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Biochar as soil amendment
– A comparison between plant materials for biochar production from three regions in Kenya

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Degree project in Biology
Agriculture Programme – Soil and Plant Sciences

Institutionen för mark och miljö, SLU
Examensarbeten 2011:12

Uppsala 2011

SLU, Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
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EX0418, Independent project/degree project in Biology, 15 credits, Basic level, G2E
Agriculture Programme – Soil and Plant Sciences

Institutionen för mark och miljö, SLU, Examensarbeten 2011:12
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Keywords: biochar, Kenya, soil fertility, pyrolysis, pot trial, interviews, soil amendment

Online publication: http://stud.epsilon.slu.se

Cover: Small-scale farm in Siaya, photo by Helena Ström

Summary

The majority of the people living in sub-Saharan Africa earn their living mainly by farming. Infertile soils and variable climate make it difficult to reach sufficient crop yields every year and therefore food security can be low. Soil quality reduction due to erosion and nutrient depletion due to limited addition and maintenance of nutrients is a common problem. One feasible measure to increase soil fertility is addition of biochar, charcoal produced during pyrolysis (organic material, usually wood, heated under low oxygen conditions), which generally is used as fuel for cooking.

This Minor Field Study is a BSc thesis based on studies of biochar as soil amendment in Kenya. The project had three main objectives. The first aim was to, through visits, describe smallholder farming systems in three areas in Western, Central and Eastern Kenya. Interviews, observation and sampling of characteristic organic materials were performed in each area. The second aim was to measure whether biochar application to soil can increase crop yields and if so, if there are any differences between biochar originating from different feedstock organic materials. The third aim was to return to the involved farmers and discuss and present the results as well as the possible practical benefits.

All the visited farms were small-scale systems with no or few external inputs. The farming systems were similar in all three areas, though some differences were found, e.g. dominating types of crops. Most of the farmers were interested in using biochar as soil amendment- if it would be proven to have beneficial effects and be economically viable.

The results from analyses showed that nutrient concentration correlated with the yield from pot trials where three treatments stood out: biochar from cassava stems, coffee leaves and fresh banana leaves. Biochar from these materials in general had the highest nutrient concentration as well as pot trial crop yield, indicating a fertilizer effect. Plant materials with different properties may be important for plant growth, but biochar rate seems to be a more significant factor, confirmed by the statistical test.

The great need of improvement in soil fertility and the farmers' interest towards biochar indicate that this approach might be possible to use in the future. However, more research on the subject is necessary if it is going to be implemented in the field, since these farmers cannot afford failures.

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1 Introduction

Figure 1. Map of Kenya and the three studied areas circled.

1.1 Kenya

Kenya is a developing country at the equator in East Africa. The altitude ranges from sea level to peaks of over 5000 m in the interior highlands. Climate and vegetation vary widely across the country, from sub-humid highlands in the West and Central areas to arid savanna in the South, and tropical along the coast. The rainfall comes in two periods, the long rain in March-May and the short rains in November-December. Due to the difference in topography the mean annual precipitation ranges from <250 mm up to >2000 mm (FAO, 2006), hence the agricultural conditions differ considerably between regions. The Great Rift Valley, crossing the central country from North to South, is one of the most fertile and productive agriculture areas in Africa, due to the volcanic soils and favorable climate. Consequently, most of the agriculture is located in central Kenya. Agriculture is essential, as ca. 75 % of the population earns their living mainly by farming. In general the farms are small-scale, run by family members. The common food crops cultivated are maize, cassava, beans, sorghum, fruits and vegetables, while the main exported cash crops are coffee, tea, fruit, vegetables and cut flowers (CIA, 2010).

Kenya has a population of 39 million and a growth rate of 2.69 % per year (CIA, 2010). The country is, as well as the entire continent of Africa, facing major problems in ensuring food security for the increasing population. As the gap between produced food and the demands of the population remains, the trend during the past decades has been a decline in per capita food production with increased poverty, famine and malnutrition as consequences. This is due to many contributing factors, for example wars and widespread corruption leading to poor communications and bad infrastructure. These and other factors have led to limited agricultural modernization, especially nutrient management which in turn has led to land degradation, mainly affecting smallholder farms who cannot afford import of external resources. Causes behind the soil degradation are for example erosion, insufficient fertility restoration, e.g. fallow, and lack of fertilizer and other means to maintain nutrients in the soil. To improve food supply for the African population and retain or re-create fertile agricultural soils it is necessary to turn this negative nutrient balance and avoid the link between soil degradation and poverty (Nandwa, 2003).

1.2 Project description

This minor field study (MFS) is BSc thesis based on biochar as a soil amendment. There were three main aims of this study. The first aim was to obtain an overview of small-holder farming systems in three different areas in Kenya. This was realized through interviews and observation on six farms in each of the three areas. The second aim was to investigate whether biochar can give an increase in crop yield and if so, if there are any differences between organic materials used as feedstock for biochar production. Crop residues/feedstock, typical for each area, were sampled and used as base material for biochar generation. Chemical analyses and pot trials were carried out to evaluate the properties of the different materials. The idea is that organic materials occurring in sufficient and available forms on the farm (plant residues, manure, food wastes etc.) could be used by the farmers themselves to make biochar on the farm. The third aim was to return to the farmers and present and discuss the results.

Our hypothesis concerning biochar as soil amendment is that incorporation/application will increase crop yields. The beneficial effects could be explained by an addition of nutrients, increased CEC and/or improved water soil dynamics (Lehman & Joseph, 2009).

The study will be a part of, and act as precursorto to a study managed by Dr Kristina Röing de Nowina and Prof. Olof Andrén at the Swedish University of Agricultural Sciences (SLU) in cooperation with The International Center for Tropical Agriculture`s Tropical Soil Biology and Fertility Institute (CIAT-TSBF). This study includes a long-term project with the purpose to evaluate the long-term effects of biochar on soil fertility.

2 Background

2.1 Soil fertility in East Africa

Considering the variation in altitude, climate conditions and vegetation, sub-Saharan Africa can be defined as different agro-ecological zones (AEZ). Areas with similar soil properties and agricultural production are defined as belonging to the same AEZ. The definition is based on many factors, but the primary determinants are rainfall and temperature (Nandwa, 2003). Although a wide range of soils are represented in Africa, the ancient geology with highly weathered parent material gives large areas low natural soil fertility (Okalebo et al., 2007). The low nutrient concentration and high soil acidity create major challenges for the African agriculture, where the main effort previously may have been put on solving problems of erosion and drought. However, nowadays soil degradation with decline in fertility is considered to be of fundamental concern for food and nutrition security. Maintenance of soil fertility by turning the nutrient imbalance, involves returning nutrients removed by harvest as well as lost via runoff, erosion and other pathways. Some crops, more than others, effectively deplete the soil of its nutrients. The nutrient depletion of the African soils is extensive and annually 4.4 Mt nitrogen, 0.5 Mt phosphorus and 3.0 Mt potassium are lost (South Africa excluded). To compensate the depletion and retain soil fertility the farmers need to re-apply nutrients regularly. However, fertilizers are expensive and the common farmer cannot afford to apply the amount equivalent to what is being removed. In general, the fertilizers are applied on cash crops for export, such as tea and coffee. In many cases, farmers have to rely on other cultivation strategies as adapted crop rotation, intercropping and fallow. Further, a growing population increases the pressure on the arable land reducing the possibilities for fertility restoring measures such as fallow (Sanchez et al., 1997).

2.2 Areas

The field work for this study was carried out in three areas in different parts of Kenya: Siaya in the west; Embu in the central highlands; and Kwale in the eastern coastal lowlands. The chosen areas represent different AEZ, with differences in altitude, climate conditions, soil properties and agricultural production. Climatic conditions and population data for the areas are found in table 1.

Table 1. Facts about the areas

	Siaya	Embu	Kwale
Area (km^2)	1520[1]	730[3]	9000[5]
Population	493 326[1]	294 000[3]	600 000[5]
Altitude (m.a.s)	1100 - 1400[2]	700 - 2500[4]	1 - 650[5]
Mean annual temperature (°C)	22.5[2]	18 - 21[4]	26.3[4]
Mean annual precipitation (mm)	800 - 2000[2]	650 - 2200[4]	400 - 1200[5]
Long rains	Mar - June[1]	Mar - May[4]	Mar - July[5]
Short rains	Aug - Nov[1]	Oct - Nov[4]	Oct - Dec[4]
Planting	Jan - Mar[1]	Mar - Apr[4]	Feb - Apr[4]
	July - Sep[1]	Sep - Oct[4]	June[4]
Harvesting	June - Aug[1]	Aug - Sep[4]	June - Aug[4]
	Nov - Feb[1]	Dec[4]	July - Nov[4]

[1]Siaya district development plan 2002-2008, [2]Jaetzold & Schmidt, 1982, [3](NCAPD), 2005).
[4]Jaetzold & Schmidt, 1983, [5]Kaguara et al., 2008.

2.2.1 Siaya

Western Kenya was represented by the district of Siaya within the Nyanza province, this area is located north east of Lake Victoria. Three areas within Siaya district were visited: Siaya, Nyalgunga and Nyabeda.

Most of the population (76%) is living in the rural areas of the district which comprises 80 % of the total area. Highest population density is found in the most fertile locations, and the average density is 325 persons/ km^2. There is low population grow rate (0.9%) due to the fact that 38.4% of the population is infected with AIDS/HIV. Totally 120 000 families are occupied within the agricultural sector and each household compromises approximately four members. An average farm in the district is small scale with the size of 1.05 ha. (Siaya district development plan, 2002-2008). Approximately 200 000 individuals of the rural population, in the district are absolute poor (not able to fulfil basic food and non- food needs). It is only during 4 months per year that the area is self-sufficient in producing food. Poverty and low yields are linked and some reasons for this are low soil fertility, traditional farming practices, high death rates because of HIV/AIDS and unpredictable rainfalls (Siaya district development plan 2002-2008).

The agro- ecological zone within the area varies from poor livestock- millet zone to productive sugarcane zone. There is a difference in rainfall between the zones of 60%. This is due to the varying altitude which raises a rain gradient with low precipitation in the low lands towards more rain when altitude is rising.

Both common crops and cash crops are cultivated and the cultivated area are 71 299 ha for common crops and 1500 ha for cash crops. Cultivated cash crops are cotton *(Gossypium spp.)*, rice *(Oryza spp.)*, groundnuts *(Arachis hypogaea)*, sugarcane *(Saccharum officinarum)*, coffee *(Coffea spp.)* and tea *(Camellia sinensis)*. Common crops that cultivated are maize *(Zea mays)*, sorghum *(Sorghum spp.)*, millet *(Panicum spp.)*, beans *(Phaseolus vulgaris)* and cassava *(Manihot esculenta)***.** Goats, sheep, dairy cattle and a local variety of zebu are the most common livestock in the area (Jaetzold & Schmidt, 1982). The majority of the population use firewood or charcoal as an energy source. As a consequence, deforestation in Nyanza province is a big problem (Siaya district development plan 2002-2008).

The fertility in the area varies but is in general low (Jaetzold & Schmidt, 1982), which partly is explained by the widespread Acrisol soil type which commonly is associated with low fertility (Okalebo et al., 2007). However, the most common soil type is a Ferralsol, which ranges from moderate to low fertility. Inputs of organic or inorganic fertilizers are necessary to most of the soils for crop production. Many areas have moraine underlying the soil and the moisture retention is poor (Siaya district development plan 2002-2008). Other problems connected to these soils are nematodes and shallow soil profile **(**Jaetzold & Schmidt, 1982).

2.2.2 Embu

The district of Embu is situated in the south of the Eastern Province on the slopes of Mount Kenya and occupies a total area of approx. 730 km^2. The population in the district was nearly 294 000 (2005), and the population density was 564 per km^2. The population growth rate 1989-1999 was 1.7 %. Half of the population is classified as poor (National Coordination Agency for Population and Development (NCAPD), 2005).

The high mountain gives a varying climate and this variation and the differences in soil fertility make it possible to grow a lot of different crops within the district (Jaetzold & Schmidt, 1983). Approximately 1/3 of the area in Embu has favorable climate and fertile soils ideal for small scale farming, but the other 2/3 only have marginal potential for agricultural practice. Agriculture stands for 70 % of the income in the district (NCAPD) 2005). The small scale farming includes cash crops: tea *(Camellia sinensis)*, coffee *(Coffea spp.)* and different vegetables and food crops: maize *(Zea mays)*, common beans *(Phaseolus vulgaris)*, bananas *(Musa spp.)*, potatoes *(Solanum tuberosum)* etc. and livestock (Jaetzold & Schmidt, 1983).

The most fertile areas are cultivated with tea and coffee whereas the poorer areas are used for livestock and millet *(Panicum spp.)*. These areas have approximately a tenth of the production potential of the better areas. This is mostly explained by soils with very poor fertility as well as low precipitation during the growth period. The infertile soils and the unfavorable climate conditions give much lower yields and permanent cultivation is becoming more difficult. The fertile soils are those originating from volcanic areas whereas poorer soils, more suitable for tolerant crops like millet and sorghum *(Sorghum spp.)* are found outside these areas (Jaetzold & Schmidt, 1983).

The visited farms were all situated in the village Kibugu located around 8 km north of Embu. The rain falls during two periods per year and planting, cultivation and harvest take place during these. During the long rains (see Table 1.), crops with good potential yield are: cabbage *(Brassica spp.)*, late maturing maize, finger millet *(Eleusine coracana)*, potatoes etc. Common beans, sweet potatoes *(Ipomoea batatas)* etc. are crops with good yield potential during the short rains. Cash crops e.g. tea, Arabica coffee and other crops e.g. bananas and mountains papaya *(Vasconcellea pubescens)* are grown all year around (Jaetzold & Schmidt, 1983).

Kibugu is classified as a Coffee-Tea, Upper Midland zone. The length of the cropping season varies from short/medium cropping season to a full cropping season, depending on where the farm is located. The farms in the Upper midlands use approximately 30 % of their land for annual crops, 20 % for perennial crops, 20 % for grazing and 6 % is used for fodder. Fertilizers and intercropping are commonly practiced in the area. The most important annual crops are maize and beans (Jaetzold & Schmidt, 1983).

Due to the closeness to Mt Kenya, the topography and soil types differ between high and low laying areas. At higher altitudes heavier soils occur whereas a wide range of soils, from light to heavy, appears in lower areas. On Mt Kenya the soils are very suitable for tea cultivation, being well drained soils with high clay content. Around Kibugu the soil called Kikuyu red loam is found and it is a soil originating from tertiary basic igneous rock. Characteristic for these soils are that they are deep, have high clay content and are well drained. The soil is classified as a Nitosol/Andosol (Jaetzold & Schmidt, 1983).

2.2.3 Kwale

The Kwale district is situated in the Coast province in the Southeast of Kenya and borders to Taita Taveta district, Kilifi district and Tanzania. The district is divided into three smaller regions: Kwale, Msambweni and Kinango. The total population is nearly 600 000 people and the population growth rate is 2.6 % (Kaguara et al., 2008).

Overall, the climate is monsoon affected with hot and dry weather from January to April, but cooler between June and August. There is a variation in altitude, from sea level along the coastline to the more hilly hinterlands. Hence, the annual rainfall ranges widely and decreases further inland (Kaguara et al., 2008).

The underlying geology is mainly originating from secondary marine sediments derived from the weathering of the Basement System rocks in the hinterlands. Erosion of the sediments has resulted in escarpments in the zones between beach plains and foothill. The soils occur in a pattern going parallel with the coastline and show a variety in properties ranging from consolidated sand, silt and clay to limestone. However, along the coastline the soils are derived from coral rocks. Due to the variation in parent material and topography the soil fertility is highly variable. Soils in the coastal uplands are in general of low fertility while soils from the uplands down to the lower plains are of low to moderate fertility. The fertility of soils derived from limestone usually is high (Jaetzold & Schmidt, 1983).

Since climate conditions and soil properties differ considerably within this region, the yield potential in the areas differs for different crops. Consequently, the area can be defined as several AEZ, where different kind of agriculture is practiced. Within the AEZ there may also be smaller sub- zones due to internal differences. Along the south coastline there is an area known as the Coastal Lowland Sugarcane zone, which receive the largest rainfall in the district and hence has a long cropping season. Interior, where the landscape turns hillier, the Coconut-Cassava zone followed by the Cashew nut-Cassava zone run in parallel with the coastline. The rainfall in this area is intermediate with a medium cropping season. The further hinterlands, known as the Coastal Lowland Ranching and Livestock-Millet zones, have rather low rainfall and short cropping seasons. In these areas the yield potential is relatively low and they are more suitable for pasture (Jaetzold & Schmidt, 1983).

Permanent perennial crops cultivated year round are coconuts *(Cocos nucifera)*, cashew nuts *(Anacardium occidentale)*, cassava *(Manihot esculenta)* and citrus *(Citrus spp.)*. During the first rains the main food crops are maize *(Zea mays)*, sometimes intercropped with common beans *(Phaseolus vulgaris)* or cow peas

(Vigna unguiculata), and sweet potatoes *(Ipomoea batatas)*. During the second rains, the dominating crop is maize and maize intercropped with common beans or cow peas. Due to difference in the onset of the long rains over the district, the time of planting and harvesting vary. Cashew- and coconuts are harvested year around but mainly during autumn and winter (Jaetzold & Schmidt, 1983).

Agriculture is the major livelihood within the Kwale district, where over 90 % of the population is practicing mixed farming, i.e. a combination of crop production and small-scale livestock, or only livestock farming. The remaining proportion is occupied with fisheries or within the tourist industry. Throughout almost the entire Kwale district, the trend in food security is deteriorating. The main reasons are a small proportion cultivated area and yield failure due to low and poor distributed rains. The production of grains, vegetables and beans is equivalent to 60 % of the district requirements and the deficit is met from import from neighbor districts (Kaguara et al., 2008).

In the Kwale district six farms from two areas where part of the study, three in Mbegani and three in Mwachome, both found within the Cashew nut-Cassava Zone. The area receives intermediate rains and has a medium cropping season. During the long rain, crops with a good yield potential are maize, sorghum *(Sorghum bicolor)*, millet *(Panicum spp.)*, sweet potatoes, beans and most vegetables. During the short rains sorghum, millet, common beans and sweet potatoes have a fair yield potential in the main part of the area. Whole year around crops are coconuts, cashew nuts, cassava and fruits such as mangoes *(Mangifera spp.)*, papayas *(Carica papaya)* and bananas *(Musa spp.)* (Jaetzold & Schmidt, 1983).

2.3 Biochar

Biochar is charcoal produced during pyrolysis, a process where organic material is heated under low oxygen conditions. One usage of biochar from crop residues is as soil amendment whereas charcoal, made from wood, generally is used as fuel. Besides generating biochar, pyrolysis also results in liquids and gases which can be used as sources of energy. The energy derived from the heating process can be used for other purposes e.g. cooking. Due to the high stability of carbon in biochar, biochar added to soil may act as a carbon sink and might be part of a solution to the global warming problem by reducing the concentrations of carbon dioxide (CO_2) in the atmosphere. An example of the stability of biochar is the Terra Preta soils found in South America. 2000 years ago Indians added organic wastes to the soil which due to the anaerobic conditions turned into stable forms. These soils are still very fertile and suitable for agriculture (Biochar International Initiative). Glaser et al. (2000) proved Terra Preta soils to be more fertile than the Ferralsols and Acrisols in the area. The Terra Preta soil had higher concentrations of C, N, P, Ca and also higher cation exchange capacity (CEC), base saturation (BS) and pH, indicating higher fertility. Wolf (2008) showed that possible global production of biochar from crop residues could be 1 Pg C /year, based on the mean C concentration of 48 % in biochar. This corresponds to 549 million tons of CO_2 (Scherr & Sthapit, 2009).

Besides acting as a carbon sequester, biochar has several beneficial effects on soil properties, such as increased water holding capacity (Karhu et al., 2011), enhanced CEC, BS (Yuan & Xu, 2011), as well as add nutrients and improve the plant uptake of nutrients (Lehmann & Joseph, 2009). However, research on biochar's effect on soil CEC is not coherent. Novak et al. (2009) did not find a significant increase in CEC after biochar addition.

2.3.1 Production conditions

Primary factors determining the quality of biochar are type of organic material used as feedstock and process temperature (Gaskin et al., 2008). Different elements such as lignin, hemicelluloses and cellulose are degraded at different production temperatures. Since organic material differs in the composition of these elements the decomposition rate between plant species will vary. Further, time for harvest, climate and nutrient status of the soil affects the composition. All organic materials start to undergo thermal decomposition at temperatures above 120˚C. The ash content is important for the physical properties of biochar and varies between organic materials. High ash content may cause deterioration of structure, hence resulting in less stable biochar (Lehmann & Joseph, 2009).

Biochar produced under low temperature conditions (<300- 400 ˚C) has low surface area and are only partly carbonized, whereas higher temperatures (400-600˚C) increases the porosity (Lehmann & Joseph, 2009). The active surface area is enhanced by high temperature conditions, while CEC is decreased as a result of loss of functional groups (Gou & Rockstraw, 2007). Further, studies have indicated that high temperatures might result in nutrient loss via volatilization (Jensen et al., 2000; Olsson et al., 1997). When the temperature exceeds 500˚C as much as 50 % of N may be lost (Gaskin et al., 2008). In addition, P concentration decreases at higher temperatures. Other factors affecting the properties of biochar are heating rate, heat transfer inside the vessel and pressure during production (Lehmann & Joseph, 2009).

2.3.2 Nutrient properties

Biochar affects soil fertility in many ways; it can add nutrients by itself or make them more available for plant uptake by enhance the decomposition of organic material- or, possibly, reduce decomposition rates of other organic material thereby increasing soil C concentration in the long run. Moreover, the large surface area results in increased CEC, which may prevent nutrient leaching and thus eutrophication (Lehmann & Joseph, 2009). Lehmann et al. (2003) found a significant decrease in leaching of applied fertilizers after charcoal addition. Further, improved plant uptake of P, K and Ca was observed. By increasing CEC, applied fertilizers can be adsorbed to the surface area and thereby used more efficiently by plants (Steinbeiss et al., 2009). Incorporation of biochar may therefore give higher yield with the same amount of fertilizers. Nutrient uptake and availability can also be affected by change in pH as a result of biochar addition (Lehmann & Joseph, 2009).

The total nutrient concentration in biochar can be high, however the proportion of plant available nutrients can vary. Depending on which kind of feedstock is being used for biochar production, the proportion of available nutrients differs (Lehmann et al., 2003). Nutrients, as N and S, in organic compounds, are tightly bound and therefore less available to plants, which has been proven from previous studies (Lehmann & Joseph, 2009). Carbon is the major fraction in biochar. When produced from plant residues Wolf (2008) found the average carbon concentration in biochar to be 47.6 %. However, Gaskin et al. (2010) showed that carbon concentration in biochar produced from poultry manure and pine chips can range between 40-78 %.

In general biochar has a high C/N ratio (mean value of 67) which indicates that immobilization of nitrogen can occur when applied to soil. Because of the carbon stability it cannot easily be digested by microbes and therefore N mineralization can occur. The surface area can be colonized and small pores act as refugee site for microbes to avoid grazers. The variation in pore size of biochar promotes different habitats and thus microbe diversity (Lehmann & Joseph, 2009).

2.3.3 Properties in the soil

Large surface area has many beneficial effects, e.g. on soil fertility by increased CEC, biological activity, water and air circling in the soil. Large surface area is enhanced by considerable proportion of pores and results in high CEC (Lehmann & Joseph, 2009), as well as enhanced biological activity (Steiner et al., 2008). However, some researchers have found contrary results showing a decrease in microbial biomass carbon after biochar addition (Dempster et al., 2010). Porosity can increase gradually if biochar contains high concentration of ash which eventually will leach from the pores (Lehmann & Joseph, 2009). An increase in biochar CEC in soil over time has also been shown, due to oxidation (Chen et al., 2008).

It is primarily micropores, with a diameter <20 Å, that contribute to the surface area, and it has been shown that microporosity increases with temperature during production. Micropores adsorb small molecules as gases and common solvents whereas macropores are more important for root development and soil microbes. The proportion between micro- and macropores depend on the substrate and its properties, e.g. the dominating cell types in the plant material. The surface area of biochar is as big as or bigger than the surface area of clay. The properties of biochar resemble clay aggregate properties and therefore application of biochar could give soil conditions with a more clayish feature, providing some of the beneficial properties a clay soil has for plant growth (Lehmann & Joseph, 2009).

2.3.4 Earlier work in Kenya

Torres and Lehmann (2009) have carried out a study in western Kenya where the purpose was to investigate smallholding farmers' possibilities to use biochar as soil amendment, while using the energy, derived from burning, for cooking. The yield on the farms was investigated to examine whether the plant residues were enough for using for biochar (Lehmann & Joseph, 2009).

A study by Kimetu et al. was started in western Kenya 2005, where biochar was added to agricultural soils. The aim was to investigate the effects of biochar addition to fields in different stages of degradation. The results showed best effect on fields furthest in degradation. The effect on yield could not alone be explained by addition of nutrients, but also by enhanced water holding capacity (Cornell University, n.d.).

In the Nandi district in western Kenya there is ongoing research on production and usage of biochar. The research is run by the Biochar International Initiative and is part of a project with the purpose to make an adequate pyrolysis cooking-stove for biochar production. Further, the aim is to extend biochar application as a practice within small-scale farming in Kenya (Biochar International Initiative).

3 Material and methods

The study was divided into two parts: 1) fieldwork and 2) laboratory work with samples from the field. The project was carried out during a two month period. The report is written collectively, except from the parts about the areas, where Tellie has written about Siaya, Kajsa about Embu and Helena about Kwale.

The first part consisted of field work and to attain the first aim, i.e. to get a general overview of Kenyan small hold farming system, interviews were held in three different areas, six farms in each area. Observation and sampling of organic materials characteristic for each area were done. Finally, the results were presented and discussed with the involved farmers.

The second part consisted of laboratory work, where a production method of biochar, was devised. Biochar from each material was produced and analyzed for nutrient concentration. To examine whether biochar could give an increase in crop yield, a pot trial with a soil from one of the studied areas were set up. Different rates of biochar were added and a comparison of plant height and dry weight was made to identify any possible differences between the organic materials.

3.1 Selection of study objects

The farms included in the study were situated in three different areas in Kenya. Six farms in each area were visited: Siaya in the western, Embu in the Central Highlands and Kwale on the south eastern coast (See figure 1).

All visited farms were already part of existing experiments connected to CIAT-TSBF (Tropical Soil Biology and Fertility of CIAT) managed by Dr. Kristina Röing de Nowina and others. Hence, contact with the farmers was already well established before the visit.

3.2 In situ

3.2.1 Fieldwork methodology

The fieldwork was carried out during three visits. The first visit consisted of introduction, interviewing and observation in order to get a general idea of small hold farming in Kenya. Further, to observe which types of organic materials which were dominating and could be used for biochar production. Based on observation at the first visit, two different organic materials per area were sampled during the second visit. Photos of the farmers and the surroundings were taken at both visits and were given back together with the results of the study at the third and last visit. The fieldwork was carried out during two weeks and interviews and sampling took place in Siaya: 8-11/4-10, Embu: 13-14/4-10 and Kwale: 15-19/4-10. The results were presented in Siaya: 21/5, Embu: 25/5 and Kwale 27/5.

3.2.2 First visit- interviewing and observation

When arriving to the farms presentation and introduction were held with help from a local assistant that was familiar with the farms and the area. The assistant also translated the questions into local language when necessary. One person asked the questions and the other two took notes and photos. In Siaya 5 farmers were interviewed by Tellie, in Embu Kajsa acted as interviewer and Helena held the interviews in Kwale. Six farmers in both Embu and Kwale were interviewed. A questionnaire (see Appendix 1) was designed together with an assistant, to ensure that the questions were applicable and appropriate, and later used as a template during the interviews. A mixture of general opened- and closed-end questions were asked to get an overview of the farming system practiced on the farm and their attitude towards biochar as soil amendment.


Figure 2. Interviewing in Embu. Photo H. Ström

After the interviews a walk around the farms was carried out while observing which organic materials were dominating and typical for the area. Criteria for assessment were that it should be characteristic for the area, occur in sufficient amounts and not have other important usages. Some of the observed materials that existed in big amounts were taken as fodder and therefore not available for biochar. After observation a decision concerning the following materials was taken:

Siaya: Fresh residues from banana plant ("fresh banana leaves") *(Musa spp.)* and maize stovers *(Zea mays)*.
Embu: Wilted banana leaves *(Musa spp.)* and coffee leaves *(Coffea ssp.)*.
Kwale: Cassava stems *(Manihot esculenta)* and coconut leaves *(Cocos nucifera)*.

3.2.3 Second visit- sampling of organic materials and soil

The second day, sampling of two organic materials per area was accomplished. In Kwale, due to weather conditions, some sampling was carried out during the first day. The materials were collected with help from a local assistant and at some farms from the farmer, and put and stored in marked paper bags. To get a good mix and an adequate total amount, small amounts were collected at each farm.

Initial tests (see 3.3.2.) of biochar production from similar materials had given a rough estimate of the quotient between produced biochar and substrate dry material. From this quotient, an approximate amount of material needed could be calculated and sampled. Additional amounts, more than needed for biochar production, was collected for losses through analysis and spill.

To simplify the comparison between the organic materials one soil was used for the pot trials. With several soils more variables would influence the result and make the interpretation of the effect of biochar more difficult. The soil for pot trials was sampled from Embu for logistical reasons. The fertility of the soil should be neither too fertile nor too poor in order to see the possible effects on nutrient addition biochar might have. Hence, a soil of medium fertility was selected and sampled from one of the farms based on the farmer's estimation of soil fertility on his fields. Topsoil (10-20 cm) was sampled from an area of approximately 5 m^2 and put in five plastic bags à 50 kg. The total amount, approximately 250 kg, was derived from the number of pots and also from losses through analyses and spill.

3.2.4 Third visit - feedback

During the third visit the results from the nutrient analysis and the results from pot trials were presented and explained to the farmers. They were given a folder with a short description of the study and the results (see Appendix 2). This feedback visit also gave them an opportunity to ask questions regarding the project.

3.3 Laboratory work

3.3.1 Method of producing biochar

Not many results from similar studies are to be found and it is only recently that interest has been directed towards biochar as soil amendment. Therefore, a production method suitable for our conditions had to be designed. In discussion with supervisors and complementary literature a decision upon a method was decided. The method had to be relatively easy to operate but at the same time also reproducible.

The method decided upon was to use a metal can with a tight lid with small holes. Both temperature and time had to be tested considering the differences between the base materials. On site, the methodology has changed several times due to insufficient laboratory equipment and scarce information about biochar production. Hence, the methodology has been adjusted to conditions on site as well as to the available literature and the short time period under which the study was taken place.

3.3.2 Initial test of production method

Before fieldwork, pre- experiments were carried out to decide upon which production method that should be used for the true experiment. Organic materials tested were similar to those sampled from field and collected from Kenya Agricultural Research Institute (KARI) in Nairobi. The objective was to find out the quotient between produced biochar and dry material, and based on the results calculate the required amount to be sampled in field. Besides to obtain the quotient, the tests were performed to investigate whether it was at all possible to generate biochar from the organic materials. Different temperatures and times were tested to examine what conditions that seemed most suitable for the different organic materials. Plant material were put in a metal can and burned in a furnace placed in a fume, due to the produced gases. For list of used materials, see Appendix 3.

The tests were (see Appendix 4):
Maize stovers 350˚ C in 1.5 hour
Maize stovers 450˚ C in 1 hour
Leaves collected on the ground from different trees 450 ˚ C in 1 hour

The quality of produced biochar was evaluated through ocular examination. All organic material should be completely transformed to charcoal, the structure maintained and easily grained. If this qualities were fulfilled the charcoal was considered to be suitable.

3.3.3 Production of biochar

The organic materials were put in a drying room to decrease the water content. Time for drying depended on the material and when estimated dry it was taken for production. Materials with higher water content were dried in an oven at 105˚C for a couple of hours in order to speed up the drying. Samples of same material were bulked together and cut into smaller pieces. A metal can with a lid with small holes was filled with organic material, weighed and put in the furnace. Different temperatures and times were tested (see Appendix 5) and after ocular evaluation a temperature of 450 ˚C were decided upon for each material. Properties in consideration were that the material should be completely converted into charcoal with as low ash content as possible. The structure should be porous and easily grained.

These qualities were fulfilled at different times for each material due to variation in lignin content and size of material etc. After removal from the furnace, with a metal plier, the can was left to cool before weighing. To obtain a sufficient amount of biochar from each material for the pot trial, approximately three loaded cans were required. The produced biochar from each material was bulked together and stored in paper bags. This procedure was repeated for each material. For list of used materials, see Appendix 3.

Figure 3. Biochar from coffee leaves. Photo H. Ström

3.3.4 Preparation of biochar for analysis

When production of biochar from all materials was completed, the products were ground in order to enhance the active surface area and to obtain appropriate size for incorporation for pot trials. 5-6 gram of biochar from each material was put in plastic bags and sent for analysis at Crop Nutrition laboratory in Nairobi. Besides carbon, biochar was analyzed for total concentration of: N, P, K, Ca, Mg, Fe, Zn, Mn, Cu, B and Na. The analysis of carbon concentration was later repeated at TSBF/ICRAF.

3.4 Preparation of soil and pot trials

From Embu 250 kg (5 bags à 50 kg) soil was sampled. At ICRAF, Nairobi the soil was ground through a 4 mm sieve in order to sort out stones and bigger particles but also organic material, whose nutrients might influence the result of the pot trials. After sieving, the soil was spread on sterile plastic covers and left to dry in the sun for one day before it was mixed and stored in plastic buckets. 700-800 g was sent to Crop Nutrition laboratory, Nairobi and analyzed for; soil particle size, carbon and nutrient concentrations (P analyzed with Olsen-P method). For list of used materials, see Appendix 3.

Pre-trials were carried out in order to find a fast growing crop suitable for the trial. The considered plants were millet *(Panicum spp.)*, sorghum *(Sorghum spp.)* and an unknown variety of grass. The planting took place 1/4-10 for millet and sorghum and 7/4-10 for the grass. Three weeks after planting, the plants were cut in order to examine the re-growth. After ocular evaluation sorghum showed to be most suitable for the trial as it had the best re- growth and well developed roots.

For the pot trials, plastic pots of 2 liters were filled with 1.6 kg dry soil. Two rates of applied biochar were tested in order to determine any differences in yield between the treatments. Rate 1 was to be normal, 1,5-2 ton carbon per hectare, and rate 2 extreme, 5-6 ton carbon per hectare (Vanlauwe, B., pers. comm., 2010). In total the trial consisted of 39 pots, based on three replicates for three sites, two organic materials, two biochar rates and three controls (see Appendix 6).

<u>Constants used for calculations:</u>

Carbon concentration of biochar: Maize, 60 % (Lehmann & Joseph, 2009). The aim was to examine potential differences with the equivalent mass of biochar added from each material, why 60 % carbon concentration was applied to all materials. Since the method should be replicable for the farmers *in situ*, the applied amount should be based on mass and not carbon concentration. Also, because of the time limitation the pot trial had to start before the results from analysis of carbon concentration were received.
Soil density: 1,2 g/cm^3 (Andrén, O.,pers. Comm.,2010).
Soil dept: 10 cm. To what depth the biochar may be incorporated in field (Vanlauwe, B., pers. comm., 2010).

Rates in pot trials (calculations, see Appendix 7):
Rate 1 = 4 g biochar per pot
1,5-2 ton C per ha → approx. 3.3-4.6 g biochar per pot.
Rate 2 = 12 g biochar per pot
5-6 ton C per ha → approx. 11.1-13.3 g biochar per pot.

The weighed amount of biochar was carefully mixed with the soil in the pots and 400 ml distilled water was added. Before planting, the sorghum seeds were sterilized in calcium hypochlorite, $Ca(ClO)_2$, for five minutes and afterwards rinsed three times with distilled water. Seven seeds were planted in each pot, 30/4-10. After one and a half week, 11/5-10, the pots were thinned and the three biggest plants were kept. Once a week, the height was measured approximately 1 cm above soil surface with an accuracy of 0.5 cm. All three plants were measured in order to calculate average height for both pots and material. During the pot trial watering and weeding were done when needed.

Harvest was carried out 2/6-10 after four and a half weeks of growth. The plants were cut with a pair of scissors approximately 1 cm above soil surface. Plants were weighed individually and together from the same pot. Afterwards they were put in paper bags to dry in the greenhouse for 24 hours and then placed in a drying cabin at 60 °C for another 24 hours. Finally the dry weight was measured.

3.5 Statistical method

The results, i.e., plant yield, dry mass and height were statistically analyzed using a two-way ANOVA in the SAS procedure GLM (SAS Institute, 1996). Main effects were: The different materials and the dosage. Significant differences between materials or doses were investigated using Tukey's test.

4 Results

4.1 Interviews

4.1.1 Siaya

Figure 4. Agricultural landscape in Siaya. Photo H. Ström

Conditions for farming

The average field size on the visited farms was 0.6 ha, based on interviews from two of the visited peasants. Each farm consisted of mud houses in a compound with a small farmyard and the fields were situated close to the compound. The topography was flat, except from one farm. All labour on the farm was performed only by family members. The fertility varied between and within the fields due to erosion, moraine and applied manure.

Crop production and livestock

The most commonly grown crops were cow peas *(Vigna unguiculata)*, maize *(Zea mays)*, common beans *(Phaseolus vulgaris)*, sukuma *(Brassica spp.)*, sweet potato *(Ipomoea batatas)*, cassava *(Manihot esculenta)*, bananas *(Musa spp)*, avocados *(Persea Americana)*, groundnuts *(Arachis hypogaea)* and vegetables. Groundnuts and avocados were cash crops and the other crops were for domestic consumption. Production was enough for household consumption and if there were surpluses it was sold. All farms practiced intercropping and the most widespread combination was maize and beans. One farmer intercropped cassava, maize and beans.

Livestock on the farms were cows, calves, goats and chickens. The number of cows differed between the farms; some had one cow or more whereas others shared a cow. The cows were used for milk, meat, manure and ploughing. All farmers had chickens for meat, egg and selling. Goats were mostly used for meat. Chickens were free ranged, goats and cows were tethered to a rope and moved around the farmyard.

Cultivation method

Tillage and cultivation were carried out by hand with a hoe at all farms, although two farmers occasionally used animals for ploughing. Crop residues were handled in different ways. Two of the farmers mulched them into the soil and at one farm residues were left on the fields. One farm gave the residues to the animals and then spread the manure. All farmers, except one that only applied organic fertilizers, used organic and inorganic fertilizers. The largest amount of inorganic fertilizer applied was 20 kg/ha but in general it was 11 kg/ha.

Problem areas

Three farmers had problems with erosion and utilized measures were ditches and terraces. All farmers had pests and diseases on the crops and the most affected crops were bananas, maize and beans. Only one farmer applied pesticides and the low usage among the other farmers had financial reasons. The farmers mentioned that they would use pesticides if they could afford it.

Fertility was also a major problem among the farmers. They noticed a big difference where manure had been applied and not.

Biochar

Two of the farmers were interested in using biochar and one farmer would consider applying biochar if there was a proven increase in yield. Two of the farmers were not interested at all. The farmers that showed interest towards biochar all had some experience with charcoal as a soil amendment and had seen improvement in yield.

4.1.2 Embu

Figure 5. Agricultural landscape in Embu. Photo H. Ström

Management

All visited farms were located in the village Kibugu near Embu. The farms consisted of a small house, made from wood or clay and some farms had several small houses where family members lived. The fields were located in slopes near the house of the farm and the average field size was 0.4-1.2 ha. Most of the farms consisted of 4-5 family members working with the daily duties but there were often more people living at the farm, children and older people, not able to participate in the work. Some of the farmers hired people to help them during the harvest period of coffee (Nov-Dec) and tea (March-Aug).

Most of the crops were taken for domestic consumption but all farms cultivated cash crops e.g. coffee *(Coffea spp.)*, tea *(Camellia sinensis)*, bananas *(Musa spp.)*, avocado *(Persea Americana)*, macadamia nuts *(Macadamia spp.)* and fruits. All farmers in the area were members of a coffee cooperation called Rathangariri factory which they ran together. If they had surpluses some of the farmers sold maize *(Zea mays)*. None of the farmers could give an exact number of the average yield. All farms kept a few animals for milk, meat, eggs and manure. The average farm had 2 cows, some goats, sheep and chickens. None of the famers used animals for tillage but used a hoe to hand-cultivate the soil.

Crop production

The most common crops in the area were: Napier grass *(Pennisetum purpureum)* used for fodder, bananas for domestic consumption and measures to prevent erosion, coffee and tea as cash crops, common beans *(Phaseolus vulgaris)* and maize mostly for domestic consumption but some selling occurred if surpluses. Some of the farms also had English- *(Solanum tuberosum)* and sweet potatoes *(Ipomoea batatas)* and macadamia nuts.

All farms practiced intercropping with as many of the cultivated crops as possible. The most common combination was maize and beans and overall beans were commonly used in intercropping due to its N-fixating ability and value as protein crop. Another explanation for a big interest in intercropping was to prevent erosion as intercropping keep most of the ground covered with vegetation. All plant residues were given to the animals as fodder and then returned to the fields as manure. If the farmers had some plant materials left, after giving it to the animals, the residues were left on the ground without being incorporated into the soil.

Fertility

All farmers said that they experienced a great variation in fertility between the fields. They had noticed that fields applied with manure were more fertile than those without any application. One farmer mentioned that the amount of manure was not sufficient to all fields which explained the variation in fertility.

Prioritized crops, cash crops, received application of inorganic fertilizers at all farms except from one. The most used fertilizers were NPK (Nitrogen Phosphorus

Potassium), DAP (Double Ammonium Phosphate) and CAN (Calcium Ammonium Nitrate). The fertilizers grade or percentage of nutrients was unknown but the amount applied was: NPK: 150 kg on tea, 50-125 kg on coffee and 25-50 kg on other crops. Some farms added 50-100 kg CAN on coffee. The remaining shells from coffee beans, after washing, cleaning and drying at the factory, were given back to the farmers and used as fertilizers. All farms applied manure to all crops.

Problem areas

All farms mentioned that they had big problems with pests and diseases. The most common problems were maize stalk borer on maize and coffee berry disease and fungus on coffee. One farmer stated that he had experienced an increase in attacks from pests and diseases after introducing intercropping. He experienced that diseases moved from beans onto the coffee trees. Several of the farms used CuO on coffee as a pesticide and ash were added on maize leaves as a protection against diseases. Buldock were a commonly used pesticide used on maize against maize stalk borer. Two of the farms did not have any measures against pests and diseases because of financial reasons but said that they would appreciate if they could use pesticides. Several of the farms mentioned erosion as a problem but they all had effective measures e.g. terraces, ditches, planted bananas among the crops, eucalyptus and arrow roots.

Biochar

All farmers, except one, said that they would be interested in using biochar if it had beneficial effects and was economically possible. Some of the farmers had heard about trials with charcoal and also about its positive effects on yield. Some thoughts that the farmers had about biochar were how much organic material that would be needed to make sufficient amounts of biochar. Also if it could be economically possible or if it would take too much time and work with the production of biochar. Only one farm said that they were not at all interested because they did not think it would give any positive effects.

4.1.3 Kwale

Figure 6. Agricultural landscape in Kwale. Photo H. Ström

Management

Interviews were done at six farms located at two different places, three in Mbegani and three in Mwachome. Considering management and crop production, the farming practises were very similar in the two places. The average farm size varied between 2-4 ha. However, all fields were not cultivated since large proportions were kept as fallow, at some farms as much as 90 %. At all farms the workers were family members, including children unless they were too young, but two farmers hired labour on daily basis if necessary. The common livestock all over the area were goats and chickens for meat, eggs and selling. Two farms also had cows for milk and tilling. Though tillage mainly was done by hand sometimes a bull was hired, while in Mwachome all three farmers occasionally even hired a tractor.

The farmers in Mbegani also worked in a cooperative where they cultivated a part of land together. The harvest was sold and the profit used for common purposes within the cooperative.

Crop production

Crops in common for all farms were maize *(Zea mays)*, cassava *(Manihot esculenta)* and common beans *(Phaseolus vulgaris)*. Mostly grew vegetables and to some extent even fruits like bananas *(Musa spp.)*, mangoes *(Mangifera spp.)*, papayas *(Carica papaya)*, oranges *(Citrus spp.)*, passion fruits *(Passiflora spp.)* and cashew nuts *(Anacardium occidentale)*. The harvest was mainly for household consumption, but if there were surpluses most of the farmers could sell maize. All except one farmer also had coconut trees *(Cocos nucifera)* since coconuts along with fruits were the dominating cash crop in the area.

All farmers intercropped maize and cassava but a common combination were also maize and beans, if cultivated at the farm. A couple of farmers experienced a positive effect on yield the year after cassava which might be explained by the physical effect cassava roots have on soil structure. Plant residues were left on the fields, but one farmer put some of them in a row in order to prevent erosion.

Fertility

All farmers stated that there was a variation in soil fertility between fields and mentioned that fields applied with manure were more fertile. Furthermore, the farmers in Mwachome faced fertility problems due to stones which also complicated tillage. In Mbegani, on the other hand, there were large fractions of sand and problems with erosion were mentioned, but these were mitigated after incorporation of manure. This year, inorganic fertilizers had been applied on four out of six farms. Two farmers only applied manure and one of them stated that he could not afford inorganic fertilizers this year but had used 50 kg of each DAP and CAN last year . Two farmers used 5 kg each and the other two 50 kg of which one received it from the government. The inorganic fertilizers used in the area were DAP, CAN and NPK and the prioritized crops were maize and vegetables.

Problem areas

All farmers faced problems with maize stalk borer and used Bulldock against it. Some mentioned crop damage caused by insects. One also had some sort of pest but did not know what kind and could therefore not adopt an appropriate measure. All, except one farmer, had problems with erosion but only three of them were able to control it with terraces.

Biochar

All farmers seemed to have a positive attitude towards biochar and would like to try it if it had a proven beneficial effect on yield.

4.2 Nutrient analysis

Table 2 and 3 show the nutrient concentration in biochar produced from different plant materials. The variation in concentration of carbon and the macronutrients N, P and K are illustrated in Figure 7-10.

Table 2. Carbon and macronutrient concentration (%) in biochar from different plant materials

Plant material	C	N	P	K	Ca	Mg
Fresh banana leaves	51.2	1.05	0.16	8.68	1.83	0.76
Maize stovers	52.2	0.58	0.10	1.03	0.64	0.50
Wilted banana leaves	54.0	1.37	0.12	0.55	4.13	0.72
Coffee leaves	54.1	2.63	0.27	4.80	3.33	1.01
Coconut leaves	61.0	0.47	0.10	3.00	1.29	0.55
Cassava	60.8	1.73	0.31	4.01	3.22	0.99

Table 3. Micronutrient concentration (ppm) in biochar from different plant material

Plant material	Mn	B	Zn	Fe	Cu	Na
Fresh banana leaves	1637.0	20.80	126.20	2762.0	15.01	706.8
Maize stovers	363.7	4.63	137.40	5368.0	11.31	573.2
Wilted banana leaves	7348.0	32.93	325.50	2298.0	10.75	570.6
Coffee leaves	1305.0	141.00	211.70	6019.0	123.80	1026.0
Coconut leaves	390.0	28.03	62.25	349.5	6.45	9497.0
Cassava	387.9	20.35	75.46	209.5	11.75	777.9

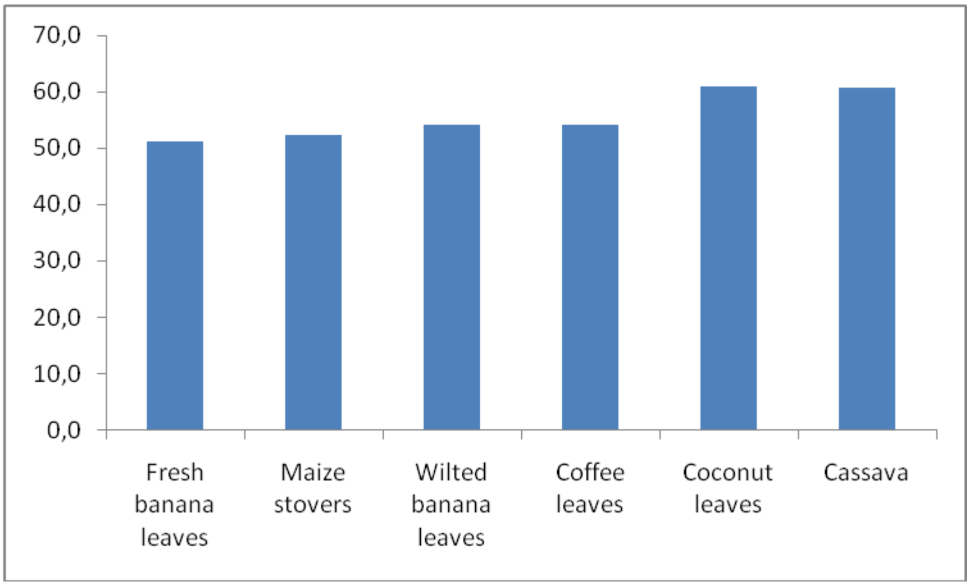

Figure 7. Carbon (C) concentration (%) in biochar.

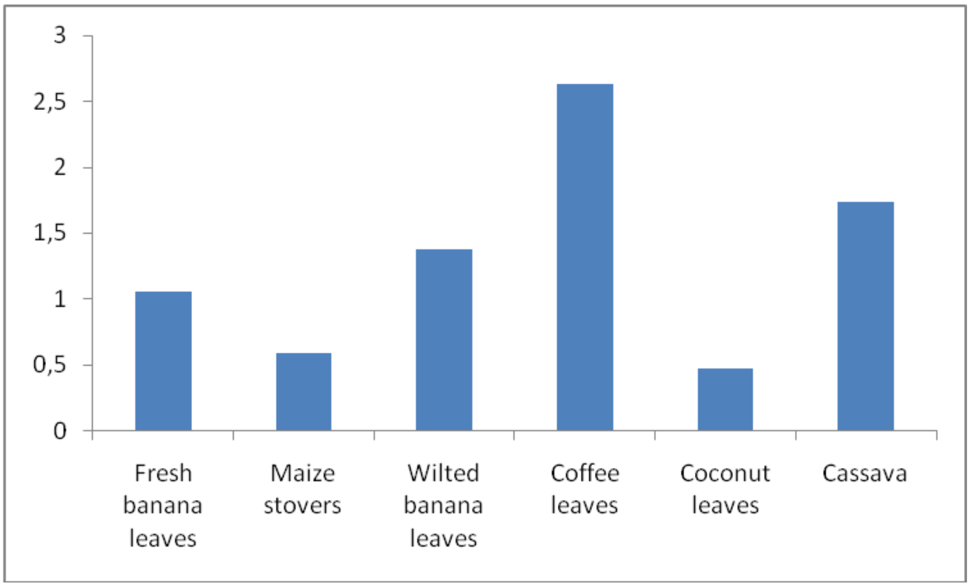

Figure 8. Nitrogen (N) concentration (%) in biochar.

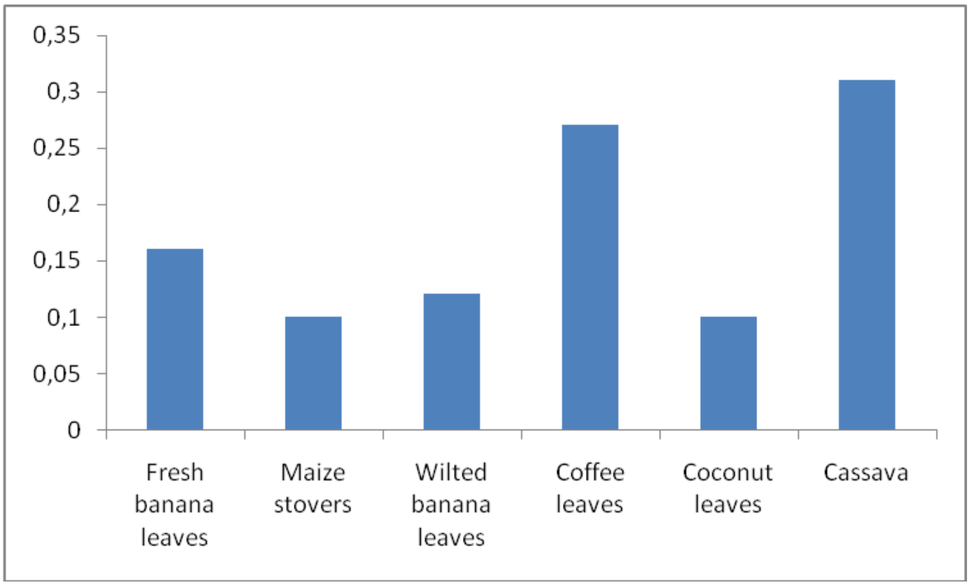

Figure 9. Phosphorus (P) concentration (%) in biochar.

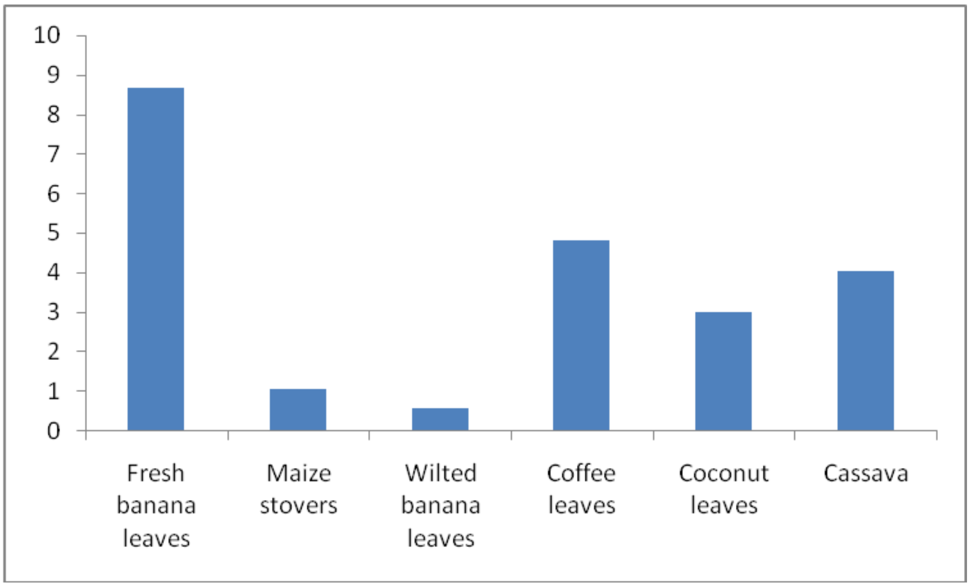

Figure 10. Potassium (K) concentration (%) in biochar.

Apart from the carbon concentration, where there do not seem to be any obvious differences, the analyses demonstrate a variation in nutrient concentration between biochar produced from different types of organic material. The concentration of macronutrients N, P and K in figure 8-10, appears to be highest in biochar produced from coffee leaves and cassava. Lowest amounts of N, P and K are found in biochar from maize stovers. The potassium analysis shows the largest variation between the organic materials used as feedstocks, where fresh banana leaves appear to have very high concentration.

4.3 Pot trial and plant growth

Table 4 shows the result from analysis of the soil used in pot trials. The results of plant growth are shown in figure 11-13 and Appendix 8. Measurements were taken on average height, fresh- and dry weight.

Table 4. Soil analysis

pH	CEC	Sand %	Silt %	Clay %	C %	N %	P ppm	K $exK100g^{-1}$
4.61	4.3	60.0	17.0	23.0	3.0	0.3	12.0	0.35

S $exS100g^{-1}$	Ca $exCa100g^{-1}$	Mg $exMg100g^{-1}$	Mn ppm	B ppm	Zn ppm	Fe ppm	Cu ppm	Na $exNa100g^{-1}$
0.5	0.77	0.35	224.0	0.3	3.1	112.0	1.6	0.2

Results from the soil analysis demonstrate that it is a sandy clay loam with low pH and CEC and quite high carbon concentration.

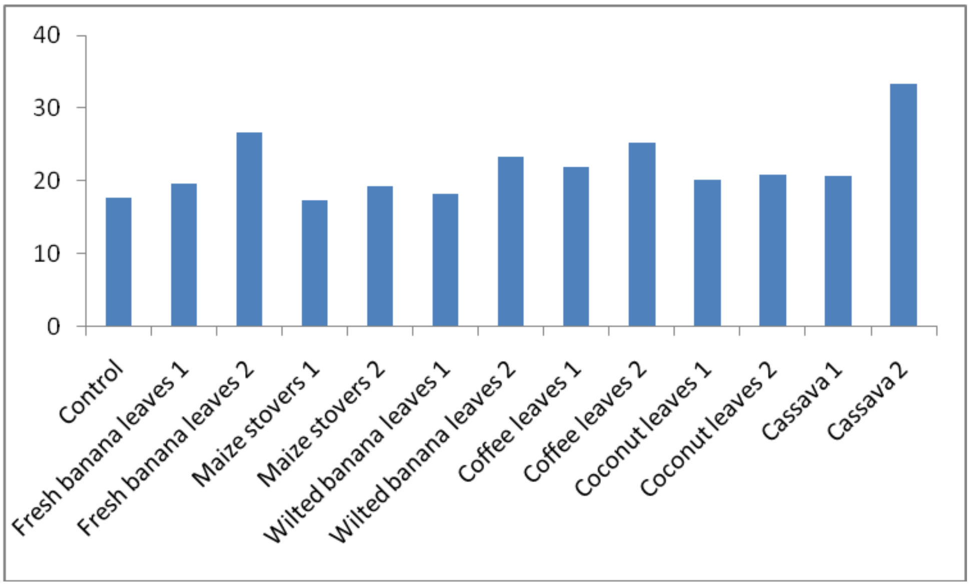

Figure 11. Height of plants at harvest, mean of three replicates (cm).

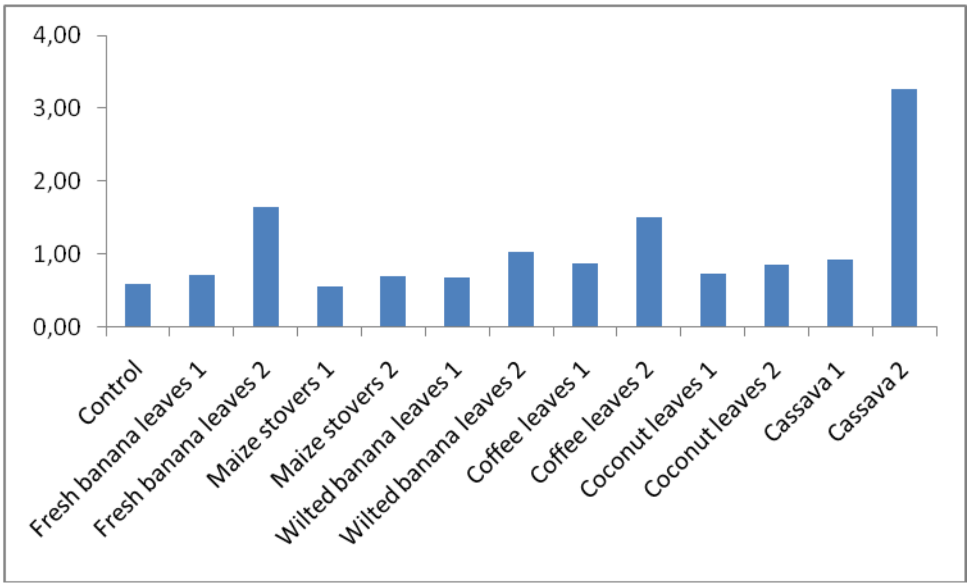

Figure 12. Fresh weight of plants, mean of three replicates (g).

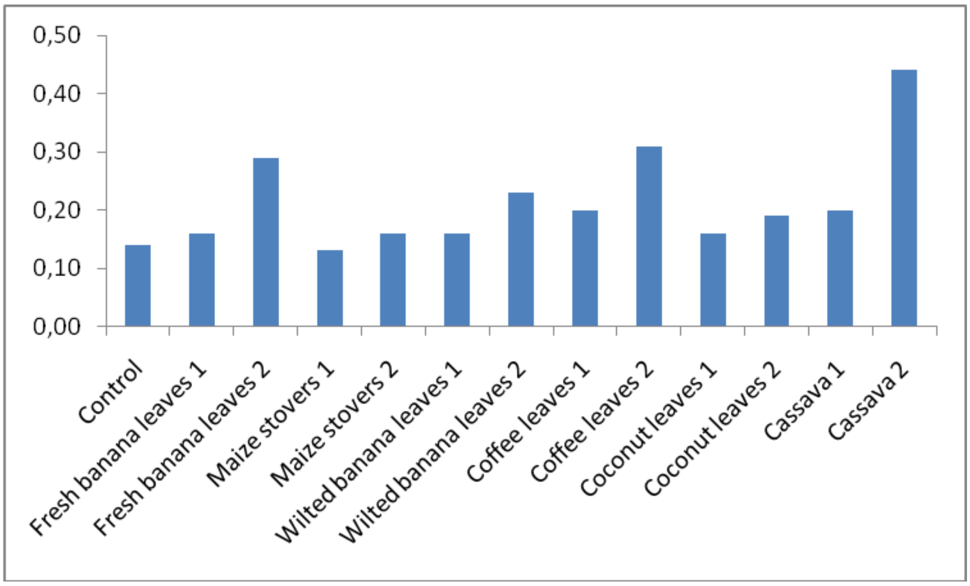

Figure 13. Dry weight of plants, mean of three replicates (g).

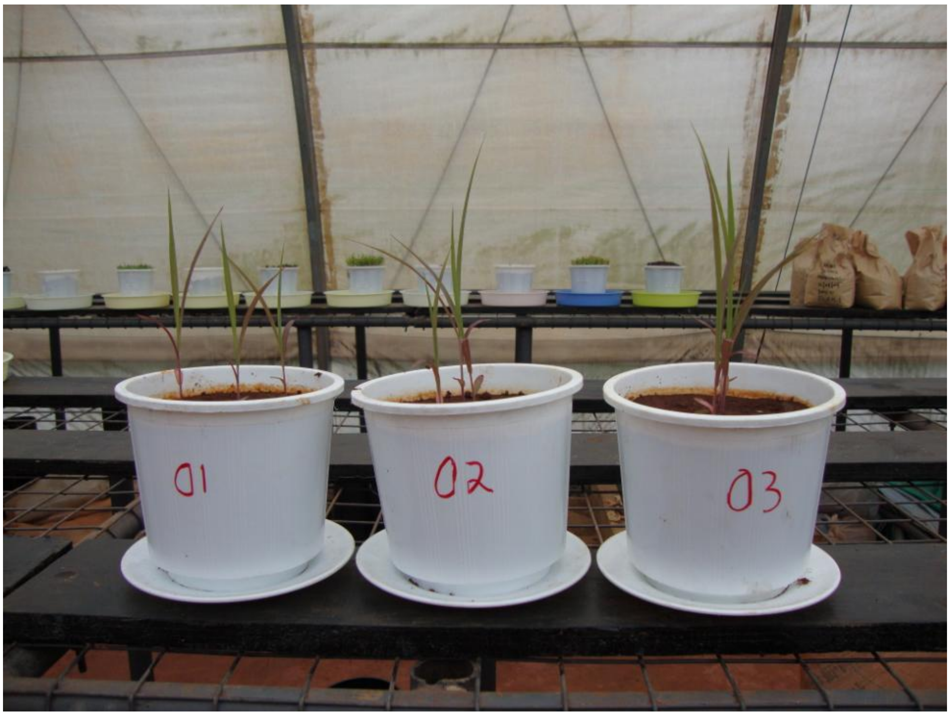

Figure 14. Control treatment. Photo H. Ström

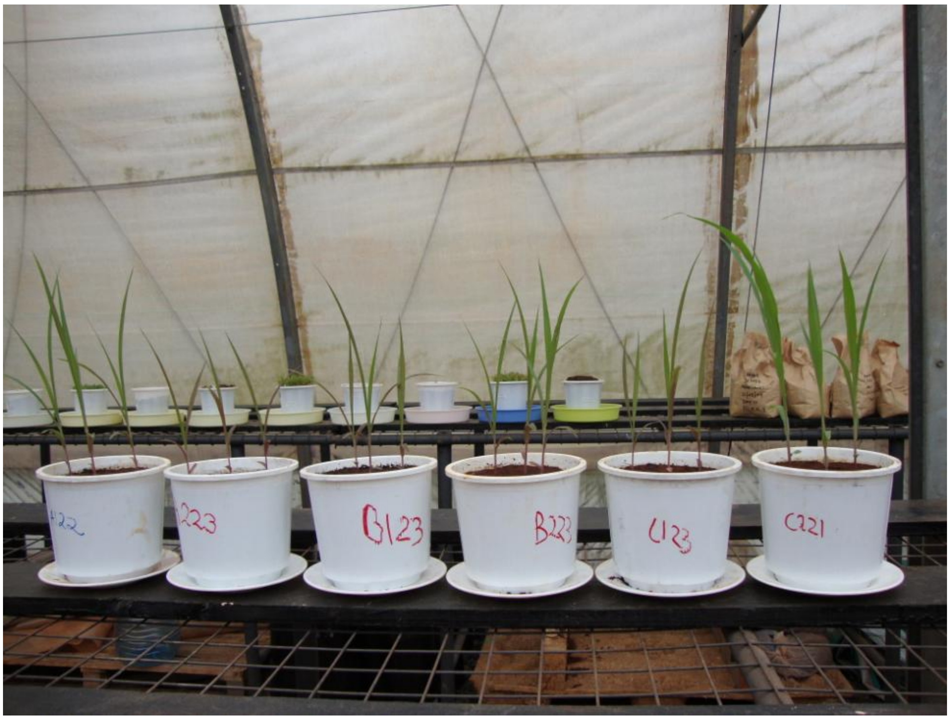

Figure 15. Pot trial with rate 2 and biochar from (left to right) fresh banana leaves, maize stovers, dry banana leaves, coffee leaves, coconut leaves and cassava. Photo H. Ström

Figure 11-13 demonstrate differences between the treatments where some are distinguishing. Most distinct are the differences regarding plant weight. The treatment with most positive effect on growth appears to be *Cassava 2*, followed by *Fresh banana leaves 2* and *Coffee leaves 2*. For detailed data, see Appendix 8. Figure 14-15 show the differences in plant height between control treatment and biochar with different origin.

The statistical test revealed that the materials had different effects on plant dry mass ($p<0.001$). Cassava was significantly higher than the other materials, fresh banana leaves and coffee leaves were intermediate, significantly higher than the other materials ($p<0.05$). The low dose of biochar was not significantly different from the zero dose, but the high dose was significantly higher than both zero and low dose ($p<0.05$).

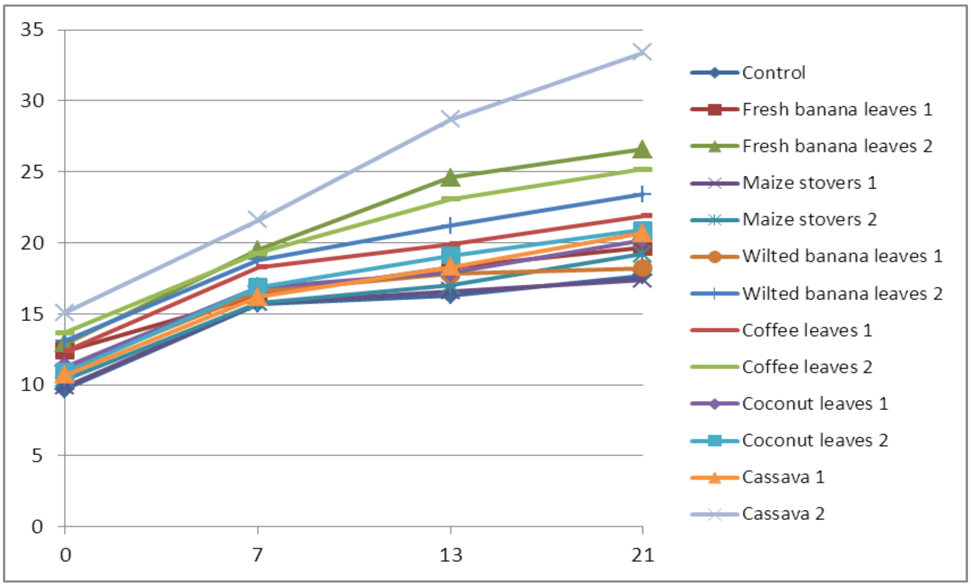

Figure 16. Development in plant height (cm) after x days.

Figure 16, which demonstrates the development of height during the time of growth, confirms *Cassava 2* to be a beneficial treatment.

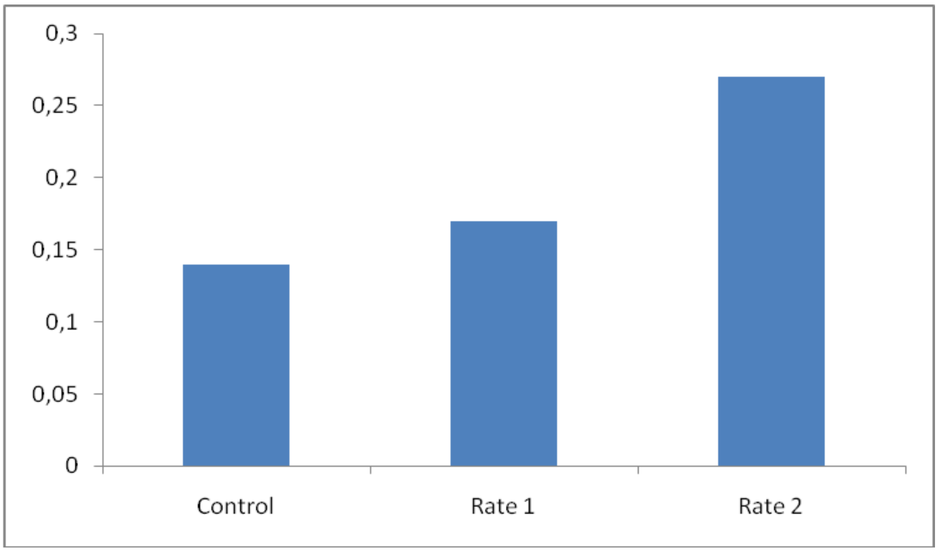

Figure 17. Average dry weight of plants with different treatments compared to the control,

In figure 17, a comparison is made in order to examine whether there are any differences between the applied amounts of biochar. The average dry weight of plants is 21 % higher for rate 1 compared to the control treatment, while it for rate 2 is 93 % higher. Figure 18 shows the difference in plant growth between rate 1 and 2 in pot trials with biochar from maize stovers and cassava. A significant difference in plant height between rate 1 and 2 can be observed in cassava (see right photo). No significant difference is observed in maize stovers (see left photo).

A statistical test showed that the materials had different effects on plant height ($p<0.001$). Cassava, fresh banana leaves and coffee leaves were significantly higher than no addition or maize stover, and maize stover was not significantly different from no addition ($p<0.05$). Also regarding height, the low dose of biochar was not significantly different from the zero dose, but the high dose was significantly higher than both zero and low dose ($p<0.05$).

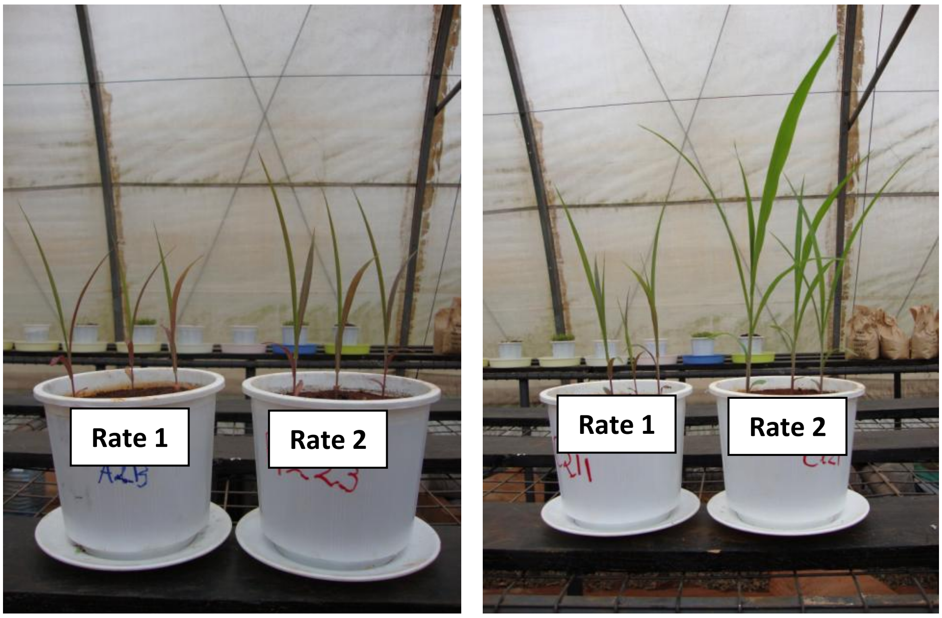

Figure 18. Pot trials with different rates of biochar of maize stovers (left) and cassava (right). Photo H. Ström

5 Discussion

5.1 Literature

Since we did not have access to recent data from the three areas, some information might not be accurate, e.g. crop distribution and yield. However, the general picture of the agricultural systems would still be true.

5.2 Field work

Uncertainties regarding the interviews were information about e.g. yield and field size, which the farmers could not answer. This was the first time anyone of us held an interview. Moreover, having a translator made the interviews more complicated. Further, we were not sure of how applicable the questions would be and some questions were changed after the first visit. If the study was to be repeated with the same methods, it would be recommended to better prepare the questions and ensure that they are applicable.

When collecting the organic materials at the farms, some other plants than the intended as well as soil particles might have been included, this may have affected the homogeneity of the samples. Further, different state of decomposition of wilted plant material has not been considered.

Uncertainties regarding which knowledge the farmers had made it difficult to prepare the feedback visit. The folder should not be too simple nor too complicated. During the feedback visit the majority of farmers did not seem to be that interested in the results. Whether they did not understand or if it was lack of interest are unknown. However, the objective was not only to explain the results but also to go back to the involved farmers and give them something in return and thank them for their contribution to the study.

The agricultural systems were similar in the three areas. The farms had small scale production for household consumption and none or very few external inputs. Differences between the areas were dominating crops and the farmers' interest and commitment to their farming practises. Hence a future implementation of biochar as soil amendment would probably be easier in some areas.

5.3 Biochar production

Depending on the properties of the different materials, e.g. composition of carbon compounds, the time in the oven during production varied (see Appendix 5). The coarser material, the longer burning time was needed to obtain good quality. Cassava stems had the longest burning time while coffee leaves had the shortest, which could be explained by the differences in composition. We found the biochar ratio to differ between the materials, the longer burning time the lower ratio. Studies have shown a decrease in biochar ratio with increasing pyrolysis temperature (Yip et al., 2010; Gaskin et al., 2008). However, it is unclear whether the ratio and burning time are related in the same way as ratio and temperature, or only a result of the material composition.

To ensure good quality and stable biochar it is important to have controlled conditions during production, e.g. anaerobic conditions and high temperature (Biochar International Initiative). With our invented production method and the scarce instruments and conditions found *in situ*, production conditions could not fully be controlled. The temperature of the oven fluctuated during burning and completely anaerobic conditions could not be obtained. Due to the low capacity of the oven, several batches of the same material had to be produced which made it impossible to have exactly the same conditions. Hence, preferable would have been to produce biochar from the same material at the same time. However, since biochar from the same material were carefully mixed at the end, this should not have had significant influence on the results. When taking out the batch from the oven, some material started to glow. This might have affected the carbon concentration since some of the material was transformed into ash. To prevent the oxidation, the batch was left to cool down with the lid still on.

Ocular evaluation, based on our own opinion, was done to determine whether the material was of good quality. Since the evaluation was subjective, we are not sure of how accurate it was. However, from literature we got some references to compare with (Lehmann & Joseph, 2009). For future experiments with a similar production method, it would be recommended to have an oven with bigger capacity to enable the same production conditions. Also, constant temperature and oxygen conditions are preferable to obtain good quality of biochar (Biochar International Initiative).

A production method had to be designed that would be replicable and performable in the laboratory conditions *in situ*. This was fulfilled, but if farmers should be able to produce their own biochar, the production method has to be designed differently. The production method has to be simple and not require many inputs. Already existing methods on farms are charcoal kilns where the organic material is covered with wood and soil and burned during anaerobic conditions. Another simple method, based on principles described by Günter (2008), is to fill a metal can or tin with organic material, put on a tight lid with small holes and place it in a fire, This may be the best alternative for farmers since they all use open fires for cooking. However, these methods make it difficult to control production conditions, e.g. temperature. A completely burned and porous material with big surface area and high nutrient concentration are important qualities if biochar shall work as soil amendment (Lehmann & Joseph, 2009). In field, the farmer might need to compromise between a practicable production method and good biochar quality.

From the pot trial, both fresh and dry weight were measured. One plant was stuck in the drying fan during the drying process and not included in the dry weight graph.

5.4 Nutrient analysis and pot trial

Analysis demonstrated a variation in nutrient concentration between biochar from different plant materials. Further, nutrient concentration correlates with the yield from pot trials and three treatments demonstrated this clearly: cassava 2, coffee leaves 2 and fresh banana leaves 2 (see table 2 and figure 13). Biochar produced from these materials had in general higher nutrient concentration. The condition of the materials seems to be important, which might explain the differences in K concentration in banana leaves. Biochar produced from fresh banana leaves had the highest concentration of K, whereas biochar from wilted banana leaves contained least K of all materials (see figure 10). Although these two materials were sampled at different sites, the difference in K concentration can probably be explained by allocation of K from wilting leaves to fresh parts of the plant since K has high mobility (Havlin, et al., 2005).

During pyrolysis, N is easily volatilized (Gaskin et al., 2008) and therefore the concentration in biochar depends on production conditions. Biochar from coffee leaves had the highest N concentration which might be explained by the short burning time, preventing volatilization. Another of our theories is that the high N concentration in biochar from coffee leaves can be explained by the high initial N concentration in the fresh material due to relatively high application of fertilizers. We did not analyze the nutrient concentration of the fresh plant materials, however Gaskin et al. (2008) stated that high nutrient concentration of the base material generates a high nutrient concentration in biochar.

Biochar produced from cassava residues had the highest P concentration, followed by coffee leaves and fresh banana leaves. In the pot trial, all plants except cassava 2 treatment showed symptoms of P deficiency. This indicates an uptake of P, but it is uncertain whether it is due to higher availability or higher P concentration in cassava. According to the soil analysis, plant available P concentration is 12.0 ppm (see table 4). The availability of P in the soil solution is determined by soil pH where phosphate may form insoluble compounds at different pH. Between pH 4-5.5 P is mainly fixed in Al- and Fe-complexes (Eriksson et al., 2005). Since pH of the soil in the pot trials was 4.61 (see table 4) the P deficiency demonstrated by the plants is most likely a result of low pH where P is bound in Al- and Fe-complexes. Yuan & Xu (2011) showed a positive correlation between soil pH and biochar pH why biochar addition therefore might have possible beneficial effects on acid soils. We did not analyze pH of biochar but according to Yuan & Xu (2011) one theory we have is that biochar addition might have enhanced pH and therefore P availability in our pot trial. If the soil had not been low in available P, maybe some of the other treatments would have resulted in higher yield.

The concentration of micronutrients was much higher in biochar than in the soil, why addition of micronutrients as well as the increased concentration of macronutrients might contribute to plant growth. The positive yield effect due to addition of nutrients from biochar was stated by Lehmann et al. (2003). Positive effect on yield due to nutrient addition was one of our hypotheses. According to the law of minimum (Havlin et al., 2005), where the lowest concentration of an essential nutrient is the limiting factor, micronutrients could be of great importance.

The assumption of C concentration in the soil (see table 4) was underestimated and therefore addition of biochar C was lower than intended. Because of the time limit the pot trial had to start before the result from soil and biochar analysis was received. The outcome of the pot trial may have been different if biochar addition would have been based on the analysis. In this trial it would imply higher addition of biochar, hence more nutrients. Figure 17 demonstrates the importance of biochar rate.

If biochar is applied to a soil with characteristics as high sand content, low CEC and low pH, as the soil used the pot trial, biochar might enhance these properties (Yuan & Xu, 2011) as well as water holding capacity (Karhu et al., 2011). Hence, the soil will be more suitable for plant growth. As CEC increases it might retain nutrients and prevent leaching and therefore applied fertilizers could be more efficiently used by the plants (Lehmann et al., 2003). The combination of biochar and fertilizer optimize nutrient use efficiency, compared to if they were applied separately. In a study (2007), Chan et al. did not find an increase in radish yield when biochar from green waste was applied in absence of N-fertilizers compared to the positive yield effect when applied together. This strengthen the theory that biochar improves the nitrogen use efficiency from fertilizers. In future research it would be interesting to examine the effect on yield by biochar produced from different plant materials with addition of fertilizers.

As water holding capacity of the soil was not analysed and the plants were not exposed for water stress, the possible effect biochar might have on moisture retention could not be evaluated. However, improved water holding capacity has been demonstrated by Karhu et al. (2011). CEC of biochar was not analysed but as the soil had low CEC (see table 4), biochar might work as supplement, also expressed by Yuan & Xu (2011). The properties of the soil appear to be very important for the outcome of the trial. Depending on soil type, the interactions might differ which in future research would be interesting to compare in order to maximize the beneficial effects of biochar. According to van Zwieten et al. (2010) the plant growth responses varied between soil types but also biochar characteristics, plant species and fertilizer application proved to be important.

A comparison of the results from the pot trials showed that most of the treatments did not differ significantly from the control. *Maize stovers 1* was lower than the control (see figure 13), which might be explained by a high C/N ratio and thereby immobilization which results in lower yield. On the contrary, Rajkovich (2010) demonstrated a minor increase in yield with biochar from maize stovers even though a high C/N ratio, which indicates that other factors may have influence on plant growth, e.g. nutrient concentration and production conditions (Lehmann & Joseph, 2009). Notable is that the three treatments that demonstrated the highest yield also are the ones that appeared to be relatively high in nutrient concentration: *Cassava 2, Coffee leaves 2* and *Fresh banana leaves 2* (see table 2 and 3). The nutrient concentration had therefore presumably beneficial effects on plant growth. This was also stated by Lehmann et al. (2003) which confirms our hypothesis. Moreover, the result indicates that the applied amount of biochar also had a significant role since the rate 2 treatments in general gave 93 % higher yield compared to the control. The statistical test confirms some treatments (cassava, coffee leaves and fresh banana leaves) to be significantly higher both considering dry weight and height. However, the test demonstrates rate 2 to be significantly higher than rate 1 and control. Therefore, the differences demonstrated in the pot trial can probably be explained by a dose effect rather than plant material. In previous studies the dose effect gives contradictionary results. Chan et al. (2007) did not see any dose effect with biochar addition in absence of N-fertilizer while Lehmann et al. (2003) and Chan et al. (2008) demonstrated higher plant growth in correlation with biochar rate. When Rajkovich (2010) compared different base materials produced during different temperatures, both positive and negative dose effects were observed. However, most materials gave a positive yield effect up to a biochar rate of 96 t/ha.

In our trial, rate 2 is equivalent to 9 t biochar/ha (see Appendix 7). If this amount of biochar produced from cassava stems (ratio of 17 %, see Appendix 5) would be incorporated into soil, 53 t cassava stems would be needed. For the farmer this amount is unrealistic but since biochar remains stable in the soil, continuous incorporation of smaller amounts will probably increase the soil fertility gradually.

The differences in research results indicate that many factors are involved, affecting plant growth and the outcome of biochar addition. Hence, we emphasize on the importance of further research in the area for better understanding of the complex mechanisms of biochar in the soil-plant system.

5.5 Areas

5.5.1 Siaya

Siaya was the first site to be visited for interviews, sampling of materials and feedback. The intention was to visit six farms, but since one farmer was not at home at the time for the interviews only five interviews were held. During the interviews we noticed that the farmers did not mention all the crops and livestock we saw on the farm. The reason is unknown; however it brings uncertainties to the reliability of the interviews. The interviews revealed that it was some local differences in handling crop residues. It may indicate that even in such a small area cultural differences occur. This could affect the possibilities to introduce new methods in different parts of the district. Apart from handling crop residues, farm practices were similar, but conditions for farming differed e.g. livestock, farm size.

The results from nutrient analysis and pot trials showed that organic materials collected in Siaya, *maize stovers* and *wilted banana leaves*, were not best suited for biochar production compared with the results for the other materials e.g. cassava (see table 2) . However, cassava was grown on every farm in Siaya and could be available for biochar production for the farmers in the area. The small scale agricultural systems make it feasible for the farmers to incorporate biochar little by little. Climate conditions in the area as high humidity and temperature, resulting in high degradation rate (Eriksson et al., 2005), would promote the usage of biochar. Instead of the practice where crop residues are mulched biochar application could increase the amount of organic material in the soil. Moreover, plant residues, left to mulch in the soil, could be a green bridge for pest and fungi to survive (Fogelfors, 2001). If the residues were used for producing biochar the bridge could be inhibited which could help the farmers to better control pests since they could not afford pesticides.

The low fertility of the soils could be improved by application of biochar. Positive effects as enhanced CEC, could be obtained (Lehmann & Joseph, 2009). Further, the moisture retention in the soil could be improved and provide enhanced growing conditions for the crops (Kahru et al., 2011). Furthermore there is a predicted decrease in rainfall during the long rains in western Kenya, by which moisture retentions importance might increase (Mati, 2000). In a study performed by Kimetu et al. (2008) biochar application, to a highly degraded field in western Kenya, doubled maize yield. The result emphasizes on the possibility to use biochar as a soil amendment, in the area, to increase yield.

The low yields in the area were partly due to the use of old methods in agriculture practices (Siaya district development plan, 2002-2008). It could be difficult to break and change old patterns and habits on the countryside and especially when there is little money to invest. Also, the farmers might be afraid that yields would be even lower if they tried a new system. However, the main reason for low yields is probably the scarce amount of fertilizer applied. During the interviews, variation in soil fertility among fields was explained by manure applications. At harvest more nutrients are withdrawn from the soil than regained through fertilizer and manure, which result in a nutrient imbalance in the soil. Since the farmers cannot afford to buy fertilizer their yields are low and they do not get any income from selling crops, hence they do not get enough income to restore the nutrient depletion.

During the last visit, the majority of the farmers did not seem to be interested in the results and some of them were not at home. Further, the feedback visit in Siaya district was the first visit and the folders with information about the study and the results were changed before the other visits in Embu and Kwale. Consequently the majority of farmers in Siaya may have been given the information in a different way.

5.5.2 Embu

From our visits and interviews we saw that coffee were a commonly grown cash crop in the villages around Embu. The results from the nutrient analysis and pot trials show that biochar made from coffee leaves were one of the better materials used for biochar production. Further, from observations we saw that coffee tree leaves a lot of residues, mostly leaves which is not taken as fodder or used for other purposes. Hence, coffee leaves are often available in quite large amounts at the farms and could be used as base material for biochar production.

The visited farms were all member of a coffee cooperation which the farmers in the area owned together. This makes it possible for them to negotiate the price and also to get better conditions concerning the production. Moreover, the opportunity to influence their situation increases. Also, the cooperation results in a strong fellowship where the farmers can help each other and exchange knowledge, something that many farmers mentioned as positive during the interviews.

The results from the analysis, of the soil sampled in Embu, show that it is a soil with sandy properties, e.g. low CEC, pH (table 4), which imply poor fertility. This was also confirmed by the farmer. By incorporating biochar, CEC (Yuan & Xu, 2011), and water holding capacity (Karhu et al. (2011), of the soil may increase which could be explained by an increase in organic matter content and the big surface area of biochar (Lehmann & Joseph, 2009). This may improve the fertility of the soil and its properties as growing habitat for crops. The soils around Embu vary a lot in texture and structure and thus properties, therefore addition of biochar will give different effects depending on the soil type, which also was confirmed by Zwieten et al. (2010). Nevertheless, most of the soils are very poor in fertility and the agricultural production suffers from low yields, mainly explained by that most of the farmers cannot afford fertilizers (Jaetzold & Schmidt, 1983). Biochar may therefore work well as soil amendment, improving some of the fertility problems related to these soils. Novak et al. (2009) demonstrated an increase in soil fertility after biochar application on a soil with poor fertility, similar to the soil from Embu. However, more research is needed before implementation can be performed in the fields, also stated by several other authors (Steinbiess et al., 2009; Cheng et al., 2008; Liang, et al., 2005; Lehmann et al., 2003).

From our interviews, many of the farmers seemed interested in using biochar as soil amendment and several of them had heard about trials with charcoal and its many beneficial effects. Many farmers in the area grow cash crops and get an income from which they can buy some fertilizers which, as earlier research and trials have showed, give better effect when incorporated together with biochar (Lehmann & Joseph, 2009; Chan et al., 2007). Further, all visited farms had small fields and were small scale systems making it easier to produce biochar on the farm and introduce production and usage of biochar in the daily chores at the farm. If the agricultural systems were larger, more biochar would be required and the production would be more complicated. The farmers' attitude towards using biochar is of great importance if implementation is going to be feasible. Yet, it still remains many uncertainties regarding biochar and the production, usage, and effects. To convince farmers to start using it as soil amendment it is essential to show economical benefits by adding biochar and also to give more exact instructions on how to produce and incorporate it.

5.5.3 Kwale

The visited farms were located at two different places in the Kwale district: Mbegani and Mwachome. The interest in agriculture varied between the farmers and areas. In Mbegani, the farmers to some extent worked in a cooperative where they cultivated an area together and used the profit for common purposes in the village. The shared agricultural interest might enable exchange of knowledge and strengthen the fellowship within the village. Further, the farmers might have more influence in the price negotiation when selling the harvest and hence get a better income. On the other hand, cooperation may also give rise to disagreements and conflicts.

In Mwachome a significant proportion of the land was not cultivated and instead kept as fallow. Some explanations, apart from land restoring practices, could be that the farmers earn their living by selling cash crops or work within the tourist industry and are therefore not as dependent on agriculture. Some people in the area around Kwale expressed their dissatisfaction about the arable land in fallow and implied that the reason behind was laziness.

Problem areas concerning soil fertility that the farmers mentioned during the interviews were big proportion of sand, mainly in Mbegani, and stones in Mwachome. Since the soils in the area have a rather coarse texture, the CEC and water holding capacity ought to be low (Eriksson et al., 2005). Incorporation of biochar may increase the amount of organic matter and binding sites and should thereby improve the soil fertility (Lehmann & Joseph, 2009). Common crops in the area are cassava and coconut. The analysis and pot trial show that biochar produced from cassava residues is high in nutrient concentration and probably promotes the proportion of plant available P. Cultivation of cassava gives a lot of plant residues (e.g. stems) and instead of just leave them on the field, production and incorporation of biochar could be a good alternative. All the farmers grow maize for domestic consumption but since biochar made from maize residues did not seem to enhance plant growth significantly, it is better used as fodder or mulch.

Considering the farmers' interest in using biochar as soil amendment, they all seemed positive if it would be proven to have a positive effect on yield. In the cooperative, it would maybe in the future be possible to invest in a simplified biochar furnace, e.g. as described by Günter (2008), that the members could use in order to produce their own biochar from plant residues and meanwhile use the energy for cooking.

6 Conclusions

One of the aims of the project was to investigate whether biochar produced from different plant materials, applied in different amounts would have effect on crop yield. The results show that plant materials with different properties may be important for plant growth, e.g. through addition of nutrients, which was one of our hypotheses. However, biochar rate seems to be a more significant factor, confirmed by the statistical test. Beneficial effects biochar may have on soil fertility include increased CEC, addition of nutrients, water holding capacity and enhanced microbe-plant interactions. The properties of the soil are of great importance and hence, if a different soil was used in the trial the results might have been different. The interactions in the soil-plant system are complex and more parameters than included in the study are certainly involved. Since this was a pot trial in a greenhouse it would be interesting to examine whether biochar produced from different materials would give similar effect in field.

Another aim was to get familiar with the Kenyan small scale agricultural systems. We found the farming systems to be similar in all three areas and most of the farmers seemed interested in using biochar as soil amendment. However, before biochar can be implementable in the field a lot of research remains to be done. Many factors regarding biochar, such as production methods, amounts, application and effects on different soils, are still rather unknown. In laboratory, production of biochar is, compared to field conditions, more easy to control. From the farmers point of view the production method has to be applicable to their conditions and not require too much inputs nor compromising the quality of biochar.

In conclusion, we believe that biochar has good potential as soil amendment in order to improve soil fertility. However, the huge amounts required will most certainly impede the implementation in field and we want to emphasize the importance of more research in the area, also stated by several other authors (Steinbiess et al., 2009; Cheng et al., 2008; Liang, et al., 2005; Lehmann et al., 2003).

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Acknowledgement

This thesis was supported by the minor field study (MFS) scholarship from the Swedish International Development Cooperation Agency (SIDA). The research was performed in Kenya with the help of the Tropical Soil Biology and Fertility International Center of Tropical Agriculture (TSBF-CIAT) in Nairobi. We would like to thank Dr. Kristina Röing de Nowina, Prof. Olof Andrén and Prof. Bernard Vanlauwe, our supervisors in Kenya and Sweden for giving us the opportunity to go to Kenya and for helping us with our work. We would also like to thank our "activity supervisor" Livingstone "Stone" Chibole for all the practical help and Philip Malala for helping us in the greenhouse at ICRAF. At last, a thank you to all the people who assisted us at ICRAF and to Martha and Christine who welcomed and helped us during our stay in Kenya.

Appendix 1- Questionnaire

Description of farm

1) Which crops are cultivated?
2) Field size?
3) Crop rotation and intercropping?
4) Fertility? Variation between and within fields? Why?
5) Average yield? Is the yield enough to sale or just domestic consumption? How much is paid for the product? Market/company? Export?
6) Who works at the farm? Family members (how many)? How are the tasks distributed?
7) Livestock? Usage?

Tillage

8) How is tillage practiced? By hand/animals/machines?
9) What happens with plant residues? Left on ground/incorpareted/given to animals?

Fertilization

10) Usage of inorganic/organic fertilizer? Which kind/costs/amount?

Problem areas

11) Diseases? Which crops? Measures?
12) Pests? Which crops? Measures?
13) Erosion? Measures?
14) Usages of pesticides? Costs? Amounts? Application methods?

Biochar usage

15) If there was a proven beneficial effect on yield after incorporation of biochar to soil, would you be interested in using it?

Appendix 2 – Feedback folder

Local plant materials as substrate for generation of biochar for soil amendment in Kenya

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Name of farmer
Village
Area

Description of the study

This study is a school project done by three students from the Swedish University of Agricultural Science, Sweden. The aim was to compare different plant materials and their suitability as base material for biochar production. Three areas in Kenya were part of the study: West - Kisumu, Central - Embu and South coast - Kwale. Plant materials were collected from six farms in each area. The plant materials selected were typical for each area.

Kisumu: maize stovers and fresh banana leaves
Embu: coffee leaves and wilted banana leaves
Kwale: coconut leaves and cassava stems

The materials were heated under low oxygen conditions to generate charcoal and analysed for nutrient concentrations. Pot trials are ongoing with sorghum to examine if there will be any increase in yield. Two rates of biochar addition are tested.

What is biochar?

Biochar is charcoal made from organic material burned during conditions with low oxygen level (pyrolysis).
Previous trials have showed that biochar can or will in small scale farming:

- Add nutrients and improve uptake of applied fertilizers
- Increase water holding capacity of the soil
- Increase carbon concentration in the soil
- Remain resident in the soil over a long period of time
- Affect decomposition rates of organic compounds

Results

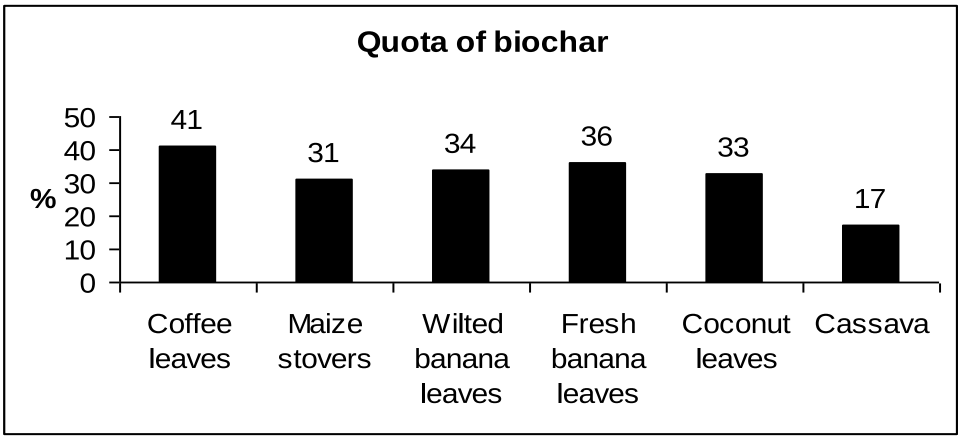

Figure 1. Quota between produced biochar and weighted dry plant material.

Figure 2-5 show the differences in nutrient content between biochar made from different base materials.

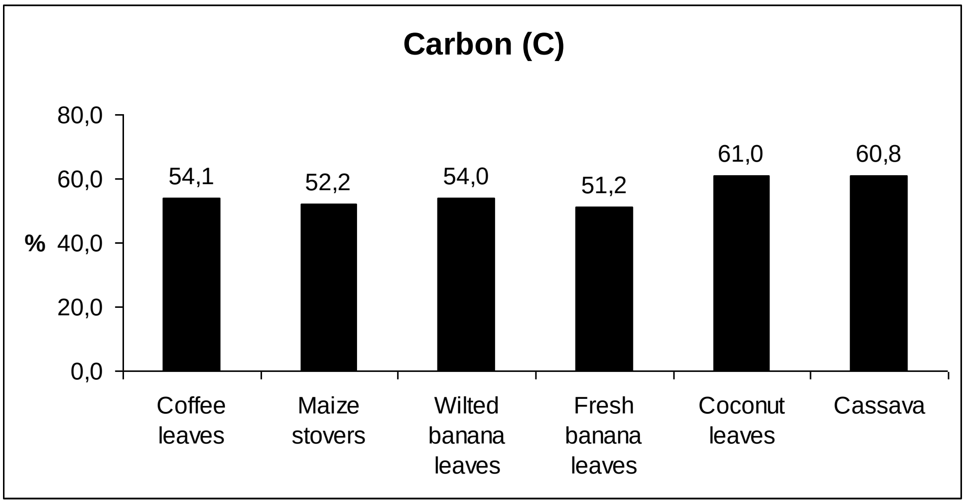

Figure 2. Carbon content in biochar from different plant materials.

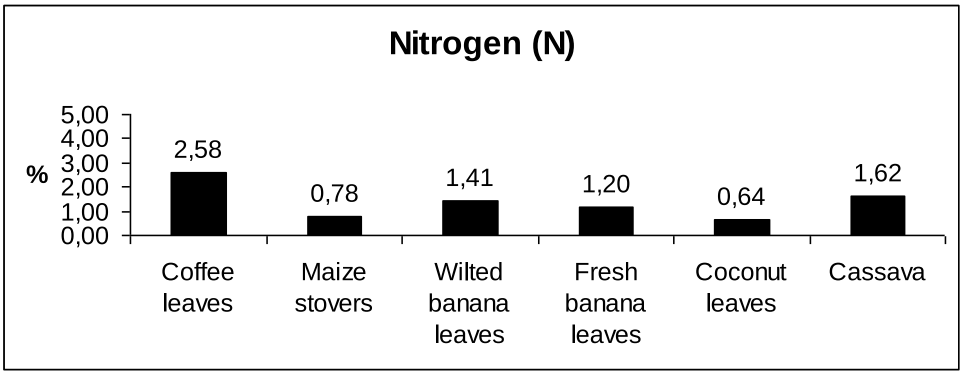

Figure 3. Nitrogen content in biochar from different plant materials.

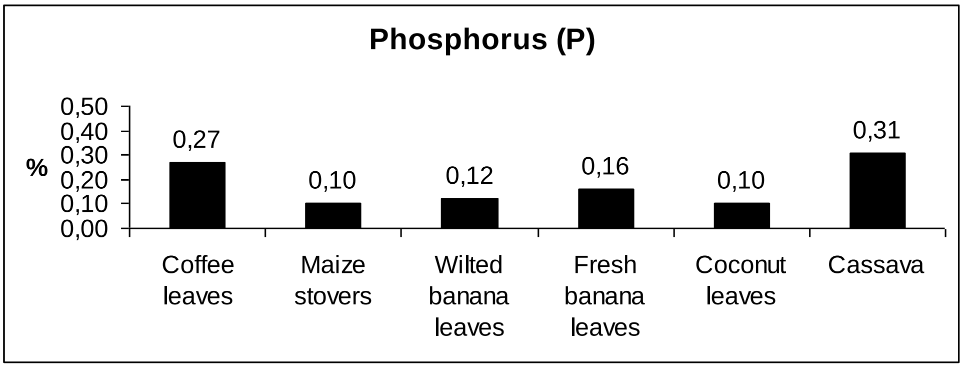

Figure 4. Phosphorus content in biochar from different plant materials.

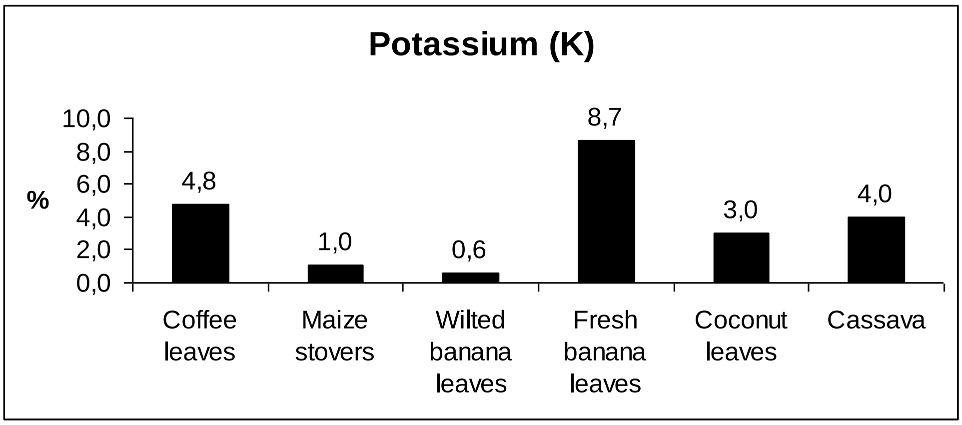

Figure 5. Potassium content in biochar from different plant materials.

The analyses do not reveal a big variation in nutrient content between the materials. One exception is the potassium content, where fresh banana leaves show a larger proportion. Also coffee leaves have high potassium content. In general, coffee leaves and cassava have higher nutrient content compared to the other plant materials. Poorest in nutrient content are maize stovers.

The analyses only give the total nutrient content and do not show whether they are plant available. Although the nutrient content may be high, the nutrients can be bound in stable forms and therefore not be available for plant uptake. High nutrient content is not necessary equivalent to plant availability.

This is only a school project and for further implementation more research on biochar is needed.

Appendix 3 – List of materials

Biochar production

- Furnace (Gallenkamp, Hotspot furnace, tactical 308. Size: 12,5x11x18 cm)
- Oven (Memmert, Beschickung-loading model 100-800)
- Balance
- Can for production
- Can for pretrial description
- Metal tong
- Paper bags
- Box for mixing
- Protocol

Pot trials

- Pots (2 l) and plates (diameter 17,5 cm)
- Balance
- Seeds *(Poaceae, Panicum spp., Sorghum spp.)*
- Graduated cylinder
- Plastic cover
- Sieve (4 mm)
- Destilled water
- $Ca(ClO)_2$
- Ruler
- Scissors
- Paper bags
- Alcohol (70 %)
- Marker
- Tea spoon
- Spade
- Plastic buckets

Appendix 4 – Initial test of biochar production

Material	Temp. (˚C)	Time (min)	Can weight (g)	Dry weight (g)	Biochar weight (g)	Biochar ratio
Maize	350	90	142,13	35,98	15,27	0,4244
Maize	450	58	141,33	25,29	8,37	0,331
Leafs	450	60	139,09	40,57	14,84	0,365

Appendix 5 – Protocol biochar production

Date	Area	Material	Temp (˚C)	Time (min)	Can weight (g)	Dry weight (g)	Biochar weight (g)	Biochar ratio
20-apr	Embu	wilted banana	450	75	141,33	37,74	14,78	0,3916
21-apr	*Embu*	wilted banana	*450*	*74*	*453,18*	*67,08*	*20,2*	*0,3011*
21-apr	*Embu**	wilted banana	*450*	*89*	*519,45*	*66,27*	*22,56*	*0,3404*
21-apr	*Embu**	wilted banana	*450*	*89*	*533,72*	*80,54*	*26,44*	*0,3283*
21-apr	*Embu**	wilted banana	*450*	*87*	*544,32*	*91,14*	*33,04*	*0,3625*
22-apr	*Embu**	wilted banana	*450*	*89*	*540,52*	*87,34*	*28,71*	*0,3287*
22-apr	Embu	coffee leaves	450	59	541,77	88,59	34,32	0,3874
22-apr	Embu	coffee leaves	450	60	540,28	87,10	33,56	0,3853
22-apr	Embu*	coffee leaves	450	45	556,09	102,91	42,55	0,4135
22-apr	Embu*	coffee leaves	450	45	555,55	102,37	42,42	0,4144
23-apr	Siaya	maize stovers	450	59	542,84	86,84	-	-
23-apr	Siaya	maize stovers	450	90	536,67	80,67	-	-
23-apr	Siaya*	maize stovers	450	120	544,91	88,91	26,94	0,3030
23-apr	Siaya*	maize stovers	450	119	539,87	83,87	27,69	0,3302
26-apr	Siaya*	maize stovers	450	120	531,86	75,86	23,34	0,3077
26-apr	Siaya*	fresh banana	450	90	552,28	96,28	33,39	0,3468
26-apr	Siaya*	fresh banana	450	90	562,92	106,92	40,29	0,3768
26-apr	Siaya*	fresh banana	450	90	544,65	88,65	31,32	0,3533
27-apr	Kwale	coconut	450	120	565,54	112,64	36,97	0,3282
27-apr	Kwale*	coconut	450	148	585,1	132,2	42,71	0,3231
27-apr	Kwale*	coconut	450	148	604,38	151,48	51,21	0,3381
28-apr	Kwale	cassava	450	150	594,5	141,6	31,29	0,2210
28-apr	Kwale*	cassava	450	180	642,84	189,94	32,42	0,1707
28-apr	Kwale*	cassava	450	180	663,67	210,77	37,29	0,1769

*Batches used in pot trial

Appendix 6 – Explanation of pot trial codes

ID	Area	Material	Biochar rate	Biochar (g)	Repl.
A111	Kisumu	Fresh bananas	1	4	1
A112	Kisumu	Fresh bananas	1	4	2
A113	Kisumu	Fresh bananas	1	4	3
A121	Kisumu	Fresh bananas	2	12	1
A122	Kisumu	Fresh bananas	2	12	2
A123	Kisumu	Fresh bananas	2	12	3
A211	Kisumu	Maize stovers	1	4	1
A212	Kisumu	Maize stovers	1	4	2
A213	Kisumu	Maize stovers	1	4	3
A221	Kisumu	Maize stovers	2	12	1
A222	Kisumu	Maize stovers	2	12	2
A223	Kisumu	Maize stovers	2	12	3
B111	Embu	Dry bananas	1	4	1
B112	Embu	Dry bananas	1	4	2
B113	Embu	Dry bananas	1	4	3
B121	Embu	Dry bananas	2	12	1
B122	Embu	Dry bananas	2	12	2
B123	Embu	Dry bananas	2	12	3
B211	Embu	Coffee leaves	1	4	1
B212	Embu	Coffee leaves	1	4	2
B213	Embu	Coffee leaves	1	4	3
B221	Embu	Coffee leaves	2	12	1
B222	Embu	Coffee leaves	2	12	2
B223	Embu	Coffee leaves	2	12	3
C111	Kwale	Coconut	1	4	1
C112	Kwale	Coconut	1	4	2
C113	Kwale	Coconut	1	4	3
C121	Kwale	Coconut	2	12	1
C122	Kwale	Coconut	2	12	2
C123	Kwale	Coconut	2	12	3
C211	Kwale	Cassava	1	4	1
C212	Kwale	Cassava	1	4	2
C213	Kwale	Cassava	1	4	3
C221	Kwale	Cassava	2	12	1
C222	Kwale	Cassava	2	12	2

C223	Kwale	Cassava	2	12	3
O1	Control		0	0	1
O2	Control		0	0	2
O3	Control		0	0	3

Appendix 7 – Calculations

1 ha = 10 000 m^2
10 000 m^2 * 10 cm = 1000 m^3 soil/ha
1000 m^3 * 1,2 g/cm^3 = 1,2 * 10^6 kg soil/ha

Rate 1
1,5 ton carbon/60% = 2,50 ton biochar/ha
2,50 * 10^3 kg / 1,2 * 10^3 kg = 2,08 g biochar / kg soil
2,08 g * 1,6 kg = 3,33 g biochar / pot

2 ton carbon/60% = 3,33 ton biochar/ha
3,33 * 10^3 kg / 1,2 *10^3 kg = 2,78 g biochar/kg soil
2,78 * 1,6 kg = 4,45 g biochar/pot

1,5-2 ton C/ha → approx. 3,3-4,6 g biochar/pot.
Rate 1 = 4 g biochar/pot (= 3 ton biochar/ha)

Rate 2
5 ton carbon/60% = 8,33 ton biochar/ha
8,33 * 10^3 kg / 1,2 * 10^3 kg = 6,94 g biochar/ kg soil
6,94 * 1,6 kg = 11,10 g biochar/pot

6 ton carbon/60% = 10,0 ton biochar/ha
10,0 * 10^3 kg / 1,2 * 10^3 kg = 8,33 g biochar/kg soil
8,33 * 1,6 kg = 13,33 g biochar/pot

5-6 ton C/ha → approx. 11,1-13,3 g biochar/pot.
Rate 2 = 12 g biochar/pot (= 9 ton biochar/ha)

Appendix 8

Average of height at harvest, fresh weight and dry weight

	Average height	Average fresh weight	Average dry weight
Control	17,7	0,59	0,14
Fresh banana leaves 1	19,7	0,72	0,16
Fresh banana leaves 2	26,6	1,65	0,29
Maize stovers 1	17,4	0,55	0,13
Maize stovers 2	19,2	0,70	0,16
Wilted banana leaves 1	18,2	0,67	0,16
Wilted banana leaves 2	23,4	1,03	0,23
Coffee leaves 1	21,9	0,87	0,20
Coffee leaves 2	25,2	1,50	0,31
Coconut leaves 1	20,2	0,73	0,16
Coconut leaves 2	20,9	0,85	0,19
Cassava 1	20,7	0,93	0,20
Cassava 2	33,4	3,26	0,44