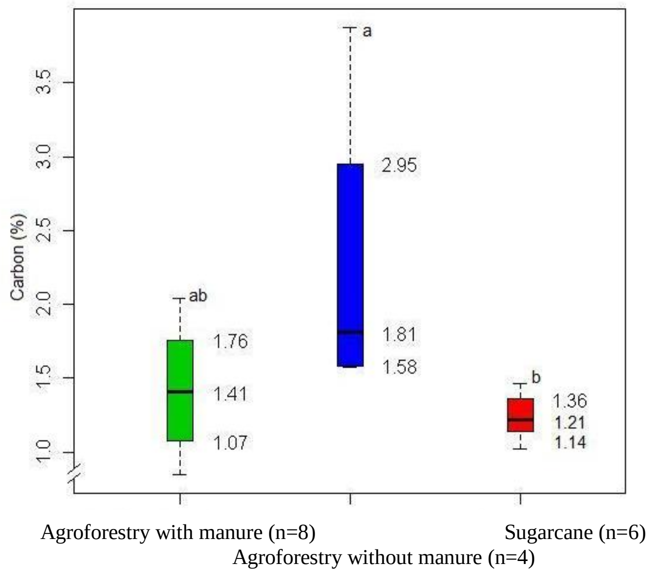

Figure 8. Carbon concentration (weight-%) in the topsoil, measured by elemental analysis, in the systems: Agroforestry with manure (green), Agroforestry without manure (blue) and Sugarcane (red). Different letters above the bars indicate a significant difference ($p<0.05$) between the systems. The extreme values are defined by the end of the bars and the edges of the box represent the quartiles. The line within the box defines the median value.

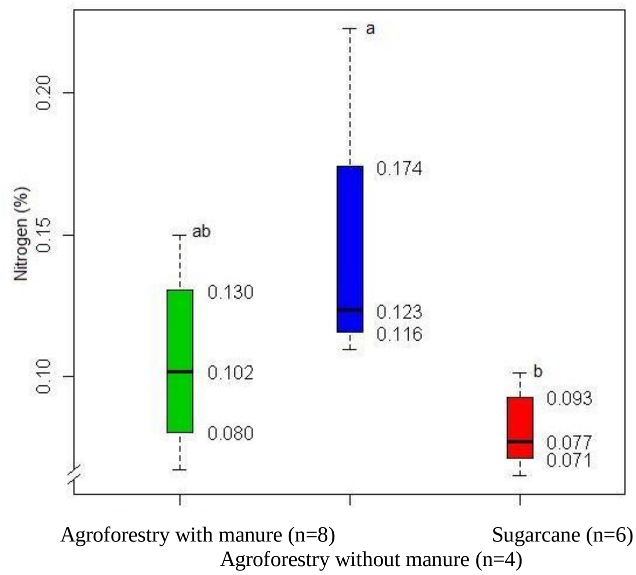

Figure 9. Nitrogen concentration (weight-%) in the topsoil, measured by elemental analysis, in the systems: Agroforestry with manure (green), Agroforestry without manure (blue) and Sugarcane (red). Different letters above the bars indicate a significant difference ($p<0.05$) between the systems. The extreme values are defined by the end of the bars and the edges of the box represent the quartiles. The line within the box defines the median value.

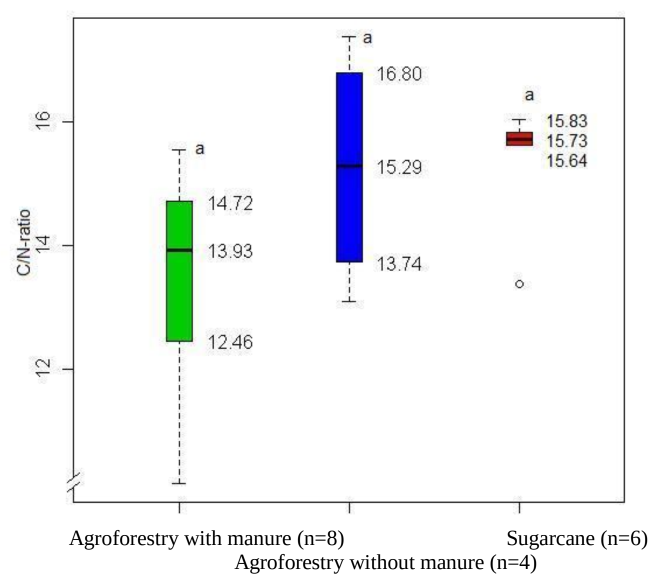

Figure 10. Carbon/nitrogen ratio in the topsoil in the systems: Agroforestry with manure (green), Agroforestry without manure (blue) and Sugarcane (red). There were no significant differences between the systems ($p>0.05$). The extreme values are defined by the end of the bars and the edges of the box represent the quartiles. The line within the box defines the median value.

The analyses of organic fertilisers (compost and green manure) showed that the plant residues used as green manure had higher concentrations of both carbon and nitrogen than the composts (Table 3). In *Sesbania sesban*, the nitrogen content was particularly high (4.35%) and therefore the C/N ratio was lower (10) than for the other plants (mean: 17.5).

The two composts including household waste had lower concentrations of both nitrogen (0.15% and 0.19%) and carbon (2.9% and 2.2%), but the one containing ash had a higher carbon content than the one without, giving a higher C/N ratio (19 compared to 11). Furthermore, the undisturbed (not turned during the time of decomposition) cow dung had a higher concentration of the two elements compared with the manure from other ruminants but the decomposition rate of the two components was rather similar, and therefore the C/N ratio (12 and 13 respectively) was similar to that of the other composts analysed in this study.

Table 3. Percentage of carbon and nitrogen in five different composts and three different plant materials. The term 'material' indicates the main component of the composts. Results from elemental analysis of dry matter. One sample per material.

Material	%N	%C	C/N
Cow dung	0.54	6.7	12
Cow dung (undisturbed)	1.29	16.5	13
Animal manure	0.47	5.9	13
Chicken dropping	0.19	2.2	11
Household waste	0.15	2.9	19
Thevetia peruviana	2.14	42.2	20
Tithonia diversifolia	2.91	42.4	15
Sesbania sesban	4.35	45.4	10

4.2.3 Bulk density

The bulk density measurements for the topsoil showed that the agroforestry systems, both with and without manure applied, tended to have a lower bulk density (0.91-0.93 g/cm^3) than the sugarcane systems (0.98 g/cm^3), however there was no significant differences (Figure 11).

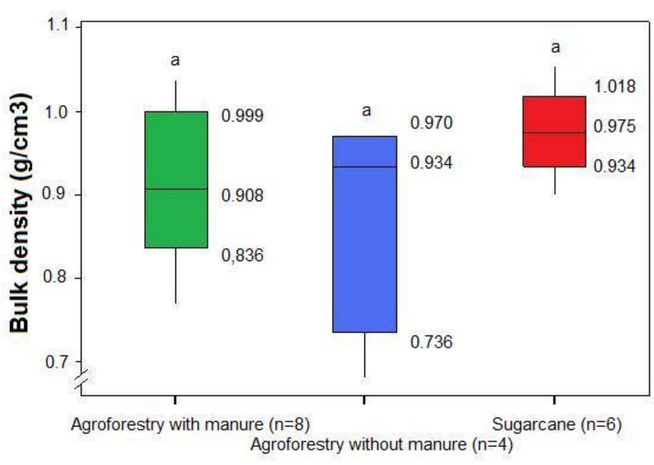

Figure 11. Bulk density in the topsoil (0-15 cm) for the systems: Agroforestry with manure (green), Agroforestry without manure (blue) and Sugarcane (red). There were no significant differences between the systems (p>0.05). The extreme values are defined by the end of the bars and the edges of the box represent the quartiles. The line within the box defines the median value.

The bulk density measurements for the samples from different horizons in the soil profile showed no differences or trends between the systems. However, measurements of the depth of the different horizons indicated that the topsoil layer was deeper in the sugarcane systems (mean: 41 cm) than in the other systems (mean: 32 cm) (Appendix IV).

The data on bulk density and carbon concentration in the soil were used to calculate the carbon content per hectare in the topsoil. The depth of the topsoil was assumed to be the sampling depth (0-15 cm) in these calculations (Figure 12). These calculations resulted in median carbon content for Agroforesty with manure 19.60 ton/ha, for Agroforestry without manure 24.62 ton/ha and for Sugarcane 17.76 ton/ha. It should however be noted that some of the fields in the agroforestry systems has been cultivated prior to soil sampling.

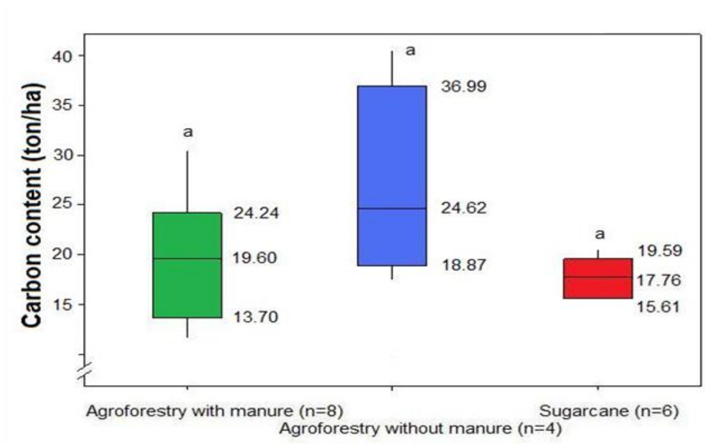

Figure 12. Carbon content (ton/ha) in the topsoil (0-15 cm) for the systems: Agroforestry with manure (green), Agroforestry without manure (blue) and Sugarcane (red). There were no significant differences between the systems ($p>0.05$). The extreme values are defined by the end of the bars and the edges of the box represent the quartiles. The line within the box define the median value.

4.2.4 Water and erosion

All the farmers included in the study reported a problem with erosion, which can be related to the topography in the area in which the farms are located. However, 12 of the 16 farmers with agroforestry systems stated that this problem had decreased since they changed their farming system to agroforestry. The reasons mentioned for the reduction in erosion were knowledge about planting along the contours and how to make ditches and using trees and shrubs in hedges to slow down the water flow. Out of the five respondents without agroforestry systems who were not connected to Vi Agroforestry, two reported major problems with erosion.

Of the 11 respondents with mainly agroforestry systems, nine reported that water infiltrates quite easily into the soil and thereby the surface runoff is quite small. Six of the nine have noticed an improvement in how the soil absorbs water since they started to apply the new knowledge. They have also noticed that the soil seems to conserve moisture for a longer period after the rains with the new farming practices.

4.3 Environmental aspects

4.3.1 Nitrogen flows and balances

According to the field gate balances made during the study (Table 4), the biomass removed from the different farming systems was higher in the sugarcane systems (range: 110-226 kg N/ha)) compared with the systems where agroforestry is practised (range: 1.1-12.5 kg N/ha). In addition to the inputs shown in Table 4, all the farmers included in the study left some of the crop residues from harvest in the fields. However, the amount of residues from sugarcane was much less than that from other crops, since the sugarcane crop was burned before harvest. In most cases the nitrogen balance was negative, with the highest losses in the sugarcane systems (-42.7 to -184.9 kg N/ha).

Table 4. Nitrogen flows at field level in the different farming systems based on interviews and standard values of nitrogen concentration in different materials included in the calculations. One of the Agroforestry without manure fields is omitted due to lack of data.

Farming system	Farm no	Inputs			Outputs	Input-Output
		Mineral fertiliser (kg N/ha)	Organic fertiliser (kg N/ha)	Seeds (kg N/ha)	Harvest (kg N/ha)	(kgN/ha)
Agroforestry with manure	1	-	93*	0.3	4.9	88.4
Agroforestry with manure	4	-	0.9*	0.1	2.9	-1.9
Agroforestry without manure	4	-	*	1.1	12.5	-11.4
Agroforestry without manure	11	14.8	*	1.1	1.1	14.8
Sugarcane	4	41			121	-80
Sugarcane	13	67.3			110	-42.7
Sugarcane	16	38.5	2.6		226	-184.9

*Leaves from nitrogen-fixing trees around the fields are also applied.

4.3.2 Aboveground carbon pool

Measurements of the trees showed that the size and number of trees were important for the amount of carbon stored aboveground in the field (Table 5). All the farmers with high carbon stocks had either a small field with hedgerows around the field or a larger field with hedgerows around the field and additional rows within the field (Table 5). Where the farmers had a lot of hedgerows, the amount of carbon was almost twice as high (mean: 10968 kg C/ha) as in areas where there were only scattered trees and small hedges (mean: 3850 kg C/ha).

Table 5. Field area and carbon content in trees in the different fields included in the study. Each column represents one farm. Unfortunately one of the farmers in agroforestry with animals had cut down trees just prior to our visit so accurate measurements were impossible. This farmer is excluded from the table. * indicates hedges within the field as well as around the field.

	Agroforestry with manure						**Agroforestry without manure**				
Farmer	1	2	3	4	5	6	7	4	8	9	10
Field area (ha)	0.050	0.014	0.025	0.065	0.015	0.060	0.066	0.060	0.046	0.063	0.030
Carbon in trees above ground (kg/ha) (1)	1860	4930	80	0	0	850	500	520	7910	3870	0
Carbon in hedges above ground (kg/ha) (2)	1040	8500*	0	3200	3930*	0	7940*	2500	90	0	8230*
Total aboveground carbon (kg/ha) (1+2)	2900	13430	80	3200	3930	850	8440	3020	8000	3870	8230
Total belowground	480	3860	40	920	1130	250	2450	870	2330	1130	2400

carbon (kg/ha)(3)											
Total carbon (kg/ha) (1+2+3)	3380	17290	120	4120	5060	1100	10890	3890	10330	5000	10630

4.4 Socio-economic aspects

Since many of the interviewees had more than one of the studied systems on their farm, the socio-economic aspects were difficult to interpret.

4.4.1 Workload

Four of the respondents reported that the work on the farm had become more time-consuming since they changed their farming system to agroforestry. The higher workload was attributed *e.g.* to a higher demand for weeding, since the soil has become more fertile. This finding is illustrated in Appendix VI, which shows that the annual workload was lowest in the sugarcane system where there is no agroforestry on the farm (Sugarcane-non agroforestry). However, even though the workload may have been higher, six out of 16 farmers mentioned that the work is easier to carry out since they started with agroforestry because the soil is softer, which makes land preparation less onerous. Another reason given for why the work had become easier was the advice farmers received through the WESAME group about how to cultivate their land and when to carry out the different tasks. The possibility to collect firewood and fodder on the farm also saves time, since the farmers do not have to walk far for collection of firewood or to graze their animals.

4.4.2 Financial situation

Comparisons of the financial results for 2009 (

Table 6, Appendix VII, Appendix VIII) revealed that the farmers who mainly grew sugarcane generally had higher income (mean: 93000 KSh/ha/year) than the farmers with agroforestry systems (mean: 63 000 KSh/ha/year). However, it was also observed that the income for the sugarcane farmers was more unevenly distributed throughout the year compared with the agroforestry farmers (Appendix VIII). In addition, the interviews revealed a trend of the sugarcane farmers being very dependent on the income from the sugarcane, since they only grew food crops for the household and therefore had less diverse sources of income.

Since the maintenance of sugarcane is rather expensive, some farmers were losing money on their plantations. However, since they get a large payment after the harvest (and sometimes forget about the expenses) they were continuing to grow sugarcane. As one of the farmers said 'you do and forget'. The same farmer also saw the sugarcane as a form of savings, since the payment provided a lump sum of money for renovations and similar expenses.

One of the farmers (Farm 18) owned a tractor, which resulted in high income all year around because it could be used *e.g.* for transporting sugarcane and thereby generated extra off-farm income. The same farmer also bought sugarcane from people who needed money (acted as middleman), which generated additional income.

Table 6. Financial situation (2009) based on results from interviews and seasonal calendar

Farming system	Farm no.	Income (kKSh/ha/year)		Expenditure (kKSh/ha/Year)	Balance (kKSh/ha/year)
		On-farm	Off-farm		
Agroforestry with manure	1	35.1		55.8	-20,7
Agroforestry with manure	4	28.4		27.1	1.3
Agroforestry without manure	10	166.7		1333.8	-1167.1
Agroforestry without manure	11	22.4		31.4	-9.0
Sugarcane	13	4.8	6.3	35.1	-24.0
Sugarcane	16	55.0		72.2	-17.2
Sugarcane non-agroforestry	18	105.7	130.9	41.8	104.8
Sugarcane non-agroforestry	20	70.2		55.6	14.6

The interviews also revealed that farmers with agroforestry systems who used all the products from the system, through selling *e.g.* seedlings, firewood and medicine (*e.g.* Farm 10), had a higher income than other agroforestry farms that did not utilise all these products. This also spread the income over the year, since the trees could be harvested when there were no food crops to harvest on the farm.

The expenditure in the different systems was quite similar. The highest outgoings were for school fees and medical treatments, irrespective of the system practised on the farm. Maintenance of the sugarcane crop also involved quite high costs but these were spread over a longer period than the costs of one food crop.

4.4.3 Food security and health situation

Ten of the 16 interviewees reported that their food security has improved since they started agroforestry. They attributed this improvement to the knowledge they had obtained through Vi Agroforestry when applying the new systems on their farms. Food security was improved through higher yields, cultivation of more adapted varieties and a more diverse cropping system. The more diverse cropping system and higher yields not only provided the household with a more varied diet, but also provided extra income from selling the surplus products. The higher yields of food crops were in comparison to the yields before the introduction of agroforestry, not to the sugarcane crop.

Appendix IX shows the variation between the different farms in how food secure they consider their situation to be. The results are difficult to interpret and it should be considered that the interviewees mainly described their own experiences (and did not make comparisons with other farms).

The food situation was measured in numbers of meals each day, or in how diversified the diet was. This means that the food situation was closely related to the health situation, since the susceptibility to diseases increases when there is food scarcity. Some of the interviewees also mentioned that food scarcity periods most often coincide with rainy periods. During those periods the workload is high, *e.g.* during land preparation, and there are very few or no crops ready to harvest. All these factors, including the weather, can be assumed to increase the susceptibility of people to disease during the rainy periods.

5 Discussion

According to the farmers included in the study, the introduction of agroforestry systems has improved their status in terms of food security, soil fertility and financial situation. However many of the farmers still grow sugarcane, probably since it is regarded as an investment and perhaps also by tradition. The fact that the two systems are often combined makes it difficult to interpret whether it is the agroforestry system alone that gives the improvement or whether it is a combination of the two systems that is responsible.

5.1 Soil

Since sugarcane is a perennial crop, our first starting hypothesis was that the effects on the soil from an agroforestry system would be similar to those from a sugarcane system, since perennial crops and trees have time to develop larger root systems than annual crops. However, the results from this study indicate that the systems are different in some respects, *e.g.* flows of organic matter (compost and plant residues) into the system and nitrogen and carbon concentration in the topsoil. These dissimilarities were observed both in the interviews and in the soil analyses. The sugarcane systems had significant differences in the amounts of carbon in the soil compared to the agroforestry systems without manure (Figure 8).

The change in farming system has brought about many changes for most of the farmers in the study. The soil is prepared more often, since mainly short-season crops are grown, and the preparation is mainly carried out by hand. These changes in method and frequency of soil tillage may affect the bulk density as much as the farming system itself, giving a soil with higher porosity. Higher concentrations of carbon (organic matter) in the topsoil can increase the productivity of the soil (Vi Agroforestry, 2010), as confirmed by the farmers included in the study. The farmers perceived their soil to be softer today compared with before they introduced agroforestry.

According to our first and third hypotheses, the highest contents of carbon and nitrogen were expected to be found in the agroforestry system with manure applied. However, according to Figure 8 and Figure 9, agroforestry without manure applied was the system with the highest levels of carbon and nitrogen in the topsoil, which is somewhat surprising. However, this can be explained by the results of the analyses of plant materials and composts (Table 3), which showed that the plant materials, used as mulch, had higher levels of both carbon and nitrogen than the composted manure, most probably owing to losses from the composts. These losses are presumably smaller in a system where the fertiliser material is applied directly to the field. Most of the farmers store the compost in a pit or pile on the ground without covering, which means that the compost is highly exposed to losses such as emissions and leaching. Since the compost is stored without any cover, the emissions, especially of nitrogen, may be high. Another reason why the manure has lower nitrogen and carbon levels than the plant material is probably that some of the nutrients are absorbed by animals during digestion. Some of the composts were also disturbed by incorporation of new material, which increases nitrogen gas emissions (Kirchmann, 2009). As can be seen in Table 3, the undisturbed compost contained more than twice as much carbon and nitrogen as the compost with normal management (turning of the compost material).

The C/N ratio of the different composts analysed (Table 3) was low for the compost containing Sesbania and for those containing manure. A high C/N ratio is preferable since this decreases the decomposition rate (van Noordwijk *et al.*, 2000). Since the climate in the area is tropical and therefore favours a high decomposition rate because of the heat and humidity, it might be possible that an even higher C/N ratio than those reported here would be preferable in order to slow down the decomposition rate in favour of a more steady nitrogen flow.

The variation in the sugarcane systems was low (Figure 8, Figure 9), which was probably an effect of more homogeneous management between farms. In the agroforestry systems, on the other hand, a more varying amount of organic fertiliser was applied. In addition, this organic fertiliser was more heterogeneous, *e.g.* depending on the substrate, method of storage and duration of storage. In contrast, pre-determined amounts of fertilisers containing a specific amount of nitrogen were applied in the sugarcane systems.

Many of the farmers interviewed were under the impression that water infiltration had improved since they introduced agroforestry. According to the results from the bulk density analyses, the soil under agroforestry tended to have a slightly looser structure and thereby allows faster infiltration. In the cases where only food crops were grown in the past, the difference may depend on the fields now having trees growing all the year around. This in turn means that the amount of roots in the soil is higher and the demand for water is higher. Many of the interviewees also reported that the soil water-holding capacity had improved since they started agroforestry. The reasons for this may be the management practice of adding plant residues to the soil (mulching), and shade from the trees, both of which decrease evapotranspiration. The shade from the trees may also increase infiltration, since a more moist soil absorbs water more easily (van Noordwijk *et al.*, 2000.

Some of the farmers practising agroforestry noticed a more profound improvement in soil water content closer to the trees, especially concerning the infiltration rate but also concerning the water-holding capacity. However, some researchers, *e.g.* Rao *et al.* (1998), have shown that there can be competition between trees and crops (Figure 3), with maize yield decreasing within a distance of five metres from hedgerows and trees.

5.2 Environmental aspects

Comparing the different systems, there was a large difference in nitrogen flows in and out from the fields. The farmers with sugarcane had larger inputs and outputs compared to the fields with agroforestry practiced. Also the nitrogen losses are larger in the sugarcane systems (Table 4)which means that there is an better nitrogen balance in the agroforesry systems and they are thereby more sustainable (van Noordwijk *et al.*, 2004), which confirms our third hypothesis. Most of the sugarcane farmers included in this study burned their canes before harvest, which decreases the amount of residues left on the field after harvest. According to Robertson and Thorburn (2007), more than 70% of the organic matter in sugarcane is lost to the atmosphere through burning the canes before harvesting. In contrast, the farmers practising agroforestry often left most of the residues on the field and also applied more organic matter during the planting season. Another factor contributing to the more balanced net flow in the agroforestry systems was the kinds of crops grown in these systems, which do not produce as much biomass as the sugarcane crop and thereby a smaller amount of material is removed. However more research is needed to examine the total flows of biomass and nitrogen in the different systems.

If the locally recommended dose of nitrogen for maize and sorghum (33 kg nitrogen per hectare according to interviews in Kopere, 2010) were to be applied, 6800 kg of composted manure or 760 kg dry matter of leaves from Sesbania would need to be put on the fields (Table 3). Production of this amount of leaves would require a large amount of trees, which would also generate other benefits for the climate, such as carbon sequestration and nitrogen fixation, which would lower the need for chemical fertiliser. However, since rather large amounts of organic matter are necessary to fulfil the nutrient requirements, a supplementary chemical fertiliser could be a good idea if the farmer can afford it.

In the agroforestry systems the tillage is more frequent, which can lead to higher decomposition rates and thereby higher emissions of carbon dioxide compared with the more undisturbed soil in the sugarcane system.

The size and density of trees are important for the amount of carbon stored in the field. This is demonstrated in Table 5, where a large amount of carbon was stored in hedgerows where the tree density was high. The results from the carbon storage calculations indicated that the hedgerows in most circumstances represented a larger proportion of the carbon storage than scattered long-term trees. This might be since most of the farmers just have planted the long-term trees at rather large spacings, or have planted only a few trees around a rather large field. In light of this, a system with hedgerows within the field as well as around the borders is preferable to having long-term trees along the borders. However, the ability to store carbon may be different in these two options. The trees and hedgerows also compete for water and nutrients (Lwakuba *et al.*, 2003).

5.3 Socio-economic aspects

5.3.1 Workload

Our fourth hypothesis was confirmed, since the farmers interviewed reported that their workload has increased since they introduced agroforestry. However, they also noted that the work is easier to carry out compared with the previous work on the farm.

It is difficult to determine whether the differences in workload are connected to the different farming systems, or to other changes made in farming practices, *e.g.* how the land is cultivated. The work being easier to carry out in the agroforestry system may be connected to the loosening effect of the tree roots around the field. However, it may also be related to different types of soil preparation. Many of the farmers changed land preparation methods during the time they started agroforestry. These changes also included introduction of new crops. If the soil is prepared more carefully and more often than before, the effect will be a looser structure and thereby a soil that is easier to cultivate. It is difficult to say how much the loose structure is an effect of the larger amount of organic matter that is applied and how much is due to changes in land preparation or introduction of new crops (Lwakuba *et al.*, 2003).

In this study, some farmers stated that the higher demand for weeding is one reason for the increased workload in the agroforestry systems. However Rao *et al.* (1998) reported that weed problems should decrease in an agroforestry system due to *e.g.* shading and competition with the trees. The findings of Rao *et al.* (1998) might be applicable in the long run, but in the beginning of the agroforestry system the more frequent tillage may stimulate germination of weeds (Fogelfors, 2001).

Almost all the interviewees practising agroforestry stated that they also get a lot of other products from the agroforestry system, such as firewood and fodder. These are products that would otherwise have to be collected from off-farm, which takes a lot of time, especially for women and children who usually do the collecting.

5.3.2 Financial situation

One of the major problems with the farmers included in the study was the lack of record-keeping, which made the financial data in particular unreliable and thereby difficult to analyse.

In relation to our fifth hypothesis, the results in this report indicate that the agroforestry systems do give a more evenly spread income throughout the year, provided that the farmers utilise all the resources that the trees generate (Appendix VII and Appendix VIII). This confirms findings by David (1996) that the income of small-holder farmers in western Kenya to a large extent depends on the season. Farmers practising agroforestry have a more diverse farming system and thereby the income is more diverse and spread over the year. The agroforestry farmers included in this study were all connected to WESAME, which is cooperating with KENFAP to find better markets for the crops grown in the area. Because of this, the farmers connected to the group may be more aware of the importance of marketing their products and thereby get a more evenly spread income. This fact indicates how important knowledge is to spread risks and find profitable channels for selling products.

Most farmers depending on agroforestry have a small income every month, which can help to cope with buying necessities such as supplementary food or occasional hospital visits. However the income is rather small and most of the farmers connected to WESAME rely on loans for their major expenses. Some of the interviewees noted that their financial situation had improved since they joined the WESAME group.

This study also indicates that income from sugarcane farming is higher than that from agroforestry (

Table 6). However, it is clear that farmers using their agroforestry system in an intensive way, *e.g.* farmer 10, have an annual income that is similar to the income from sugarcane farms and, in contrast to the sugarcane system, is evenly distributed over the year. The exception was farmers with large off-farm income, which was found to make a great difference in terms of liquidity.

The improved income can in some cases also be connected to higher yields (Babu and Rhoe, 2002). The higher yields make it possible for farmers to sell a larger proportion and thereby generate a higher income. An improved income and a more diverse cropping system with higher yields also improve the food situation according to this study, as well as according to Shelemew (2005) and Babu and Rhoe (2002).

5.3.3 Food security and health situation

Our fifth hypothesis stated that agroforestry systems (and those with manure applied) would lead to more food-secure households. There were no clear differences between the two agroforestry systems but most of the farmers associate a better food situation with a more varied diet (Babu and Rhoe, 2002). The animals will at least provide the household with some milk and eggs if they have dairy animals and poultry. The animals (similarly to trees) also make an important buffer, where money can be released during difficult periods if needed.

As the diagrams in Appendix IX show, there was large variation in food security between the different months. In contradiction to our hypothesis, the system giving the most even food situation seemed to be the sugarcane. However, there were no consistent differences.

Some of the farmers included in this study, regardless of system, also associated the improved food security with an improvement in the health situation in the household. Even though the sugarcane systems tended to have higher, or at least more uniform, food security (Appendix IX), farmers claimed that their food situation had improved with the change to agroforestry systems. Since the farms mainly depending on sugarcane were usually larger than those with agroforestry (Table 1), this may have contributed more to the food security than the system itself. Therefore agroforestry systems might improve food security more on smaller farms.

5.4 Uncertainties

Since 16 of the 21 study farms are connected to WESAME and Vi Agroforestry, the selection was not made randomly and all the farmers had at least some knowledge about sustainable agriculture. This can have led to them giving answers they thought were 'correct' instead of describing how they are actually running their farms. In addition, when working with interpreters there is always a risks of misunderstandings.

Most of the nitrogen balances calculated in Table 4 are negative, i.e. the nitrogen outputs were higher than the nitrogen inputs. This would mean that the soil fertility decreased every year, and that the productivity also decreased. Since the outputs in some cases are much larger than the inputs, it is reasonable to suspect that some components were overlooked in the study. When working with nature it is necessary to consider that many factors might be hard to measure, such as amount of litter on the ground. This factor is hard to estimate, since the leaves fall from the trees at different times of the year.

6 Conclusions

Since the sample of interviewees in this study was relatively small, it is difficult to draw general conclusions. However, the results indicate that there are differences between the agroforestry and sugarcane farming systems both concerning their effects on the soil and concerning their effects on the situation for the household.

- An agroforestry system gives a more diverse cropping system than a sugarcane system. This improves the situation for the household in terms of both food and health situation, especially on smaller farms.
- To have as many benefits as possible from the agroforestry system, all resources such as firewood, litter and seedlings have to be utilised, either in the household or sold.
- The financial situation may not be improved by agroforestry compared with sugarcane but the lower financial flow seems to be more evenly spread over the year. All systems studied had very low incomes and most farmers had problems with debts. The only system that seemed to be economically sustainable was sugarcane-non agroforestry, possibly due to higher turnover.
- Agroforestry systems are more time-consuming than sugarcane systems, but the work may often be easier to carry out. On the other hand, the agroforestry system can provide the household with *e.g.* firewood and fodder for the animals, collection of which from outside the farm can be a time-consuming task.
- The soil bulk density in the agroforestry systems is more varied than in the sugarcane system. This might be an effect of tree roots, the use of organic fertiliser instead of chemical and/or differences in soil tillage.
- The concentration of carbon and nitrogen in the soil tended to be higher in the agroforestry system without manure applied. This may be related to higher levels of carbon and nitrogen in leaves and root litter from the agroforestry trees compared with the composts analysed. However, the amounts of soil carbon per hectare in the topsoil (0-15 cm) did not differ between the systems.

Overall, the study indicates that the most important factor is not the kind of farming system in place, but the amount of knowledge available to farmers. If the farmer knows how to conserve available resources, such as by-products from the different systems and the nutrients from household, animal and plant residues, and plan for the future of the farm, the efficiency in the flows to and from the farm can be increased. This improves the overall livelihood of the household.

Further studies including quantification of socio-economic aspects such as farm income and costs would be very interesting since these data would give better opportunities for evaluation of the farmers' situations. It would also be interesting to perform a complementary study comparing farmers not connected to any advisory network to the farmers connected to a WESAME or a similar network .

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Appendix I – Semi-structured interview topics

Social and Human Capital

- Family circumstances?
    - Number of members on farm and off farm?
    - Family members to cook for?
    - Ages?
- Occupation of family members?
    - Education
    - Work ability
    - Employees, including family?
    - Off-farm work?
    - Labour exchange between neighbours?
- Food situation?
    - Percentage of food bought / grown on-farm?
    - How much food is traded with neighbours or others?
- Number of individuals to feed?
- Number of school fees to pay?
- Hours of work? Distribution throughout the year? Most time-consuming task?
- Decision making on the farm?
- Connection to any networks, VI-agroforestry, WESAME and/or others? For how long?
    - How often do you have meetings within these groups?
    - Do you feel that these groups have been useful to you and your farm?

Natural Capital

- Acreage of the farm? Acreage of the fields?
    - Owned and/or leasehold land?
- Crop seasons per year?
- Products grown?
    - Most time-consuming production?
    - Product use? Household/sale/animals?
    - What do you think about your soil, compared with that on neighbouring farms?
    - Have you seen any differences within the fields, *e.g.* border effects
- Animals kept?
    - Grazing or zero grazing?
    - Fodder source?
    - Manure management?
    - Other organic matter input
- Access to water and its purity?
- Water harvest management?
- Firewood collection?
- Are you affected by neighbours' cropping system?

Financial Capital

- Incomes from the farm? From what and how much?
- Other sources of income

- Distribution of the incomes throughout the year?
- Other incomes? From what and how much?
- Expenditure on the farm? Which is the largest and how are is expenditure apportioned throughout the year?
- Living expenses (the major ones)?
- Financial situation during the establishment of the agroforestry system?

Physical Capital
- Equipment on the farm? Do you need anything extra for the agroforestry part?
- Pest management?
- Tillage systems?
- Plant nutrients –bought or from farm animals?
- Value addition?
- Transport of goods/products?

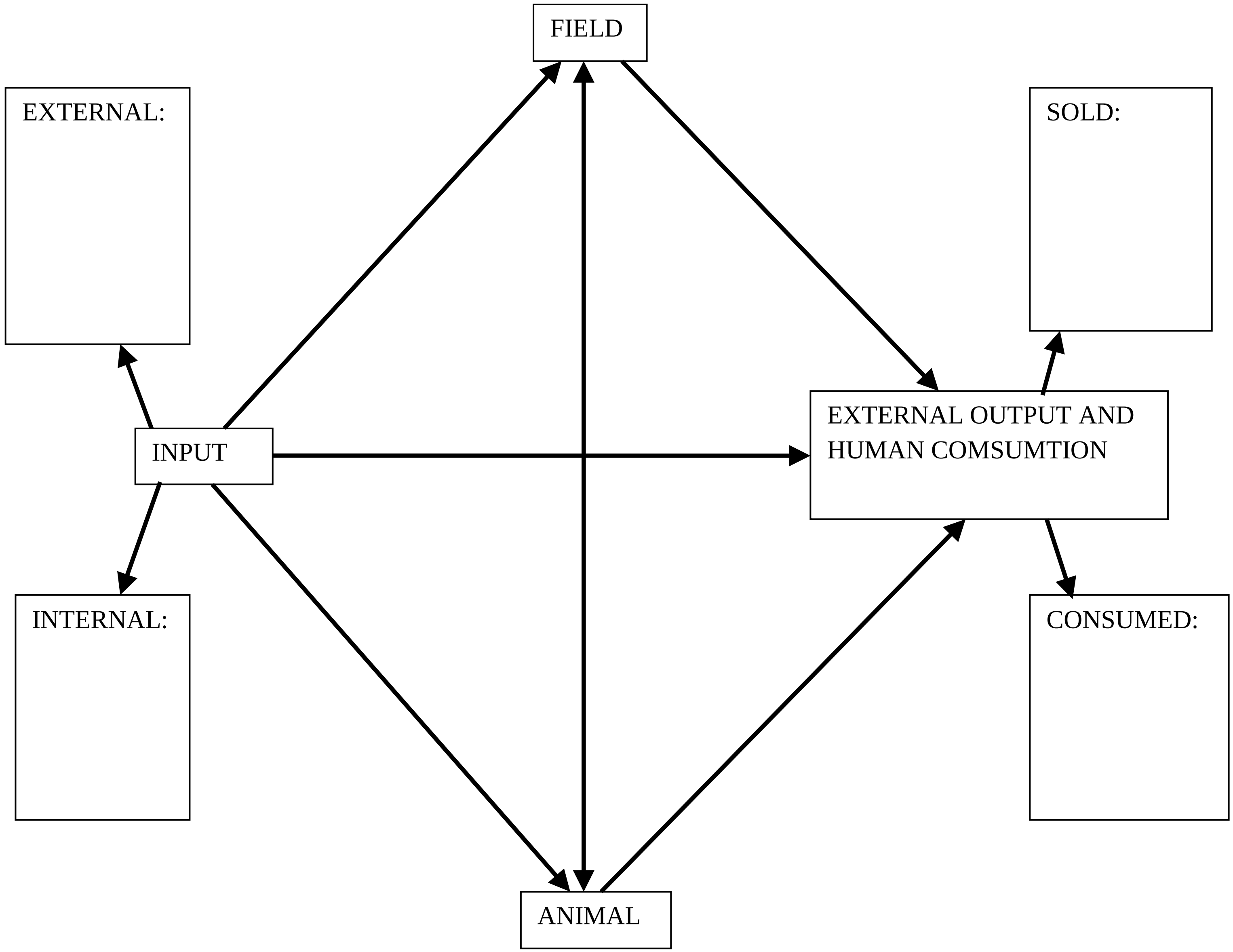
Other facts
- Farm location?
- Topography?
- Type of soil?
- Timeline
    - Rain, When? How much?
    - Dry periods?
    - Major crops over the years?
    - Agroforestry? Do you see any changes in the areas with and without agroforestry?
    - Animal management?
    - Inorganic and organic fertilisers? And how much?
    - Tillage and weed management?
    - Any difference in the soil after the changes?
- Before/after Agroforestry
    - Yield?
    - Workload?
    - Incomes throughout the year and other changes?
    - System change investment? (Costs, adopting time)

Appendix II – Seasonal calendar

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Comments
Incomes													
Expenditure													
Financial situation													
Food situation													
Health situation													
Work situation (men/women)													
Products for household/sale													
Access to water													
Animal keeping (grazing/forage)													
Crop 1 *													
Crop 2 *													
Crop 3 *													
Erosion													
Rains and droughts													

* Tillage, Sowing, Weeds & Management, Nutrients, Harvest

Appendix III – Field gate balance



Appendix IV – Soil pit description

	Farmer 1	Farmer 4 (AF with manure)	Farmer 4 (AF without manure)	Farmer 4 (SC)	Farmer 10	Farmer 11	Farmer 13	Farmer 16
Depth A	0-37	0-22	0-30	0-25	0-47	0-25	0-55	0-42
Depth B	37-	22-65	30-60	25-67	47-	25-75	55-	42-73
Depth C	---	65-	60-	67-	---	75-	---	73-
Change, horizons A-B	Very diffuse	Rather sharp but hard to see	Diffuse	Quite sharp	Diffuse	Diffuse	Quite sharp	Diffuse
Change, horizons B-C	---	Rather sharp but hard to see	Sharp	Quite sharp	Diffuse	Diffuse	Quite sharp	Diffuse
Animals	A termite nest	Some termites in A	---	---	Few termites in topsoil	Some ants	A few ants	A few ants
Clay A	5 mm	3-4 mm	2 mm	1-2 mm	1 mm	---	2 mm	5 mm
Clay B	2 mm	1 mm	1 mm	1 mm	<1 mm	---	1 mm	5 mm
Clay C	---	1 mm	1 mm	<1 mm	---	---	---	1 mm
Roots A	Few mainly 3 mm, up to 1 cm	Quite a few main 1 mm, up to 2 mm	Few mainly 1 mm, to 1 cm	Quite a few main 2 mm	Some about 2 mm	Few tree roots	Some main 1 mm	A few mainly 1-2 mm, ->5 mm
Roots B	Some thin roots to 68 cm	Some main 1 mm, up to 2 mm	Few thin	Quite a few very thin	---	Few very thin	Very few thin	No roots 40-60 cm
Roots C	---	---	Very few, very thin in upper part	---	---	Few very thin		60-80 cm: Some very thin roots
Pores	Some made by ants	---	---	---	---	---	---	---
Cracks	---	Some up to 3 mm, main 1 mm	---	---	---	---	---	---
Plant residues	---	Some in A	Some in A	---	Some in surface layer	---	Some in A	Little on the surface
Colour A	Brownish-black	Brownish black	Brownish-black, Rust spots	Blackish-brown	Black (->50-60 cm)	Brownish-black	Brownish black	Dark brown
Colour B	Dark reddish-brown	Black	Brownish-black, Rust spots	Brownish-black	Brownish-black (60 cm->)	Dark reddish-brown	Yellow-red brown	Brown
Colour C	---	Brownish black	Dark reddish-brown	Brown	---	Rusty red	---	Reddish-brown
Structure	Quite homogeneous	Granular/Prismatic	A. Single, B: Small granules, C: Granular	Granular	Granular	Single grain	Large granules/prismatic	Homogeneous, small gravel layer 48-58 cm
Texture	---				---	Large pebbles mainly in B	Slightly more sandy than B	---
Hardpan	36 cm	65 cm	B and C harder than A	40 cm	22 cm	---	---	34 cm
Filled hole	Slightly higher	Higher	---	Slightly higher	---	---	---	Slightly lower

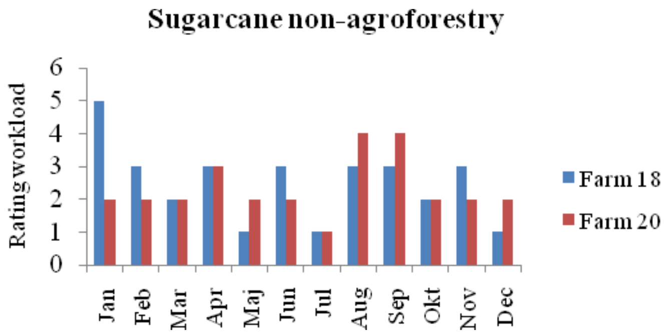
Appendix V – Elemental analysis, raw data

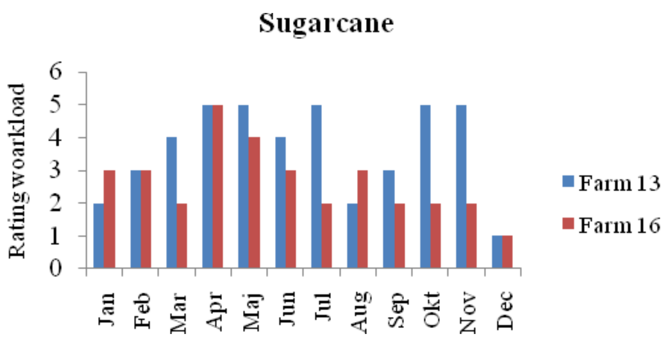
Raw data from elemental analysis of the topsoil (0-15 cm)

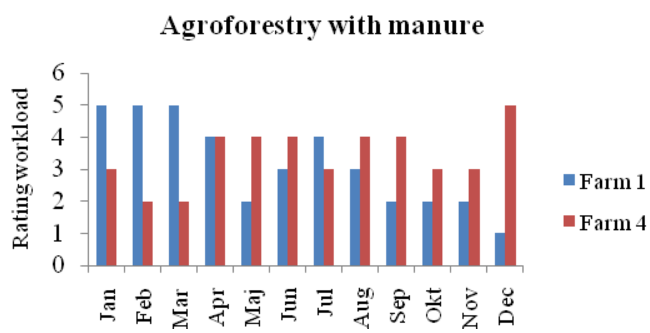
Plot treatment	Nitrogen (%)	Carbon (%)	C/N
Agroforestry with manure	0.15	1.52	10.15
Agroforestry with manure	0.08	0.94	12..35
Agroforestry with manure	0.07	0.84	12.57
Agroforestry with manure	0.11	1.55	14.02
Agroforestry with manure	0.08	1.21	14.21
Agroforestry with manure	0.13	1.97	15.22
Agroforestry with manure	0.13	2.04	15.55
Agroforestry with manure	0.09	1.29	13.85
Agroforestry without manure	0.12	1.59	13.10
Agroforestry without manure	0.11	1.57	14.38
Agroforestry without manure	0.13	2.03	16.21
Agroforestry without manure	0.22	3.88	17.39
Sugarcane	0.10	1.36	13.38
Sugarcane	0.07	1.15	15.64
Sugarcane	0.06	1.02	15.70
Sugarcane	0.09	1.46	15.74
Sugarcane	0.08	1.28	15.83
Sugarcane	0.07	1.14	16.04

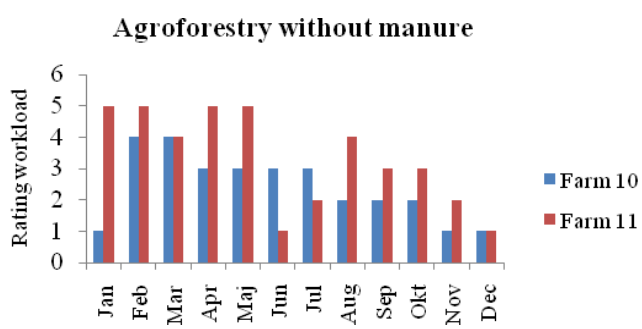
Appendix VI – Workload

Farmers ratings of workload over the year.









Appendix VII – Incomes and expenditure, raw data

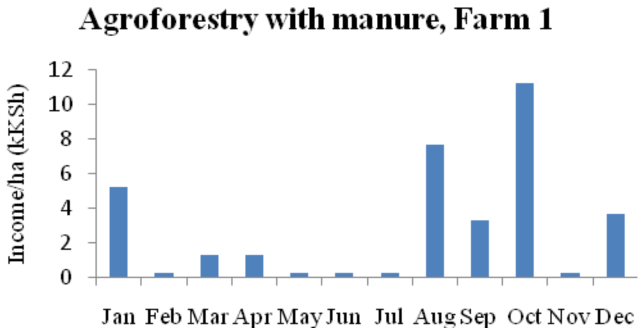
Incomes and expenses (kKSh/ha) for the different farming system. Incomes are divided in on-farm and off-farm incomes.

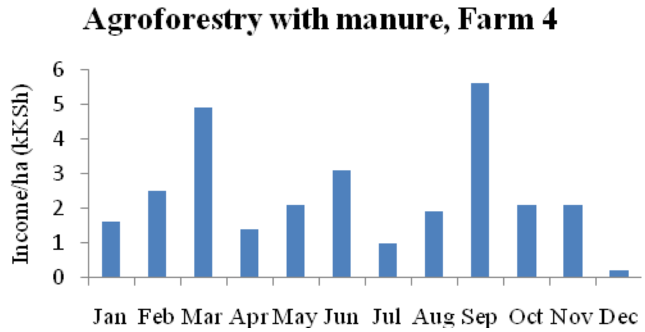
	Agroforestry with manure (Farm 1)			Agroforestry with manure (Farm 4)			Agroforestry without manure (Farm 10)			Agroforestry without manure (Farm 11)		
	Income		Expenditure	Income		Expenditure	Incomes		Expenditure	Incomes		Expenditure
	On-farm	Off-farm		On-farm	Off-farm		On-farm	Off-farm		On-farm	Off-farm	
Jan	5.2		23.7	1.6		1.9	17.3		123.5	1.2		3.8
Feb	0.3		3.2	2.5		2.9	6.2		49.4	0.6		3.7
Mar	1.3		4.4	4.9		4.7	4.0		24.7	2.0		3.0
Apr	1.3			1.4		1.4	17.3		123.5	4.3		3.7
May	0.3		3	2.1		2.1	3.7		123.5	0.6		2.1
Jun	0.3		3	3.1		2.3	6.2		123.5	1.2		3.7
Jul	0.3		2.7	1.0		1.1	24.2		74.1	2.5		1.2
Aug	7.7		3	1.9		1.0	55.6		98.8	2.5		1.2
Sep	3.3		4.4	5.6		4.7	5.4		148.2	0.6		1.9
Oct	11.2		3	2.1		1.9	4.2		148.2	2.5		1.9
Nov	0.3		3	2.1		2.3	18.0		123.5	3.7		4.3
Dec	3.7		2.5	0.2		0.8	4.7		172.9	0.6		1.2
TOT	**35.2**		**55.9**	**28.4**		**27.1**	**166.7**		**1333.8**	**22.4**		**31.7**

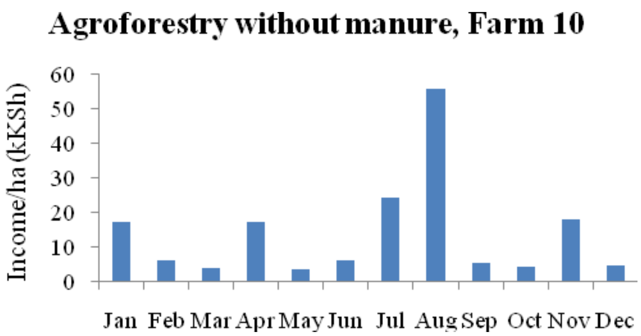
	Sugarcane (Farm 13)			Sugarcane (Farm 16)			Sugarcane-non agroforestry (Farm 18)			Sugarcane-non agroforestry (Farm 20)		
	Incomes		Expenditure	Incomes		Expenditure	Incomes		Expenditure	Incomes		Expenditure
	On-farm	Off-farm		On-farm	Off-farm		On-farm	Off-farm		On-farm	Off-farm	
Jan	2.3	0.5	5.6	1.5		0.8	11.5	9.9	8.2	59.7		15.4
Feb	0.6	0.5	7.7	0.6		13.1	0.3	11.0	4.1			3.1
Mar		0.5	1.0			45.8	1.3	11.0	4.4			2.2
Apr		0.5	1.1	47.9		3.2	23.4	11.2	2.5			4.6
May		0.5	8.6	2.5		6.3		11.0	1.6	0.4		12.4
Jun		0.5	1.1			2	13.2	9.9	3.0			3.1
Jul	0.2	0.5	1.8	0.9		0.2		11.5	2.5	0.5		1.5
Aug		0.5	1.2			0.2		11.9	3.3	8.8		0.6
Sep		0.5	3.5			0.2		11.2	2.9			9.3
Oct	0.3	0.5	1.0	1.5		0.2	19.8	9.9	1.6	0.5		0.6
Nov	0.6	0.5	0.6			0.2	36.2	9.9	2.5			0.9
Dec	0.6	0.5	1.8			0.2		12.5	5.2	0.4		1.9
TOT	**4.8**	**6.3**	**35.1**	**55**		**72.2**	**105.7**	**130.9**	**41.8**	**70.2**		**55.6**

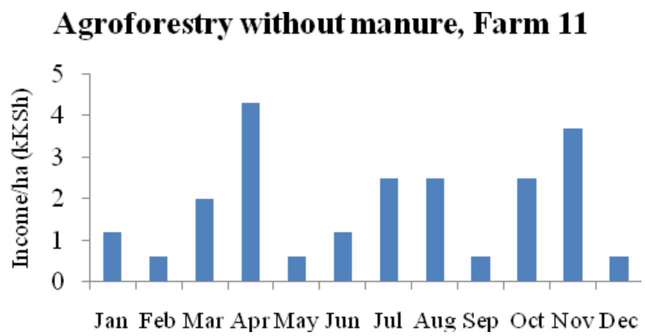
Appendix VIII – Charts of incomes on monthly basis

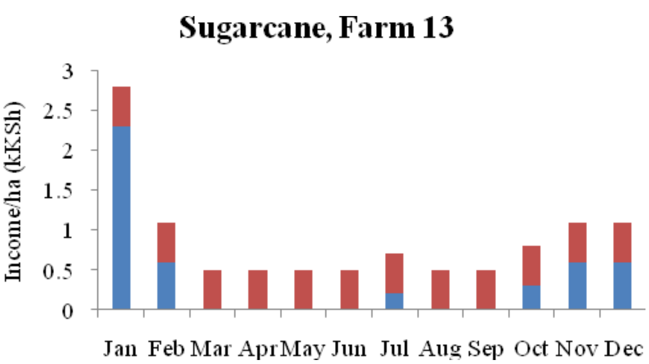
Incomes per hectare and month (kKSh). Blue bars represent on-farm incomes and red bars represent off-farm incomes. Notice the differences in scale on the y-axis between the different diagrams.

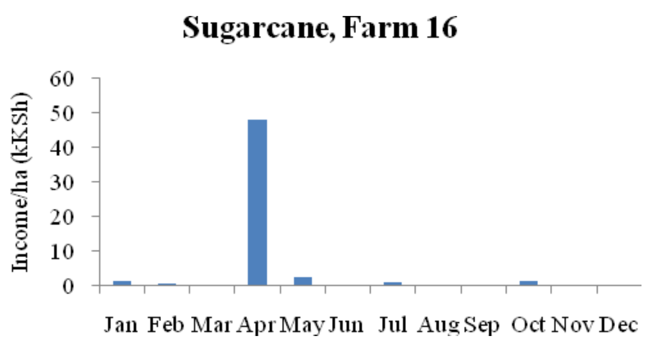


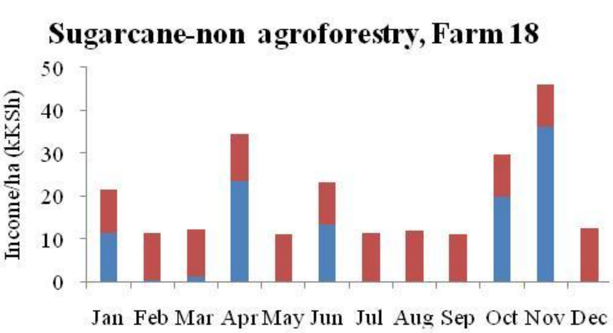


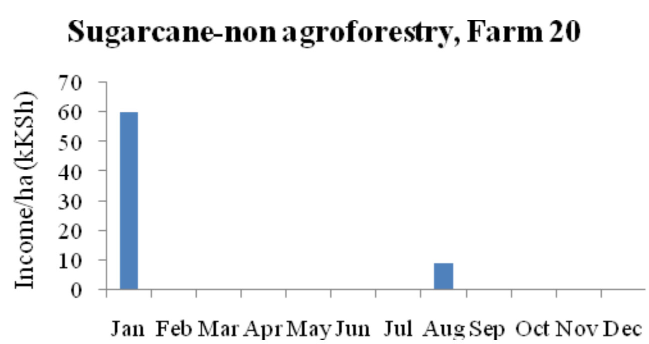












Appendix IX – Charts of food security

Ranking of food security according to the farmers. Each farmer related to the situation on his farm, so the diagrams can be difficult to compare with each other. However, they indicate the differences over the year in the different systems. 1 – one meal per day, 2 – two meals per day, 3 – three meals per day, 4 – three meals per day and a bit varied diet, 5 – three meals per day and a very varied diet.