Sustainable food production

Farmers’ management of their agroforestry systems in Tanzania.

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Abstract

The future of food production contains some challenges. The production needs to increase in order to feed a growing population, but at the same time there is an increased need to transition to more sustainable ways of cultivation. This can be a challenge since increased intensity and sustainability is not always compatible. Agroforestry systems have shown potential as sustainable food production system in previous research. The area where this study was conducted, Haraa in Babati District, has a long history of agroforestry. The aim of this study was to answer what resources agroforestry farmers used to manage their farms, to determine if the agroforestry systems could be regarded as sustainable. Circular economy was used as a theoretical framework and resource flow as an analytical tool. This study investigated how the resource flow looked like on six agroforestry farms in a Haraa, a village in Tanzania. The empirical data was gathered with semi-structured interviews from 8 informants. The analysis showed that the farmers were dependent on few external resources and could produce or perform most of the needed resources inside their own system. The farms had a circular flow to a large extent, but some of the farms have room for improvement in the management regarding sustainability.

Keywords: agriculture, circular economy, Babati district, Haraa, inputs
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1. Introduction and Background

One of the most urgent issues of sustainable development is our food production. The future of food production contains many challenges. The human population grows and the growth is not equally distributed over the countries, which means some countries are going to require a higher level of intensity in the production than others. Another problem is the global climate change which will lead to new conditions and challenges in food production systems. Agriculture is dependent on rainfall and temperature, and therefore exposed to future climate changes. This means climate change can threaten global food security (Smith & Gregory 2013, p. 26). The need for intensified sustainable food production has therefore increased at the same time as it is harder to perform (Noponen et al 2012, p. 6). It is important to improve agricultural efficiency by increased food production as much as possible relative to the inputs (Smith & Gregory 2013, p. 27).

One of the current problems with food production on the African continent is land degradation, and this problem is likely to increase with the climate change in some areas. Based on the newest projections for climate change, both temperature and precipitation will increase in the sub-Saharan area in the future (IPCC 2014, p. 12). Problems such as soil erosion, loss of nutrients, loss of vegetative cover and decreased biodiversity all fall under the term land degradation (Swift et al 2006, p. 43-44).

Natural ecosystems are provided with resilience against a multitude of problems such as land degradation, diseases and drought. Systems with multiple crops can give benefits like nutrient cycled and water conservation. Biodiversity makes farms more resilient than mono crop systems (Shivakoti et al 2005, p. 387). These natural systems can serve as guides to create sustainable food production systems. One food production system mimics some of the natural ecosystems complexity is agroforestry (Whitefield 2011, p. 275, Albuquerque et al 2005, p. 492).

Agroforestry can be part of the solution to create sustainable food production systems (Maroyi et al 2009, p. 1). It has been a way to farm for hundreds of years and millions of farmers practise it (Garrity 2006, p. 4). Regional programmes in Africa, driven by the World
Agroforestry Centre have shown that farm production can increase with intensification and diversification (Garrity 2006, p. 7).

Agroforestry can be defined as intercropping trees and other crops on the same plot, sometimes together with livestock (Albuquerque et al 2005, p. 492, Reyes et al 2005, p. 682). The reason to integrate trees in the production landscape is that they provide a wide range of ecosystem services. Steep sloped areas can sometimes only be used for agroforestry or natural forest habitats due to land degradation (Reyes et al 2005, p. 682). The soil coverage from trees and crops can reduce soil erosion, fixing nutrients such as nitrogen and improve the soil texture. The soil quality can also be stabilised and improved by the use green manure (see figure 1), fallowed land, nitrogen fixing plants and with deep rooted plants that can reach deep soil nutrients and integrate them in the farming system (Shivakoti et al 2005, p. 390).

![Figure 1: Green manure, also known as mulch, uses leaves and cut off to fertilize the ground. This also covers up the bare soil which enables the moisture to be preserved better. (Photo by author).](image)

When a diverse agroforestry is created farmers split the risk of crop failure or disease over a multitude of crops, which leads to better food security (Omont & Nicolas 2006, p. 32). In a well composed agroforestry system all crops have their own place and function which mini-
mize the competition for resources between them. Traditional agroforestry systems are often designed to integrate native species, use natural variation on the farmland and the ecological succession, include many species and use the variety between farmers and farms to suit the households needs (Albuquerque et al 2005, p. 492).

1.1. Previous Research

Previous studies of agroforestry have identified both possibilities and problems in the cropping system. Home gardens, a type of agroforestry with high complexity, have shown potential to be ecologically sustainable food production systems in the tropical regions (Albuquerque et al 2005, p. 492). Home gardens in North-eastern Brazil contributed to sustainable use of resources, and reduced the pressure on natural ecosystems. Also a large number of rare species were found in the home gardens, were they were quite common. But the number of home gardens seemed to be declining in the area in spite of that (Albuquerque et al 2004, p. 504-505).

In Nhema, Zimbabwe, another group of home gardens were studied (Maroyi A 2009 p. 2). It was concluded that access to labour, land quality and marketing strategy affected the gardening strategies in the households. Very few external inputs were used by the families. The traditional agroforestry system in Nhema has been used for 50 years, and regarding sustainability the study concluded that it is likely to continue to be a viable system, at least in the near future. (Maroyi A 2009, p. 7). The home gardens did however loose nutrients. The study showed nitrogen losses which would require regular and constant fertilisation of the soil to manage a maintained production (Maroyi A 2009, p. 7).

Regarding nutrient loss, a study in Brazil investigated how nutrients in leaves affected the agroforestry systems. (Duarte et al 2012, p. 835). Different species were studied to find out how the leaves decomposed and how the nutrient release differed (Duarte et al 2012, p. 837-838). A diversity of tree species in an agroforestry system can play a key role in producing diversified organic material. All the species had varying decomposition rates and compositions of nutrients. The diversity of species therefore helped to maintain different ecosystems services by the improved soil quality it led to. This knowledge can be used by farmers to create an agroforestry system that is well balanced in that aspect (Duarte et al 2012, p. 844-845).
In the eastern hills of Nepal a study was conducted that showed that improvement of food- and nutrient security, and the reduced risk of crop failure was managed through diversified farming. By keeping ground coverage constant and adopting intercropping systems the farmers could also reduce the risk of soil erosion and diversify their diet. A low input system was used in the study area as a higher input would have risked reducing the economic and ecological profits. The farmers used local resources, integrated pest control, multiple cropping and micro-climate management to maintain a stable agroforestry system. This kind of use of renewable products is typical for hill cropping and helps recycle farm products which is the key to a LEISA, Low External Input Sustainable Agriculture (Shivakoti et al 2005, p. 395). This study shows that agroforestry can be a safer way of food production as the resilience of the system makes it less vulnerable to sudden changes in the area than a system with mono cropping.

A possible conflict between intensified food production and sustainable production systems was found in a study in Costa Rica and Nicaragua. The study evaluated ecological efficiency of coffee production. Annual average of input and yield was used to calculate carbon footprint for the selected locations (Noponen et al 2011, p. 8). The area with moderate intensity coffee production had the lowest emission but also the smallest yield. Converting the area to grassland would increase the emission (Noponen et al 2011, p. 14).

A study in the east Usambara Mountains in Tanzania showed that as the populations’ grew, the inhabitants cultivated even the highest parts of the mountain, which was not ideal. The mountains there are 800-1250 m above sea level. The authors recommend cash crop cultivation to generate bigger incomes on smaller plots of land (Reyes et al 2005, p. 683). They compared traditional cultivation methods which was defined as few trees and few crops systems to improved agroforestry systems which could include multipurpose trees, well managed cash crops and more (Reyes et al 2005, p. 685). The study concluded improved agroforestry systems could increase the farmers’ income. It could also maintain biodiversity since the increase in diversity in production landscapes reduces pressure on the natural forests in the area (Reyes et al 2005, p. 689).
2. Problem Definition and Aim

Previous research has shown that agroforestry systems have a potential to become sustainable food production systems. There are still questions that need to be answered regarding the management of agroforestry farms. In order for food production to be sustainable, the resources needed for managing the system must also be sustainably produced.

Looking on farms at systems level can answer the question of how sustainable the system is. The aim of this study is to find out if the agroforestry systems in Haraa have potential to be sustainable food production systems. A few agroforestry farms in Tanzania will be investigated to see how dependent they are on external resources. To determine which resources are internal, which are external and how the flow of these resources look like the whole production chain of the farm will be evaluated to see how circular it is. This can in turn answer how sustainably these farms are managed.

2.1. Research Questions

1. Does the investigated agroforestry systems reuse and produce resources in a circular manner? Which external and internal resources are used in the systems?

2. Do some farmers use more external inputs? If so, why?
3. Study Area

The study was conducted in a small village outside of Babati town, Tanzania (see figure 2). Haraa, that have a long history of agroforestry farming, is the home of many knowledgeable farmers. Currently around 1144 individuals lives there (Agriculture extension officer, 2015).

![Figure 2: Haraa in relation to Babati town (Source: Google Maps).](image)

When you drive to Haraa from Babati town you know you are there when the scenery of houses and open areas are replaced with heavy vegetation such as trees and shrubs. The main road is covered with reddish soil which makes a sharp contrast to the greenery (see figure 3). The road snakes up through the vegetation to the top of the area. Every now and then the vegetation opens up and you can catch a glimpse of a small field of maize or a house that suddenly pops up out of nowhere.
Figure 3: The main road exposes the red-tinted soil. The road is side-lined by shrubs and trees (Photo by author).

Haraa village is on an altitude of 1200-1500 meters. The higher elevation of the village makes the climate a bit different than in the surrounding area. It receives a bit more rainfall that the lowlands, around 750-900 mm/year, which increases the amount of crops that can be grown (see figure 4). The farmers in the area cultivate maize, beans, sunflower, cassava, banana, pigeon peas, tomato, coffee, Irish potatoes, sweet potato, peppers and more. A lot of fruit trees can also be cultivated here such as mango, orange, avocado, jackfruit and papaya. The area also has indigenous- and exotic tree species that can produce timber. One such tree is the Grevillea, which is a popular species because it makes good timber. The agricultural extension officer in the area did however not think this tree is ideal for the agroforestry systems in Haraa. The trees’ roots are shallow and wide, which can lead water and nutrient competition with the other crops (Agricultural extension officer 2015).
Figure 4: The picture to the left shows bananas inter-cropped with ground cover vegetation. The top right picture shows a more open part with maize mixed with trees. The bottom right picture shows the view of one of the slopes in Haraa, with a lot of different trees and other vegetation (Photo by author).

According to the older informants the area has changed during the last decades. Before there were more tree coverage, which changed as the population grew. As the need for more land to cultivate increased, trees were cut down to make room for other crops. Even though the farmers integrated trees in their farming systems, the decrease was still very evident. The farmers are still getting advice to plant more trees to prevent land degradation (Agricultural extension officer 2015).
4. Theoretical Framework

To find a suitable method of categorising resources, flows and draw conclusions from the analysis, circular economy served as a theoretical framework. This chapter will give a short introduction what circular economy means, introduce the resource categories that was used in the analysis and explain resource flow as an analytical tool.

4.1. Circular Economy

Circular economy was introduced by David Pearce in 1990 (Andersen 2006, p. 133) and is an approach on how to analyse system sustainability. It is defined as a closed loop feedback system, a system based on the reuse of energy and resources to decrease waste (Geng et al 2013, p. 1526). Whether a system can be considered circular or not is dependent on how resources are used and what is disposed from the system. When looking at a closed system, it is important to keep in mind that most of the energy and resources are constant. This means that any disposal leads to less resources (Andersen 2006, p. 134).

The neoclassical, linear, economy generally consists of three categories: resource, product, and waste. (Yong 2007, p. 126). Natural resources flow from nature to society and return as waste. The waste can be beneficial to the ecosystem when it includes things such as plant matter or manure. It can however be harmful to the system when it consists of pollutions such as unwanted chemicals and nutrient leakage. The waste becomes harmful to the system when the quantity exceeds the self-cleaning capacity. Industrialisation led to unbalanced material exchange between society and nature (Yong 2007, p. 125-126).

By reusing resources in a system the need for external resources decrease. This also reduces entropy caused by resources in the wrong place or at excess quantities. One example of how non-circular systems can increase entropy is how fossil fuel ends up as abundant CO$_2$ in the atmosphere. When the CO$_2$ surpasses the “normal” levels in the atmosphere, the greenhouse gas creates unwanted side-effects such as increased temperature (Andersen 2006, p. 134-135). Recycled resources provides benefits such as reduced waste disposal, a decreased need to extract new resources, and saves the market value of said resource (Andersen 2006, p. 139).
Circular economy can be used as a model to create a balanced material flow between nature and society (Yong 2007, p. 125-126). The environment should be a factor when talking about economic growth, instead of viewing natural resources as infinite. Otherwise the system can lead to waste of natural resources and a damaged and polluted environment without any visual consequences in the economy. Since circular economy is focused on the circulation of resources, wasted resources and damage to the environment will affect the systems flow. This highlights the problems with waste of resources and encourages people to reduce these unwanted consequences (Yong 2007, p. 126). To create sustainable systems, the flow of resources should be less than or equal to the systems resilience. This can measure the efficiency of the system (Yong 2007, p. 127).

4.2. Categories

The environment can be considered as a producer of four important functions for any economic system: amenity values, resource production, sink for residual flows and as a life supporting system (Andersen 2006, p. 135). Amenity values includes recreational services like the beauty of a landscape. Resource production are all sort of resources that can be used such as crops or fish. The sink function mean that the environment has a self-cleaning capacity that enables it to deal with limited amounts of pollution. As a life supporting system it makes life possible. The four categories take different aspects of environmental services in account when analysing a system. (Andersen 2006, p. 135). This study will focus on the second category, resource production.

Resources used on the agroforestry farms was put in the categories; seeds, labour, nutrients, treatment and capital. Naturally provided is also mentioned but not part of the analysis. The resources are either internal or external. Internal resources includes both inputs, compartments and products. Outside of the farm the focus will be on external inputs rather than external resources, since the latter include many things that are not a direct compartment in agroforestry management.
4.3. Analytical tools

In this study the focus is on flow of the five resource categorises, since this shows how these systems were managed. Resources will here be categorised as what is needed to create a product. The concept resource will include resources such as services, physical inputs and products. All flows within the system will be part of the analysis, but some categories was created to organize the resource flow analysis, so that it could be reused in similar studies and easily understood.

Low External Input Sustainable Agriculture, LEISA, can be used to analyse an agricultural systems’ sustainability (Shivakoti et al 2005, p. 386). LEISA analysis have much in common with the resource flow used in this study. The external inputs will be part of the flow analysis, but the analysis is not limited to that.

The analysis will also include the flow of resources within the system. The figures that show resource flow on the agroforestry systems have some traits in common with figures that show emergy flow or with a material flow analysis. Flowcharts for those analytical tools helped develop the resource flow figures. But that’s the extent of their use in this study. Emergy is a tool to quantify costs of production (Bergqvist D 2008, p. 49) with varying quality of the previous calculations their based on (Bergquist 2008, p. 68), and study does not include any calculated quantities. Material flow analysis is used to evaluate flow and stocks of materials within a defined system (Yong 2007, p. 126) which is also part of the resource flow, but it is not limited to material flows.
5. Methodology

5.1. Interviews

The time of the field study was limited to three weeks and a qualitative approach was deemed the most appropriate. Eight informants were interviewed and seven of them had an agroforestry farm in Haraa village. The eighth informant, the district’s agricultural extension officer, was a key informant that could explain general conditions and challenges in the area. The empirical data in this study was gathered with semi-structured interviews to guide the informants in the direction of the chosen topic, without limiting their answers. An interview-guide was used as a framework during the interviews (see appendix I), and the interviews took 30-75 minutes. The interviews were conducted on February 24 - March 2, 2015. Since the aim was to look on farms at a system level, the criteria for finding suitable informants were that they lived in Haraa, and managed an agroforestry system there. It was also important to interview both men and women, since their responsibilities on the farm sometimes vary. Suitable informants were found with the help of the field assistant and the agricultural extension officer. The field assistant also translated the interviews with the farmers, from English to Swahili and back.

Four of the informants were female and four were male. The farmers’ ages varied between 35-75 years. The agroforestry farmers were interviewed at their residence. This provided opportunity to see part of their farm, which led to better follow up questions. The informants also had the opportunity to elaborate on their answers and add information they thought was relevant. Since another student researched a similar topic, the interviews in Haraa were performed as a team. Notes were taken while the interviews were conducted. Transcriptions were written as soon as possible after the interviews were over. The work as a team provided the opportunity to discuss the interviews afterwards and likely improved the quality of the data.

5.2. Analysis

The analysis of resource flow on the farms is divided in two parts. First the resources were categorised as a preparation for the flow analysis. Then the resource flow figures were constructed. The general flow represents the flow on all the informants’ farms, and then farm A,
B and C represents the individual farms analysed. To determine where the resources came from, what important service or resource they lead to and how the flow looked like a few figures were used in the resource flow analysis (See table 1).

**Table 1:** This table shows the figures in the resource flows analysis and provides a short explanation of what they mean.

<table>
<thead>
<tr>
<th>Figures used</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External resources</strong></td>
<td>This means the service or resource comes from outside of the farm boundary.</td>
</tr>
<tr>
<td><strong>Internal resources</strong></td>
<td>This means the service or resource comes from inside the farm boundary.</td>
</tr>
<tr>
<td><strong>Categories</strong></td>
<td>This means this is one of the five resource categories defined in table 1.</td>
</tr>
<tr>
<td><strong>↔</strong></td>
<td>This means the resource flow can or does go both ways.</td>
</tr>
<tr>
<td><strong>→</strong></td>
<td>This means the resource flow only goes in the direction the arrow points.</td>
</tr>
<tr>
<td><strong>-----</strong></td>
<td>The white striped line is drawn around the crops in the system, to show flows not specified to a certain crop.</td>
</tr>
</tbody>
</table>

Three out of six farms in this study were analysed, because they had the most complete sets of data which led to better resource analysis. It is important to note that the resources categories and flows only show the management of the agroforestry systems. If other factors, such as the other resources used by the family was regarded, the flows would become much more complex and extensive. Keep in mind that the analysis shows how the resources flow and not the quantity, and that the flow analysis is limited to agroforestry management.

The farmers on farm C also had a 15 acres maize-field in a nearby village. The reason was that the agroforestry did not produce enough maize to sustain the family. This is important to take into account when trying to evaluate the sustainability of the agroforestry system. None of the other farmers interviewed had other agricultural systems. The purpose of the analysis
was to examine how the farmers used resources to manage their farm, and which external inputs they need.

5.3. Methodology critique

The number of informants in this study were few and their agroforestry management should not be used to generalise agroforestry management in the study area. It only shows how the informants’ farms were managed, and does not necessarily represent the general management of agroforestry systems in Haraa. The study does not include farmers younger than 35 years, and it is possible that generation of farmers might manage their farms differently. This study should therefore not be used to make general conclusions about agroforestry management in Haraa.

The aim of the study was to look at a few specific farms and analyse their management, which was managed with the empirical data. The study can answer how the informants’ farm were managed and how that can affect the sustainability of the farms.

During some of the interviews the agricultural extension officer was present. This could have affected the answers from the informants since this is someone they turn to for advice. This is something to consider when looking at the data of this study.

To reduce the risk to misunderstand the farmers, due to lack of direct communication, follow-up questions were asked as soon as anything seemed unclear or unexpected. Since the translations sometimes had to be shortened down by the field assistant, the details of the study was discussed with her to reduce the risk of losing important information. There is however a risk that some relevant information was lost in the process.
6. Results and Analysis

6.1. Agroforestry management

The interviewed farmers’ agroforestry systems were between 1-15 acres. Five of the farmers were not the first generation to manage an agroforestry farm in the area. Their plots contained a variety of crops such as maize, beans, chickpeas, bananas, jams, cassava, sunflowers, coffee etc. Cash crops like coffee, chick peas, sunflowers and bananas provided the farmers with capital to invest in farm or family. The other crops were generally consumed by the family. The trees in the agroforestry consisted of various combinations of indigenous- and exotic trees, some of them fruit trees. The trees provided a range of benefits such as shade for crops, binding soil and soil nutrients, provided timber, firewood and fruit production. The livestock the farmers had were cows, sheep, chickens and goats. The livestock was kept in one of two ways; Either in an enclosed area where the fodder was brought to them by the farmers, or free-ranged. One farmer mentioned that these days most farmers have fewer livestock and keep them in stalls. Previously they were often kept free-ranged and in bigger herds. The livestock provided the farmers with manure for fertilization, eggs, milk, meat etc. They also served as an extra financial security in case of a bad crop yield. One farmer also had honey-bees, and the honey provided was a great source of income.

To manage land degradation, which was a problem in the area due to the slopes, the farmers had a few different approaches. Nutrient loss was managed by the use of green manure, also known as mulch, and the manure from the livestock. Some farmers also used crop rotation or fallow to further boost the regeneration of soil nutrients. Reduced soil erosion was one of the main services provided by the trees. They and other crops together created root systems that keeps the soil in place. A lot of farmers also used contours or terraces to further reduce the erosion. Most of the farmers thought land degradation was a problem, but that it was somewhat manageable with terracing and contouring. Only one of them did not see it as a problem, but thought it could be prevented with said methods. This might depend on the degree the fields sloped and the methods used to prevent degradation. The farmer that did not see it as a problem used contouring, had a large farm and only some of it was sloped.

Drawbacks that the farmers mentioned with their agroforestry systems was a lower yield of individual crops compared to other cultivation methods, that the system was labour intense
and the risk to get valuable crops stolen. The agriculture extension officer also mentioned that nutrient- and water-competition between crops were a problem, especially if nutrient loss was an issue.

The mentioned advantages with agroforestry were the constant yield of crops, improved resistance against diseases and extreme weather, better nutrient security due to the diversity in the farm, prevention of land degradation and access to firewood and timber. The extension officer also mentioned trees with deep roots could pull up deep soil nutrients and therefore increase the soil nutrients available to the other crops.

The problem with smaller and smaller plots of land inherited was mentioned. There is an increase in population and a decrease of the sizes of the farms. This can be a future problem if the population continues to grow, as it will eventually leave people with farms too small to support their family. Some informants had given their children parts of their agroforestry system already, and some had inherited a piece from their parents. To be able to support a population increase the food production will have to intensify, while the resilience of the farms must be maintained. Some of the farm systems might improve from a bigger crop diversity or if they introduced cash crops. Most likely there are limits in how productive the systems can be while being sustainable. This might lead to a situation similar to the east Usambara Mountains, were population increase led to cultivation of small and unsuitable areas.

6.2. Resource categories

As agroforestry systems are complex the different resources has been put in categories to make the next step of the analysis easier to understand and follow (see table 2). The resources are either internal or external. External resources is not necessarily less sustainable than internal ones. They do however lead to more a complex analysis of the system since these resource flow add other layers of components that need to be analysed.
**Table 2**: The table shows the different categories of resources the farmers used to manage their agroforestry. The categories will be used in the resource flow analysis.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Seeds (Seedlings, etc.)</td>
<td>Used for all planting.</td>
</tr>
<tr>
<td>2. Labour</td>
<td>Preparing, planting, weeding, treating, pruning, removing crops etc.</td>
</tr>
<tr>
<td>3. Nutrients (Soil)</td>
<td>Providing nutrients for the soil, crops and trees.</td>
</tr>
<tr>
<td>4. Treatment</td>
<td>Treating crop-diseases with chemicals or removing them.</td>
</tr>
<tr>
<td>5. Naturally provided (Sun, rain etc.)</td>
<td>The foundation for any sort of food production.</td>
</tr>
<tr>
<td>6. Capital</td>
<td>Generated from agroforestry production.</td>
</tr>
</tbody>
</table>

These categories conclude 6 different types of resources that the farmers used to manage their agroforestry system. Let’s look into why the farmers depended on these resources and what it means.

1. **Seeds.**
   The farmers needed seeds and seedlings to grow their crops. They were generally acquired in one of two ways; either the farmers planted the seeds their crops produced or they bought the seeds at the market. All the interviewed farmers bought maize-seed because the market seeds led to an increased yield. Another obvious way to plant seeds are from food bought at the market. This was however not a method practised by the farmers at this stage of their agroforestry, and will thus not be part of the resource flow analysis.

2. **Labour.**
   One of the most important resources was labour. The farm needs to be prepared, seeds planted, trees pruned, crops treated, weeds removed, crops harvested, livestock fed and cared for
and so on. There were three distinct groups in this resource category that preformed the work. The resident family, which is an internal resource in the flow analysis. Many also depended on their other kin or day-labourers to manage the farm. These two groups are external resources. The distance between these groups and the farm could vary and is not accounted for in the resource flow.

3. Nutrients
The nutrients are in this case soil nutrients, as they are the foundation for managing an agroforestry system. This resource category is required for the crops which in turn sustain the livestock and family. The farmers generally maintained nutrient levels by internal resources such as manure, and mulch. Some also replenished soil nutrients with fallow or crop rotation to reduce the pressure on the land.

4. Treatment
Regarding treatment for sick crops two methods were used by the informants. Some used chemicals (herbicides) to treat diseases when they struck. This was not preventive like in conventional agriculture. Some farmers instead removed the sick crop from the system to avoid spreading the disease. Some farmers choose to do this, and other did this because they could not afford chemical treatment. Removing the crops were also done if the disease had no treatment (See appendix II).

5. Naturally Provided
Clearly all farms are dependent on naturally contributed resources such as sunlight, wind, precipitation etc. The supply of these services could of course vary, but this is not something the farmers can affect with their management methods. This category is therefore not part of the resource analysis.

6. Capital
Capital was necessary for the farmers to acquire some of the other needed resources which could not be obtained to a sufficient degree inside their systems. To acquire capital the farmers sold cash crops such as coffee, bananas and maize, livestock products such as milk, honey and eggs, or livestock like chickens. The category capital includes capital generated from the agroforestry products. The flows show what resources the farmers invested their capital in on a regular basis to manage their farms. Capital investments that does not regard the agroforest-
ry management is shown as flow leaving the system. If no capital was generated by agroforestry products, then capital is not part of the analysis flow. This does not mean that the farmer did not have any capital to invest in the external resources, only that their agroforestry system did not produce it.
6.3. Resource flow on the farms

The general management of the informants’ agroforestry farms was to a large extent circular (see figure 5). Many of the resources were part of a closed loop system, and the systems were to a large extent based on reuse of resources. An example is how all the informants used leaves and other plant matter as mulch, and used their livestock manure to fertilize the soil. Very few resources were disposed of, even when sick crops were removed they could be used as fodder for the livestock. None of the farming systems were completely self-sufficient, but all were managed with only a few external inputs.

![Resource flow diagram](image)

**Figure 5:** An analysis of resource flow on all six farms. The black boxes shows what external resources the farmers used for management. The grey boxes signify the five resource categories presented in table 2. The white boxes shows the internal resources and products of the agroforestry. Dotted arrows means that the flow went one way, while the other arrows means that the flow went both ways. The white striped line is drawn around the crops and used as a reference when resources was used generally or in a varied way. In this case the arrow point to or from the white striped line.

When it comes to the individual farms the management varied. None of the farms were constructed and managed in the same way, but all of the system had some techniques in com-
Regarding the seeds, the farmers either bought them at the market or cultivated their own seeds. All farmers that used maize bought those seeds. Regarding treatment the farmers either used chemical treatment if their crops got a disease, or simply removed the sick crop from the production system. When it came to nutrients all the farmers used mulch and manure to fertilize their soil. Some also used fallow or crop rotation, but that is not represented in figure 5. The labour was performed by the resident family, and either by their kin living outside of the farm or by day-labourers. The dependence on outside labour varied between the farms. When it came to capital, not all systems produced it. Some farms produced no capital, and other produced plenty with cash crops and livestock. Now that the general flow of resources on the agroforestry farms have been studied, let’s look into the management of 3 of the individual farms.
6.4. Resource flow on farm A

**Figure 6:** The resource flow analysis of farm A does not include the category capital, as this farm did not create any capital. The grey boxes signify the five resource categories presented in table 2. The white boxes show the internal resources and products of the agroforestry. Dotted arrows mean that the flow went one way, while the other arrows mean that the flow went both ways. The white striped line is drawn around the crops and used as a reference when resources was used generally or in a varied way. In this case the arrow point to or from the white striped line.

This farm was managed with few external resources, partly due to limited capital. The farmer used crop rotation every year, and this year the crops consisted of maize, beans, cassava and sunflowers. The farmer had not planted any trees, so the trees included in the system were already there when the farmer took over the plot. The trees provided firewood and helped reduce soil erosion. Erosion was also prevented with contours. This year’s crops had been planted by seeds and seedlings from the farm, except for the maize-seeds. The farmer also kept cows and goats, using fodder from the farm and they produced manure used as fertiliser.
The farmers spouse was not taking part in the management of the farm, and much of the work was performed by day-labourers. If the crops got sick the farmer removed them from the system (*See figure 6*). The farmer could not afford to sell cash crops to generate capital, and all the yield was needed for the family. The farm did not produce enough to maintain the family, so additional food had to be bought. This farm was therefore not economically sustainable for the farmer. This was also the smallest farm, only 1 acre in size. Despite the problems the farmer was happy with the system and thought crop rotation worked well to keep the farm productive. Not affording to buy chemical treatment was something the farmer found problematic, as the yield was already too small to sustain the family. The family consisted of six people.

When looking at this system it is clear that something needs to be done improve the productivity of the system to provide the farmer with better food security and possibility to generate capital. Some external resources would be needed for this, either chemicals, cash crops, creating a more diverse system or simply expanding the acreage. But once such an adjustment would be done, the system could still be managed with few external resources, though perhaps with a slight increase. If the farmer can’t invest in new resources more education could perhaps improve the systems management and productivity. If nothing is changed, then the farmer could have problems with the system in a long term perspective, facing problems such as possible nutrient loss, weather fluctuations and climate change. It is still impressive that such a small agroforestry could provide fairly well for a family of six, so the system has a lot of potential to be a sustainable food production system.
6.5. Resource flow on farm B

*Figure 7:* The resource flow on farm B is a bit more extensive than on farm A. The grey boxes signify the five resource categories presented in table 2. The white boxes shows the internal resources and products of the agroforestry. Dotted arrows means that the flow went one way, while the other arrows means that the flow went both ways. The white striped line is drawn around the crops and used as a reference when resources was used generally or in a varied way. In this case the arrow point to or from the white striped line.

This farm was managed with more external resources than farm A, but was also providing the family with all they needed. The nutrients were maintained with mulch and manure, but the farmer also fallowed part of the land to decrease the pressure. The farm consisted of a total of four acres, of which two were cultivated and two were in fallow every year. The farmer kept the livestock, cows, chickens, goats and sheep, free-ranged. This means they would not necessary contain themselves to the boundaries of the agroforestry. This farmer did not need day-labourers. The family members could manage the farm together with their other kin. They bought maize-seeds, and the rest of the seeds was produced by the agroforestry. The
farmers used chemicals as treatment when the crops got diseases (See figure 7). The cash crops coffee, bananas and pigeon peas generated most of the capital. This farm was diverse and they also grew some medicinal plants. Soil erosion was prevented with terraces and contours, and the farmer stressed the importance of preventing soil erosion when creating an agroforestry in an area such as Haraa (with slopes). The family consisted of seven people.

When looking at this system it is seems rather sustainable and circular. This farm depended on more external resources than farm A but was managed in a rather circular way, as many of the resources contributed to something else within the system and little was disposed of. This system provided the family with what they needed and it seems as if it could keep providing that in the future. The farmer had no specific problem with the system.
6.6. Resource flow on farm C

*Figure 8: Farm C was the most diverse out of the three analysed farms. The farmers depended on a maize-field in another area, which of course is not to scale in this figure. The maize-field was almost twice as large as their agroforestry system. The grey boxes signify the five resource categories presented in table 2. The white boxes shows the internal resources and products of the agroforestry. Dotted arrows means that the flow went one way, while the other arrows means that the flow went both ways. The white striped line is drawn around the crops and used as a reference when resources was used generally or in a varied way. In this case the arrow point to or from the white striped line.*

The use of external inputs were more extensive here than on Farm A (See figure 8). On this farm both the spouses were interviewed about the management of the farm. The farmers did not use chemical treatment, instead they removed sick crops and fed it to the livestock. Regarding labour, the need for external resources was bigger on this farm than the other two. The farmers needed day-labourers all the time to manage their agroforestry, whilst all the
other farmers mainly needed day-labourers during the weeding season or other intensive parts of the year. This farm was significantly bigger than the other two. The farm was eight acres. The farmers also had a 15 acres maize-field in a nearby village. The reason was that the agroforestry did not produce enough maize to sustain the family. The size of the resident family on this farm is slightly unclear, as part of the farm had relatively recently been split up. The family consisted of ten people, but some of them was managing the maize-field.

This system seems rather sustainable and circular, but the other maize-field significantly reduces the circularity. This family depended on more external resources than farm A and B. The limits with the system the farmer mentioned was that the yield of maize was too little to sustain the family, which is why they needed the maize-field. The farm was significantly bigger than the other two, and provided for a bigger family as well. This agroforestry seemed to provide everything the farmers needed except for the maize.

6.7. Summary of the Analysis

This study shows that like in the studies in Zimbabwe and Brazil, a few external resources were used by the farmers. Their agroforestry systems were to a large part managed with internal resources. The systems are circular and closed-looped to some degree. The analysis shows that all of six farms reused resources and therefore reduced the need for external resources, which is part of the definition of circular economy.
7. Conclusions

*Does the investigated agroforestry systems reuse and produce resources in a circular manner? Which external and internal resources are used in the systems?*

The investigated farms are generally dependent on few external resources and to a large extent work like circular production systems.

The external resources the informants used were seeds, chemical treatment, labourers and in some cases fodder for their free ranged livestock. Not all farmers used all of those external resources, but all of them used at least one.

The rest needed to manage the agroforestry farms was provided from internal resources. This shows that the farmers kept a resource flow circling within the farm system and avoided wasting resources. The internal resources produced in the system were soil nutrients, labour, prevention of land degradation, fodder for the livestock, food for the family and capital from cash crops and livestock.

*Do some farmers use more external inputs? If so, why?*

Yes. The farmers’ way to manage their farm varied, and none of the farms were managed in exactly the same way.

All the farmers grew maize and thus bought maize seeds, which is a recent change. The market seeds were introduced in 1990 but the farmers only started to use them a while ago as they noticed the increase in yield with the seeds provided by the market.

Dependence on outside labour seemed to vary with how big the acreage of the agroforestry was, how diverse the system was and how big the resident family taking part in the management was. Bigger plot and/or a more diverse system combined with less labour resource on the farm demanded more external labour to maintain the system.

Four out of the six agroforestry systems used chemical treatment when necessary. This makes sense since none of the informants seemed to use medicinal plants or beneficial insects for
such purpose, thus the chemical treatment was the only option if the farmer wanted the yield of that crop. However, by removing sick plants the “wasted” crops could be used as a resource to feed the livestock, which meant it still served an important purpose in the management. Chemicals were a common external input amongst the informants, even if they were only used to a small extent.

How the livestock was kept and fed varied amongst the farmers. If they were kept free-ranged they could eat where they wanted. If kept in stalls most farmers fed them with fodder grown on the farm, or if that didn’t suffice on grass collected in the area.

No farm had significantly more or less external inputs that the others. However one farmer wanted transition to a new modern way of farming which would mean buying all seeds and using more fertilizers than the farm could provide. If the farmer makes that transition that farm will be using more external resource than the others. The reason the farmer wanted to change the management was that it would increase the yield.
8. Discussion

Out of the three farms in the resource analysis farm B or C would be the most sustainable since the farmers could produce an abundance and grow what crops they wanted. On farm A the farmer bought crops that was cheap to maintain and could not afford chemical treatments even if they wanted to. Farm A seemed pretty sustainable, so perhaps the system could be sustainable if only the farmer had access to a bigger land plot to cultivate.

Perhaps the use of chemicals opportunistically is a sound way to maintain a farm since it reduced the risk of crop failure. The farmer on farm B did not mention any problems with diseases this year, whilst the other two mentioned several diseases. Perhaps this was also an unfortunate coincidence which made this farm seem more sustainable, or perhaps the diseases were not thought of as a big problem when the farmers had the resources to treat them.

Farm C seemed sustainable and highly productive, but the farmers also had a maize field in a nearby village because the agroforestry did not produce enough maize for them. When asked which system they’d chose if they could only keep one they chose the agroforestry because of the food diversity and security.

The use of labourers outside of the farm residence is not necessarily a problem. Outside family-members and day-labourers work kept the agroforestry in good condition and labour-intense work could not be sustained without them, such as weeding. There could however be a problem with the sustainability with the outside workers lifestyle. For example, if the extra labourers live far away and use a lot of fossil fuel to go there, then the system is somewhat dependent upon unsustainable resources to be maintained. Since the lifestyles of the day-labourers where not investigated not much can be said about it, but it is safe to assume some farmers depended on a workforce that did not share their lifestyle.

Future climate change might pose an extra strain on Haraa since the current IPCC report concludes that precipitation is likely to increase in the area. This is not necessarily a problem, but as land degradation is already an issue the situation could escalate. If the rainfall increases there will most likely be an increase in soil erosion and nutrient runoffs.
Can the investigated farms be considered sustainable? Yes, to some degree. The systems investigated are not perfect but all hold potential as sustainable systems. They are definitely all less dependent on external resources than conventional farm systems and can still produce enough to maintain social and economic stability for most of the farmers. However, there are still some matters needed to be studies at the farm level, such as soil nutrients and future climate change, to determine if these system can maintain the farmers in the long run.

8.1. Future research

Land degradation can increase with climate change. Researching the current state of soil nutrients can be important in order to determine how sustainable the farms are. If the soils are low on nutrients, future conditions might decrease the yields to a point where they cannot sustain the farmers. Gathering soil samples and investigate nutrient content could help determine the current state of the soil fertility.

Climate change will affect the farmers’ access to naturally produced inputs such as water. To predict how this could affect the productivity of the farms, climate change models could be investigated and evaluated. This can help determine which challenges the farmers’ face that will increase. This is also important to determine long term sustainability.

The population increase in Haraa has led to some agroforestry farms shrinking in acreage. Interviewing the new generation of farmers could give valuable insight in if they see this as a problem and how they cope with it. Defining smallholder farm-owners strategies to create sustainable farmlands could both be used to find new methods of management or to investigate proposed methods of managements of small farms.

Theft of valuable crops is a problem not unique to Haraa. It is a problem connected to agro-forestry and other farming methods with valuable cash crops. Currently the inhabitants in Haraa does not seem to have any methods of dealing with this problem. Interviewing farmers in Haraa to find out if this is a big problem to them could help determine how widespread the problem is. Doing a comparative study with an area that has implemented a method of dealing with crop theft could be used to see if the method has improved the conditions for the farmers.
9. References


10. Appendix

10.1. Appendix I – Interview guide

Social facts
Name, gender, age, education, family members, ethnicity, where are you from?

Land use
Acres cultivated?
Acres of agroforestry?
Have you had any problems with soil-erosion?
Have practicing agroforestry increased your livelihood- and food security?

History
How long have you been practicing agroforestry?
Why here?
What did you do before agroforestry?

Organisation structure/gender
What is the family members’ duties? (male, female, children)
Who decides what? Is there a difference between male and female decision-making?
Is there a difference between being a woman in agroforestry systems and conventional agri-cultural systems?
Has the communication between genders increased since you started practicing agroforestry?
Other affects for women in the household?

Other agriculture
Where? What? Why? Do you use some of that produce for your agroforestry?

Crops
What do you cultivate in your agroforestry (Perennial most important)? (Banana, grevillea, coffee, beans and corn)
Can you tell us a bit about why have you chosen those crops?
Where do you get the seeds?
How do you fertilize the crop? Mulch, manure, other
How do you counteract pests? Weeds? Diseases (crop-related)
Do you own any livestock/cattle?
How do you keep them/graze them?
How do they contribute to the agroforestry (manure etc.)? How does the agroforestry contribute to them (fodder etc.)?
Is there something else the livestock needs that has to be bought?
Can you tell us about how the labour-intensity looks like during a year? (Calendar)?
Do you use day-labourers some parts of the year/sometimes?
Do you cooperate with your neighbours or some organization?
How much yield do you sell from a harvest? (Crops/logs/others)
Do you trade with the neighbours? If so, what do you trade?
Where do you get your firewood and timber (for building)?
Where do you get your food?
Do you rotate your annual crops during the years? Can you tell us a bit about it?
Any crops that you have tried but didn't work so well?

**Tenure security**
Important?
Marked boarders?

**Benefits**
What are the positive benefits with agroforestry?
What are the negative sides with agroforestry?
What is the ecological benefits of agroforestry?

**Knowledge**
Did you have a good knowledge about agroforestry when you started?
How did you get the knowledge about agroforestry?

**The transition**
Why did you start with agroforestry?
Why do you prefer agroforestry? (Knowledge of benefits, inherit, food security, non-erosion, water efficiency, increase in income, tenure security, carbon sequestration, climate change?)

RANKING

How did you start the transition? Planting a few trees? Change of crops?

Why did you choose that/those methods?

What was the main challenges or barriers with adopting to agroforestry? (Costs, lack of knowledge). Ranking?

Where you worried of any risks by adopting to agroforestry?

Attitude??

What could have made the transition easier for you?

Future

Would you like to change anything in your agroforestry in the future?

Will the children take over the agroforestry?

Do you experiment with different crops to try to find new ways to cultivate?

Are you satisfied with the security that the agroforestry system gives you?

Questions for us?

10.2. Appendix 2 – Crop diseases

Table II: Diseases mentioned by informants, their effect on crops & how to get rid of them

<table>
<thead>
<tr>
<th>Disease</th>
<th>Target</th>
<th>Affect</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee Bean Disease</td>
<td>Coffee</td>
<td>x</td>
<td>Pesticides</td>
</tr>
<tr>
<td>Coffee Leaves Rust</td>
<td>Coffee</td>
<td>Attacks leaves</td>
<td>Pesticides</td>
</tr>
<tr>
<td>Maize Stock Borers</td>
<td>Maize</td>
<td>Bores into the stock of the plant</td>
<td>x</td>
</tr>
<tr>
<td>Maize Lethal Necrosis</td>
<td>Maize</td>
<td>x</td>
<td>No treatment, removal of plant</td>
</tr>
<tr>
<td>Armyworms</td>
<td>x</td>
<td>Eats plants leaves</td>
<td>Pesticides, drowned by precipitation</td>
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<td>-----------</td>
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