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Effects of biochar amendment in soils from Kisumu, Kenya

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Cover: Part of the biochar field trial at Farm 2, photo by author, 2011.

Abstract

Agriculture in Kenya consists mainly of smallhold farming that produce the majority of the total agricultural products. Until the late 1900s soil fertility was maintained through good farming practices with fallow periods, crop rotations and fertilization with livestock manure. Due to the increasing demand for food and the scarcity of land the present agricultural production cannot maintain these practices. Agricultural land is therefore losing soil fertility as most farmers cannot afford to buy fertilizers and often lack the knowledge of other alternative practices. A possible measure to increase soil fertility and carbon content is by biochar amendment. Biochar is produced through pyrolysis, a process when organic material is turned into carbonaceous material during heating with low to no access of. Biochar consist of both stable and easy degradable parts.

This is a Minor Field Study concerning biochar amendment in smallhold farming where the maize mixed farming system is utilized. The aim was to examine the effect of biochar as a soil amendment on decomposition of organic matter and on plant growth of maize under varying soil moisture conditions in Kisumu, Western Kenya. Soils from two nearby farms were used in a pot trial.

The results from soil analyses showed that the amendment of biochar significantly increased pH, carbon content, the total amount of magnesium and calcium in both farms. I the plant growth trial with a water level of 90 % of field capacity there were no significant differences between the control and biochar treated soil, but both trial showed signs of nitrogen deficiency. For the plant trial with 40 % of field capacity both the control and biochar treated trial showed signs of drought stress but it were more severe in the control than in the biochar treated.

Keywords: Biochar, Kenya, smallhold farming, plant growth, soil moisture

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1 Introduction

1.1 The Republic of Kenya

The Republic of Kenya is located by the equator on the east coast of Africa with a land area of 580 367 km^2 bordering to Somalia, Ethiopia, Uganda and Tanzania. The population is 41 million people with a life expectancy of 59 years a population growth of 2, 5 % per year. GDP per capita is 1 600 USD (CIA a) compared to Sweden's 39 100 USD (CIA b). Kenya was a British colony from 1885 to 1963 when they became independent. Therefore the official language is English and the national language is Kiswahili. Kenya is a nation with several ethnical groups with their own local languages (CIA a). Kenya is one of the best-developed economies in eastern Africa; nevertheless it is a low-income country and almost half of the population lives in poverty. The agriculture sector is very important since 79 % of the population depends on it for most of their daily income. Kenya's agriculture consists of mainly smallhold farming systems. The smallholders produce 75 % of the total agricultural products, making them very important for the rural economy. The central and western areas are most suitable for agricultural production and have very high population densities. The high pressure on land resources due to the high population densities results in soil erosion, declining soil fertility and land degradation (Rural Poverty Portal). Most of the soils shows the typical properties for far weathered soils and have a natural declining fertility (Eriksson *et al*., 2005)

Figure 1. Location map Kenya (NE).

1.2 Objectives

This minor field study (MFS) is a BSc thesis were the aim was to examine the effect of biochar as a soil amendment on decomposition of organic matter and on plant growth of maize under varying soil moisture conditions in Kisumu, Western Kenya.

2 Background

2.1 Climate change and land use

Global warming is causing changes in climate patterns (FAO, 2012). According to worst case scenarios it will result in drought and flooding in already exposed areas, where it has fatal effects on the agriculture production (The World Bank, 2012). The developing countries will face the most severe impacts due to a major part of their economies and livelihoods depend on the agriculture production (Moorhead 2009). The cause of the temperature rise is believed to be due to the emission of greenhouse gases such as CO_2, CH_4, N_2O and water vapour that absorb infrared radiation, thus preventing the heat from leaving the atmosphere. The greenhouse effect is essential for life on Earth and without it the surface temperature would be -18°C (Campbell et al., 2008).

Another issue is the growing world population and their increasing demand for food. The increasing food demand causes a high pressure on natural resources that in worst cases leads to degradation of arable land due to the use of unsustainable management practices (FAO, 2012). In developing countries the farming systems consist mainly of smallhold farming. The agricultural production is therefore depending on the smallholding farmers that produce a large part of the food consumed in the developing areas. Even though food is produced in the rural areas, poverty and hunger are most widespread there. Availability of new technologies has intensified and improved the agricultural production in developed countries but far less has been done for the technology needed for smallholding production in developing countries (Dixon et al., 2001).

2.2 Farming systems

The agricultural sector in Kenya consists mainly of smallholder farming. The most common produced agricultural products are sugar cane, cow milk, maize, sweet potatoes, bananas, plantains, cassava, cabbage and other brassicas, vegetables and tomatoes. Kenya is a world leading exporter of black tea, other important export products are coffee, fruit and vegetables (FAO, 2010).

The Food and Agriculture Organisation (FAO, 2012) and the World Bank is defining the major farming systems in Sub-Saharan Africa, where Kenyan farming are divided into three systems; Maize Mixed Farming System, Pastoral Farming System and Coastal Artisanal Fishing Farming System (Dixon *et al.*2001).

The Maize Mixed Farming System is utilised in the plateau and highland areas with climate variations from dry sub-humid to moist sub-humid with two seasonal rains, resulting in two cropping seasons. Farm sizes are often less than two ha and population density is high. Maize is the main staple food and cattle the most important livestock.

Pastoral Farming System is a system utilised in the arid to semiarid zones. In this system the farming consists of herding of cattle, sheep, goats and camels on pastures.

Coastal Artisanal Fishing Farming System includes the coastal areas. The farming system is based on fishing, complemented by crop production, occasionally in multi-storied tree crop gardens with root crops under coconuts, fruit trees and cashews, and some animal production of mainly poultry and goats.

2.3 Soil properties

2.3.1 Erosion and land degradation

Erosion and land degradation is a natural part of the geological cycle; where soil material is being removed by wind, water or ice. Erosion can cause severe problems in cultivated land due to the lack of natural ground cover. Agricultural land in this part of the world is very vulnerable as it is low or not at all protected from the extreme weather conditions that may occur. Erosion and degradation can destroy cultivated land irreversible in a short period of time if measures are not taken to prevent the processes (Eriksson *et al.,* 2011 and WHO, 2012). Until the late 1900s soil fertility was maintained through good farming practises with fallow periods, crop rotation and fertilization with livestock manure. Due to the increasing demand for food and the scarcity of land the present agricultural production cannot maintain these practises (Ståhl 1993). The rising demands on land resources due to economic development, the growing cities and the increasing rural populations are causing unsustainable pressure on land due land use changes (Bai *et al.,* 2006). Agricultural land is therefore losing soil fertility as most farmers cannot afford to buy fertilizers and often lack the knowledge of other alternative practises (Ståhl 1993). According to Bai *et al.* (2006) 30 % of the cropland in Kenya suffered a decrease in both net primary productivity and rain-use efficiency (the ratio of net primary productivity to precipitation) over the period of 1981-2003, which probably is caused by land degradation. The land degradation is mostly due to the expansion of agricultural activity in land not suitable for cropping (Bai *et al.*, 2006). During this period 18 % of the total land area was degraded (Bai *et al.*, 2008). Erosion of soil material by rainwater declines the soil fertility due to the loss of nutrients and humus that is transported away together with the soil particles. In dry areas, wind erosion removes soil material at a size of less than 1 mm in the air, courser material are transported rolling on the ground. In the long run the effect of erosion is fertile soils turning infertile (Eriksson *et al.,* 2005).

2.3.2 The functions of organic carbon in cultivated land

Organic material has an important role as storage of organic nitrogen, phosphorus and sulphur, these nutrients becomes available for growing plants when the material decomposes. Organic material also has beneficial effects on the soil physical characteristics. Organic particles have a large capacity to hold water, commonly better than mineral particles. It improves the soil structure which in turn further improves the water holding capacity and results in a better aeration. Charges organic molecules and mineral particles function as cation exchangers; a high content of organic material in mineral soils contributes to a better cation exchange capacity. The contribution of organic material is especially important in coarse grained soils and far weathered soils with accumulations of sesquioxides and with a domination of low activity clays (Eriksson *et al.,* 2005).

2.3.3 Decomposition of organic material

Decomposition of organic material is a biological process performed by bacterial- and fungal populations in the soil. Climate is a controlling factor since soil temperature and soil moisture are controlling biological processes. Declining temperatures are often followed by a reduction in decomposition rate. Extremely high or low water contents also have a reducing effect on the decomposition rate. There is a correlation between decomposition rate and evapotranspiration, an increase in evapotranspiration implicates an increase in decomposition (Eriksson *et.al.* 2005). The activity and growth of the microorganisms primary depends on the chemical composition of the organic matter. In the initial degradation of organic matter the soluble carbohydrates like sugars, and nitrogen rich compounds are degraded during the first days. Thereafter proteins and more structural carbohydrates like hemicellulose and later cellulose degrades while the degradation of lignin is slower. The nitrogen content of the organic matter affects the decomposition rate in the beginning of the process. The soil pH affects the activity of bacterial- and fungal populations, at low pH the decomposition rate slows down (Eriksson *et.al.* 2011). The warm humid climate in Kenya results in a rapid decomposition rate of organic material (Andrén *et al.*, 2007).

2.4 Biochar

2.4.1 Production and area of use

Pyrolysis is the process when organic material is turned into carbonaceous material. Pyrolysis is combustion of organic material with low to no access of oxygen. Through the pyrolysis organic material is turned into energy products in form of fine-grained, porous and carbon rich material, gas and oil. The carbonaceous material is called char, charcoal or biochar depending on the biochar process, the original material and the use (Lehmann *et al.*, 2009 & Sohi *et al.*, 2009). Char is the pyrolysis product of fires from biomass. Charcoal is for cooking and heating, produced of animal and vegetable matter in kilns. Biochar is the product where the intention is for agriculture or environmental use. Biochar is produced through thermal decomposition of organic material at temperatures up to 700°C and at low oxygen levels (Lehmann *et al.*, 2009).

2.4.2 Biochar as soil amendment

Biochar consist of both stable and easily degradable parts. The stable components can have a half-life varying from hundreds to tens of thousands of years (Sohi *et al.*, 2009) and therefore biochar can increase the soil carbon content more permanently (Lehmann 2007). The stability can be explained by the aromatic ring structure of biochar. There is a rapid initial surface oxidation of fresh biochar that seems to be caused by abiotic processes rather than biotic processes according to a study by Cheng *et al*. (2006). This initial oxidation leads to mineralization of biochar and creates negatively charged surface areas increasing the cation exchange capacity and the cation retention which should imply soil fertility improvement (Cheng *et al*., 2006, Liang *et al.*, 2006 & Glaser *et al*., 2002). Biochar has generally a higher specific surface area than sand and similar or higher than clay and should therefore as a soil amendment cause an increase in the total soil-specific surface (Glaser *et al.*, 2002 & Lehmann *et al.*, 2009). Most of the research on the effects of biochar application is regarding crop production in areas with tropical forest and savannah climates, where the largest productivity responses were documented on weathered and acid soils with low activity clays. The increasing productivity is likely a result of direct mitigation of acid soil conditions and aluminium toxicity caused by the direct application of ash in the biochar. The response of biochar amendment on crop productivity depends on the particular soil characteristics and application may or may not bring positive effects on crop yields. Biochar applied together with mineral fertilizer has shown yield improvements that probably are a result of increased CEC due to the biochar application (Lehmann *et al.*, 2009).

2.4.3 Effect on climate and environment

Except for the purpose of increasing the agricultural production, application of biochar may also result in reduced nutrient leaching, restoration of degraded land and sequestration of C from the atmosphere (Lehmann *et al.*, 2009). The biochar production should not compete for land with any other land use options like food production and the source of biomass should therefore be waste materials (IBI, 2012).

3 Material and methods

This study consists of three parts; 1) interviewing farmers and providing feedback, 2) field work and 3) analysis and greenhouse trial. Interviews of farmers and field work were conducted in Siaya, Kisumu, and the greenhouse trial and laboratory work at the facilities of ICRAF/CIAT-TSBF in Nairobi. Both field and laboratory work was conducted together with Ida Åslund who used the same methods in another area in central Kenya (Åslund 2012).

3.1 Site description

Siaya District is located near the port town of Kisumu by Lake Victoria in western Kenya. The elevation varies from 1 140 meters above sea level in east to 1 400 meters above sea level in the west. Annual precipitation ranges between 800 and 2000 mm, monthly mean minimum temperature is 15 °C and monthly mean maximum temperature is 30 °C. The year consists of two seasonal rains, the long rains from March to June and the short rains from August to November. The main soil type in the area is Ferrasol (Siaya district development plan, 2002-2008). This part of the country is where the Maize Mixed Farming System is utilised (Dixon *et al.* 2001).

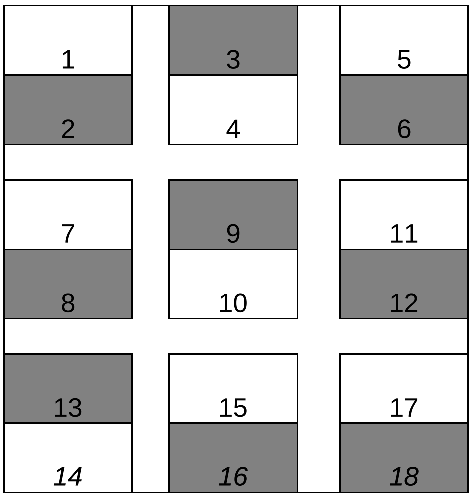
The characteristics of a Ferrasol is far gone weathering resulting in accumulation of sesquioxides and domination of low activity clays, mainly a variation of kaolinite, goethite, hematite and gibbsite depending on the parent material and drainage conditions. Ferrasols have a limited capacity to hold available water for crops due to the strong water retention at permanent wilting point and the low moisture storage at field capacity. Ferrasols have a poor fertility due to the absence of weathering minerals and a low cation exchange capacity. Therefore fertilization or fallow periods are important to maintain a good soil fertility which is essential for crop production (Driessen *et al.,* 2001).

3.1.1 Interviews of farmers

A questionnaire was compiled together with a supervisor before arrival to the farms to assure that the questions asked were applicable to the situation. Interviews of the farmer were held at the farms with the assistance of a local interpreter when the English language was not sufficient. During the interviews one person asked the questions and the other took notes. At the end of the interview a transect walk was performed to get a picture of the farm.

3.1.2 Soil sampling in Siaya

In each of the two farms a trial comprising 18 plots was initiated in November 2006. The trial consists of three primary treatments; black fallow, crop, crop + fertilizers and two sub treatments; with and without biochar amendments (Fig. 2). Each of the six treatments comprised three replicates. In the biochar plots the biochar was applied during the first two seasons with 5 kg biochar per m^2, giving a biochar rate of 50t/ha at each application. The biochar was crushed to a size of 1 cm or less prior to application. The net plot sizes are 4x6 meters. The biochar derived from Acacia tree (Röing de Nowina *et al*., 2010). In this study the black fallow treatments, with and without biochar, were of interest. Treatments without biochar amendments are in the following text called control plots and those with biochar are called biochar plots (Table 1). Soil samples were collected from the three control plots and the three biochar plots for determining of bulk density and other soil properties and also for the greenhouse pot experiment.



Plot treatments

1. crop+fertilizer
2. crop+fertilizer+biochar
3. control+biochar
4. control
5. crop
6. crop+biochar
7. crop
8. crop+biochar
9. crop+fertilizer+biochar
10. crop+fertilizer
11. control
12. control+biochar
13. crop+fertilizer+biochar
14. crop+fertilizer
15. crop
16. crop+biochar
17. control
18. control+biochar

Figure 2. Trial layout for Farm 1 and experimental treatment for the plots.

Table 1. Treatment and plot number at farm 1 and 2

	Biochar (Black fallow)	Control (Black fallow)
Farm 1 (plot number)	3, 12, 18	4, 11, 17
Farm 2 (plot number)	4, 12, 16	3, 11, 15

Two samples for bulk density were collected in each plot with a cylinder (volume of 95.4 cm^3) at 7. 5 – 12 cm depth.

Soil for chemical analyses and for the pot trial was sampled randomly in the plot with a soil auger at a depth of 0 – 20 cm. Soil was collected in a bucket up to approximately 10 kg and mixed together. For chemical analysis 0.5 kg of the mixed soil was put into small polythene bags, the remaining soil was put into bags for the greenhouse pot trial.

3.2 Soil analysis

3.2.1 Bulk density and soil water content

Soil fresh weight was determined. Thereafter, soil samples were oven-dried at 105°C for 24 hours. Thereafter the dry weight, water content and bulk density were calculated.

3.2.2 Estimation of field capacity

Soil (0.8 kg dry weight) from each plot was filled in a pot. Water was added several times during one day and excess water was drained away through holes in the pot. Water was added a last time in the evening and perforated plastic was used for covering the pots to minimize evaporation. The following day when drainage equilibrium was reached the pots were weighted. Field capacity was thereafter calculated for each plot by the differences between the weight of dry and wet soil. For the greenhouse trial water contents of 90, 70, 40 and 20 % of the field capacity were targeted. The reason for chosen water contents was that 90 % of field capacity was assumed to be optimal for a growing crop, 70 % of field capacity is needed for the seed to germinate, 40 % of field capacity was estimated to be the water content in midseason and 20 % of field capacity was the estimated water content when soil sampling was performed. The water content of 20 % of field capacity was only of interest for the decomposition experiment because the water amount was not enough for the maize to grow.

3.2.3 Chemical soil analysis

Soil samples for analysis were put into paper bags and left to dry in a drying room. Dried soil was sieved through a 2 mm sieve and larger aggregates and biochar was grinded and sieved again. The soil samples were sent to Crop Nutrition Laboratory Services for analysis of pH, CEC (cation exchange capacity) and contents of nitrogen, carbon, phosphor, potassium, magnesium and calcium. The analyze method for phosphor was Olsen P and Mehlich 3 for potassium.

3.3 Greenhouse experiment

3.3.1 Plant growth trial

Soil samples for the greenhouse experiment were sundried over a plastic cover. Thereafter, the soil was sieved through a 2 mm sieve and biochar and aggregates larger than 2 mm were grinded and sieved again. The experiment consisted of 24 pots divided into two trials (Fig. 3). The pots were filled with 0.8 kg of soil from each plot. Water was added three hours before seeding to all pots corresponding to 70 % of the soils field capacity for avoiding air bubbles that could have disrupted the germination of the maize seeds. Three maize grains were then inserted into the soil at two cm depth. The reason for planting of three seeds was to ensure the germination of at least one. Until the plants had reached a height of 5 cm they had a water content of 70 % of field capacity. Thereafter, the water content was changed to 90 % of field capacity in one treatment and to 40 % in a second treatment. When at least one of the plants in each pot had reached a height of 10 cm the other two were removed. The chosen water levels were kept almost constant through weighing of the pots every day and adjusting the weight by addition of water. As the plants grew the weight was adjusted according to reference plants grown alongside the trial. The experiment ended after four weeks when all plants were harvested 1 cm above the soil surface and plant height was measured. Fresh weight was measured and after oven-dried at 105°C for 24 hours the dry matter weight was determined.

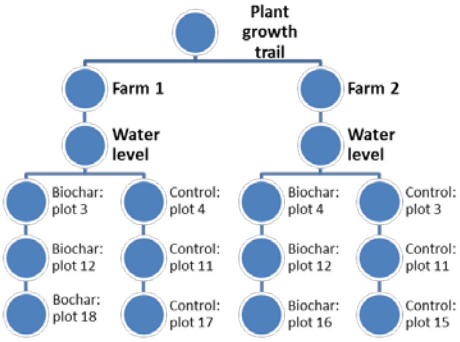


Figure 3. Plant growth trial.

3.3.2 Decomposition trial

Dried maize leaves were cut in small squares, approximately 1x1 cm. Nylon mesh bags with a size of 4x6 cm were filled with 0.5 g dry mass of maize. Three mesh bags were placed vertically in a triangle in the pots, two cm from the bottom, with the same distance to each other and the pot wall. The experiment contained 36 pots divided into three trials with different water levels: 90 %, 40 % and 20 % of field capacity (Fig. 4). Pot weight was measured and included 0.8 kg of soil, the pot and chosen water level. The water amount at each level was obtained through a daily weighting of the pots and adjusting it with addition of water. One bag was then removed from every pot at the end of the first, second and fourth week. The leaves in the mesh bags were oven-dried in 60 °C over night, the dry matter content was determined and the three replicates were grinded together for analysis of nitrogen, phosphorus and potassium.

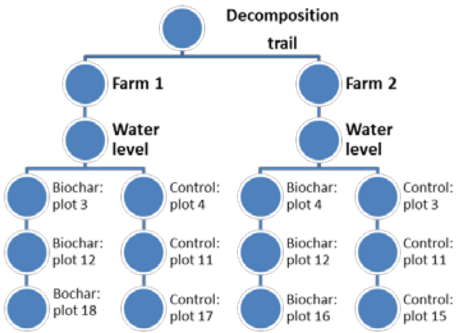


Figure 4. Decomposition trial.

3.4 Statistical analysis

In order to determine if differences between treatments were significant a t-test for two samples assuming equal variances was performed in Microsoft Excel. A significance level of 5% was used.

4 Results

4.1 Summary of interviews

The farms are managed mainly by the families; an exception is hectic periods when workers are hired. The agricultural production is the major income for the households. The farms sizes varied from 1.1 to 1.8 ha and support families from 1-8 members. The animals held on the farms are poultry, goats, sheep and cattle. The goats, sheep and cattle are kept in roofless small stables. The meat and dairy products from the animals are often sold. The crops cultivated are cabbage, bananas, maize, sweet potatoes, beans, sugar cane, coffee, arrow root and cassava. For cash crops bananas, coffee and sugar cane are cultivated and these crops are the only that are fertilized with mineral NPK fertilizers. Crops cultivated for household use are fertilized with animal manure if available. Otherwise crop residues are left in the field after harvest. Pesticides are only used for the cash crops coffee and cabbage. For soil management digging forks are used and oxen are hired for ploughing. Broadcasting by hand is the utilized sowing technique. Harvest is managed by hand with a panga. Both of the sites have two cropping seasons, the first occurs after the long rains (March – April) and the second after the short rains (August-October). Crops are sown after the rainy seasons and harvested in June-September and in January.

4.2 Soil analysis

Biochar amendment did not significantly decrease bulk density on neither Farm 1 nor Farm 2 (Fig. 5). Raw data are shown in Appendix 1.

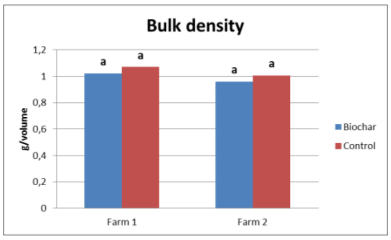


Figure 5. Bulk density in soil with and without biochar.

The application of biochar did significantly increase the field capacity on Farm 2 but not on Farm 1 (Fig. 6). Raw data is shown in Appendix 2.

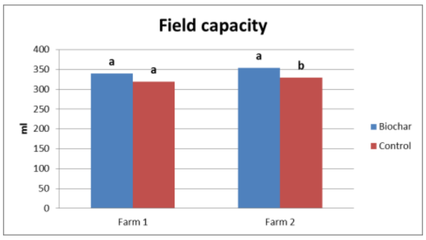


Figure 6. Field capacity in soil with and without biochar amendment.

Soil analysis results (Fig. 7) indicate that the application of biochar significantly increased pH, carbon content, total amount of magnesium and calcium in both Farm 1 and Farm 2. The pH value increased with half a unit in all of the biochar soils. For potassium and CEC the increase was only significant for Farm 2. There were no significant differences in nitrogen content and phosphorus in neither Farm1 nor Farm 2. Raw data from the soil analysis is shown in Appendix 3.

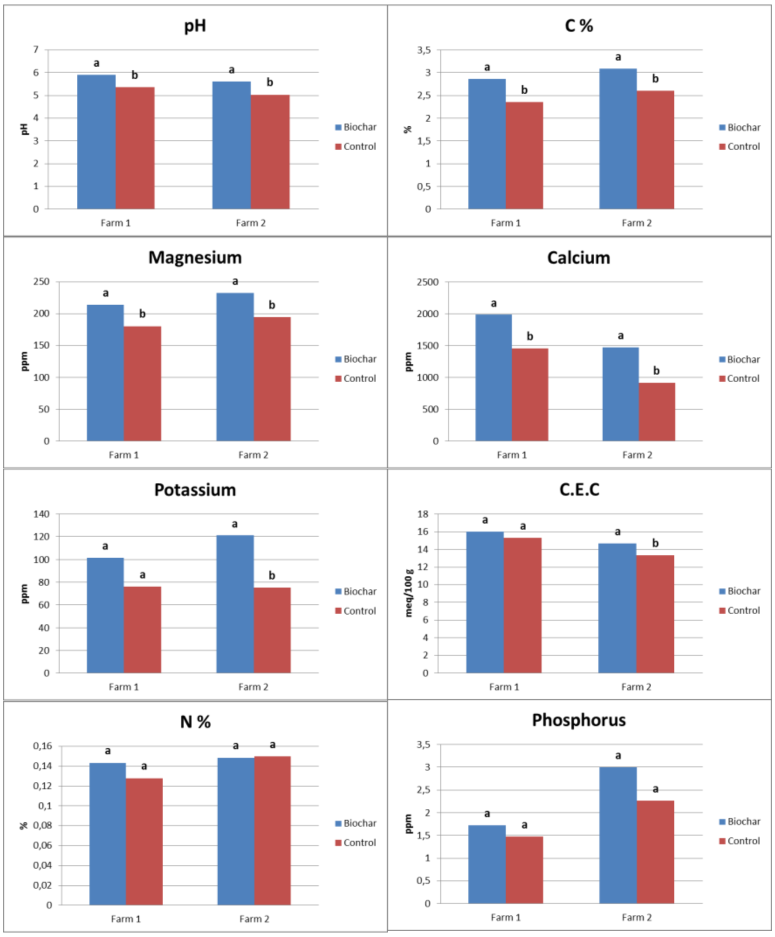


Figure 7. Differences in pH, carbon , magnesium, calcium, potassium, C.E.C., nitrogen and phosphorus content with and without biochar application in farm 1 and farm 2.

4.3 Plant growth trial

Results from the plant growth trial with a water level of 90 % of field capacity indicate that the application of biochar gave no significant differences in plant height, fresh weight and dry weight (Fig. 8). Raw data are shown in Appendix 4.

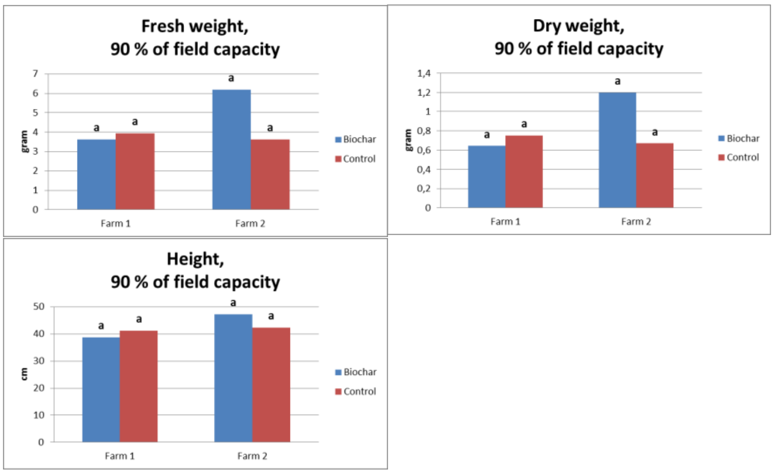


Figure 8. Fresh weight, dry weight and height of plants in soil with and without biochar application in Farm 1 and Farm 2.

Plants grown at 90 % of field capacity were not visually affected by biochar treatment. Plants from all treatments in both farm 1 (Fig. 9) and farm 2 (Fig. 10) showed signs of nitrogen deficiency.

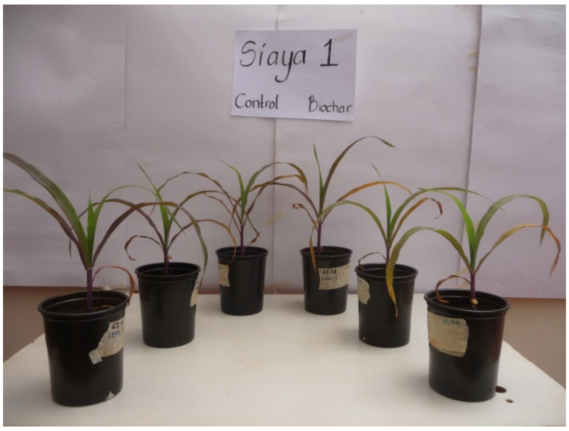


Figure 9. Maize plants grown in soil from Farm 1 with a water level of 90 % of field capacity. The three plants on the left are grown in soil from control plots and plants to the right are grown in soil from biochar plots.

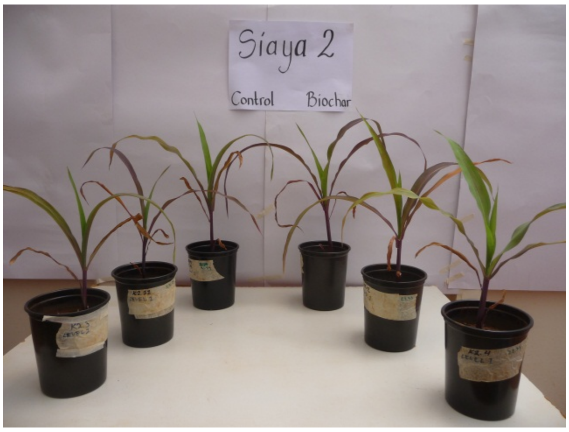


Figure 10. Maize plants grown in soil from Farm 2 with a water level of 90 % of field capacity. The three plants on the left are grown in soil from control plots and plants to the right grow in soil from biochar plots.

Plants growing at 40 % of field capacity (Fig. 11) had significantly higher fresh weight in the biochar treated soil in farm 1 but not in Farm 2. For plant height and dry weight no significant differences were obtained in neither of the farms. Raw data are shown in Appendix 4.

Plants grown at 40% of field capacity were severely stressed by drought (Fig. 12 and 13). The drought stress was more severe in soils without biochar application.

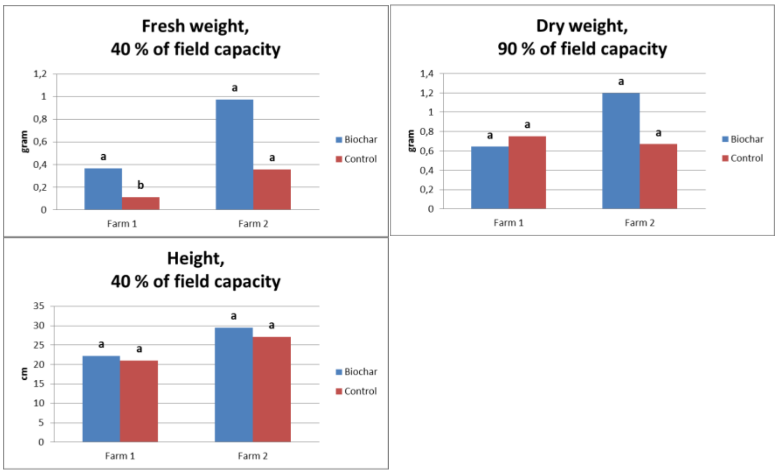


Figure 11. Fresh weight, dry weight and height of plants in soil with and without biochar application in Farm 1 and Farm 2.

Figure 12. Maize plants grown in soil from Farm 1 with a water level of 40 % of field capacity. The plants to the left are grown in soil from control plots and plants to the right are grown in soil from biochar plots.

Figure 12. Maize plants grown in soil from Farm 2 with a water level of 40 % of field capacity. The plants to the left are grown in soil from control plots and plants to the right are grown in soil from biochar plots.

4.4 Decomposition trial

In the decomposition trial no results could be obtained for the mass changes since we missed to determine the ash-content of the samples. Ash-content would have been required due to contamination of the samples with soil.

5 Discussion

According to Lehmann *et al*. (2011) biochar application can decrease bulk density when the density of biochar is lower than that of minerals and because biochar contains macro- and micro-pores. In this experiment biochar application did not significantly decrease bulk density in any of the farms. A possible reason could be that the amount of biochar added was not sufficient for significantly lowering the bulk density in this type of clay soil.

Biochar application did significantly increase field capacity in Farm 2. According to Lehmann *et al.* (2011) biochar particles have large internal surface areas and pores which retain soil moisture and nutrients. In this experiment a better soil moisture retention was only seen in Farm 2 and not in Farm 1.

The soil analysis revealed significant increases in contents of carbon, magnesium and calcium for biochar plots in both farms. For potassium content and CEC the differences were only significant for soils in Farm 2. The increase in nutrients can be explained by the direct fertilization of ash that is a combined effect of the biochar application (Glaser *et al.*, 2002, Lehmann *et al.* 2011). We have no knowledge of the nutrient contents of the biochar or ash applied but the increase should be an effect of the applied ash because the plots have not been cultivated or fertilized. The positive effect ashes from burned biomass have on soil pH is well known (Glaser *et al.*, 2002). The soil analysis revealed higher pH for soils with biochar application. The original material and the pyrolysis temperature determines if the biochar will increase or decrease soil pH (Lehmann et al., 2011). The original material used in this experiment was Acacia tree. There is no information on pH of the biochar used or the pyrolysis temperature but according to Lehmann *et al.*(2009) bark of Acacia has a pH of 7,4 when the production condition was 260°C – 360°C and measured in 1 M KCl. The soil pH in the untreated plots ranged between 4,96 and 5,42 and the pH increased with approximately half a unit in all the biochar treated plots and the increases were significant. The soil analysis for nitrogen and phosphorus content showed no significant differences between the treatments. Contents of nitrogen and phosphorus in biochar vary a lot depending on the pyrolysis process (Lehmann *et al.* 2009). As the production process of the biochar used is not known it is difficult to draw any conclusions.

In the plant growth experiment conducted at 90 % of field capacity there were no significant differences in fresh weight, dry weight and height between the treatments with and without biochar application. Plants in both treatments suffered from nitrogen shortage. The soil analysis showed that the biochar did not contribute to any nitrogen fertilization. These results are similar to the results for Chan *et al.* (2007) when studying the dry matter yield of radish in a biochar experiment. Their conclusion was that the biochar had a low nitrogen content and a high C/N ratio and that the growth of the radish were limited by nitrogen shortage.

In the trial with 40 % of water capacity the differences were only significant for fresh weight and not for dry weight or height in Farm 1. The significant result for fresh weight can be explained by the fact that when the trial ended the plants in soil without biochar application were dead but had almost the same fresh weight as dry weight. For Farm 2 there were no significant differences for any of the results. However, visual observations indicated that the plants in biochar amended soil had not suffered from drought as much as the plants in soils without biochar; two of three plants were reported dead at the end of the trial. The soil analysis indicated that there was a significant difference in field capacity between the treatments which means that the plants in biochar amended soil were given a larger water volume than the plants with no biochar. This explains treatment differences in drought stress.

When comparing fresh weight, dry weight and height between the two farms the values are higher in Farm 2 than in Farm 1. The soil analysis reveal that the available phosphorus content in Farm 2 is nearly twice as high as compared to soil in Farm 1. Phosphorus in Ferrasols is often strongly bound to oxides of Al and Fe and thereby not available for plant uptake. Shortage of phosphorus results in small and weak plants (Eriksson *et.al.*

2011). A better availability of phosphorus could therefore explain the better growth of plants in Farm 2.

6 Conclusions

In this experiment biochar application did not seem to improve the growth of maize in soil from Kisumu. However, it has to be considered that no fertilizer was added and plants in all treatments were grown under nutrient-limited conditions. Because soil analysis from the start of the field experiments was not available eventual changes in soil fertility could not be evaluated.

Biochar amendment might be a part of a new farming practise for a sustainable agriculture production in this type of climate and weathered soils, in combination with other farming practises like fertilizers, drought tolerant crops and Agroforestry.

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Appendix 1. Raw data for bulk density.

Soil samples	Label	Fresh weight(g)	Dry weight(g)	Volume	Bulk density	TS	Bulk density	TS
Farm 1 plot 3a	K1.3a	125,2	99,44	95,42194986	1,042108238	0,794249201		
Farm 1 plot 3b	K1.3b	128,41	101,56	95,42194986	1,064325348	0,790904135	1,053216793	0,792576668
Farm 1 plot 12a	K1.12a	127,5	101,06	95,42194986	1,059085464	0,792627451		
Farm 1 plot 12b	K1.12b	114,39	93,67	95,42194986	0,98163997	0,818865285	1,020362717	0,805746368
Farm 1 plot 18a	K1.18a	132,27	108,36	95,42194986	1,135587778	0,819233386		
Farm 1 plot 18b	K1.18b	99,42	80,49	95,42194986	0,843516613	0,809595655	0,989552196	0,814414521
Farm 1 plot 4a	K1.4a	127,73	102,6	95,42194986	1,075224308	0,80325687		
Farm 1 plot 4b	K1.4b	133,44	107	95,42194986	1,121335292	0,801858513	1,0982798	0,802557692
Farm 1 plot 11a	K1.11a	114,87	94,6	95,42194986	0,991386155	0,823539654		
Farm 1 plot 11b	K1.11b	119,85	100,11	95,42194986	1,049129683	0,835294118	1,020257919	0,829416886
Farm 1 plot 17a	K1.17a	116,39	95,38	95,42194986	0,999560375	0,81948621		
Farm 1 plot 17b	K1.17b	136	112,68	95,42194986	1,18086038	0,828529412	1,090210378	0,824007811
Farm 2 plot 4a	K2.4a	108,96	89,95	95,42194986	0,942655229	0,825532305		
Farm 2 plot 4b	K2.4b	114,21	92,73	95,42194986	0,971788987	0,811925401	0,957222108	0,818728853
Farm 2 plot 12a	K2.12a	113,2	92,87	95,42194986	0,973256155	0,82040636		
Farm 2 plot 12b	K2.12b	99,85	81,69	95,42194986	0,856092336	0,818127191	0,914674246	0,819266776
Farm 2 plot 16a	K2.16a	108,14	87,98	95,42194986	0,922010084	0,813574995		
Farm 2 plot 16b	K2.16b	126,16	103,48	95,42194986	1,084446505	0,820228282	1,003228294	0,816901638
Farm 2 plot 3a	K2.3a	119,33	97,49	95,42194986	1,021672688	0,816978128		
Farm 2 plot 3b	K2.3b	112,4	92,29	95,42194986	0,967177889	0,821085409	0,994425288	0,819031769
Farm 2 plot 11a	K2.11a	116,88	95,91	95,42194986	1,005114653	0,820585216		
Farm 2 plot 11b	K2.11b	117,09	95,42	95,42194986	0,999979566	0,814928687	1,002547109	0,817756951
Farm 2 plot 15a	K2.15a	119,94	98,81	95,42194986	1,035505983	0,823828581		
Farm 2 plot 15b	K2.15b	114,89	95,84	95,42194986	1,004381069	0,834189224	1,019943526	0,829008903

Appendix 2. Raw data for field capacity calculations.

Label	**Plot**	Pot + bag(g)	Dry weight(g)	Drainage equilibrium + pot	Drainage equilibrium	Field capacity	90 % of field capacity	70% of field capacity	40 % of field capacity	20% of field capacity
K1.3	Farm 1 plot 3	22,54	800	1160,87	1138,33	338,33	304,497	236,831	135,332	67,666
K1.12	Farm 1 plot 12	22,79	800	1145,54	1122,75	322,75	290,475	225,925	129,1	64,55
K1.18	Farm 1 plot 18	22,6	800	1181,52	1158,92	358,92	323,028	251,244	143,568	71,784
K1.4	Farm 1 plot 4	22,51	800	1119,79	1097,28	297,28	267,552	208,096	118,912	59,456
K1.11	Farm 1 plot 11	22,16	800	1147,97	1125,81	325,81	293,229	228,067	130,324	65,162
K1.17	Farm 1 plot 17	21,72	800	1155,99	1134,27	334,27	300,843	233,989	133,708	66,854
K2.4	Farm 2 plot 4	21,92	800	1177,7	1155,78	355,78	320,202	249,046	142,312	71,156
K2.12	Farm 2 plot 12	23,09	800	1184,32	1161,23	361,23	325,107	252,861	144,492	72,246
K2.16	Farm 2 plot 16	22,46	800	1167,67	1145,21	345,21	310,689	241,647	138,084	69,042
K2.3	Farm 2 plot 3	21,84	800	1156,63	1134,79	334,79	301,311	234,353	133,916	66,958
K2.11	Farm 2 plot 11	22,39	800	1153,44	1131,05	331,05	297,945	231,735	132,42	66,21
K2.15	Farm 2 plot 15	22,08	800	1144,94	1122,86	322,86	290,574	226,002	129,144	64,572

Appendix 3. Soil analysis

Crop Nutrition Laboratory Services
Healthy, Profitable Farming

Client TSBF-CIAT
Farm Kisumu
Analysis Soil
Crop Maize
Date 17-mar-11

Sample Number	Field	pH	P(O)	K	Ca	Mg	Na	C.E.C	C	N		Ca	Mg	K	Na	OB	H	Ca:Mg
			ppm	ppm	ppm	ppm	ppm	meq/100	%	%		%	%	%	%	%	%	%
CT042SA1756	AK 1.3	5,87	2	120	1953	222	19	16	2,74	0,15		61,32	11,63	1,94	0,53	5,66	18,93	5,27
CT042SA1757	AK 1.12	5,94	1	99	2011	208	26	16	2,95	0,15		64,39	11,08	1,62	0,71	5,51	16,68	5,81
CT042SA1758	AK 1.18	5,93	2	85	1996	213	31	16	2,91	0,13		63,72	11,31	1,39	0,87	5,54	17,16	5,64
CT042SA1759	AK 1.4	5,28	1	113	1600	202	18	18	2,38	0,11		45,05	9,49	1,63	0,45	6,84	36,54	4,75
CT042SA1760	AK 1.11	5,42	2	58	1387	170	17	14	2,27	0,14		49,4	10,11	1,06	0,54	6,56	32,34	4,89
CT042SA1761	AK 1.17	5,40	2	57	1382	170	18	14	2,42	0,13		48,78	9,98	1,04	0,54	6,6	33,06	4,89
CT042SA1762	AK 2.4	5,52	3	102	1420	231	13	15	2,96	0,15		48,79	13,23	1,79	0,39	6,36	29,43	3,69
CT042SA1763	AK 2.12	5,67	3	124	1535	232	19	15	3,11	0,15		52,86	13,29	2,19	0,57	6,07	25,02	3,98
CT042SA1764	AK 2.16	5,65	3	138	1463	236	17	14	3,20	0,15		51,44	13,84	2,48	0,52	6,11	25,62	3,72
CT042SA1765	AK 2.3	5,09	3	76	947	204	19	13	2,62	0,16		35,56	12,75	1,46	0,62	7,23	42,39	2,79
CT042SA1766	AK 2.11	5,07	2	74	990	202	16	14	2,75	0,14		35,71	12,16	1,36	0,51	7,27	42,99	2,94
CT042SA1767	AK 2.15	4,96	2	76	822	179	15	13	2,45	0,15		32,74	11,85	1,56	0,52	7,48	45,84	2,76

Appendix 4. Plant trial results.

90 % of field capacity

Plot	Height(cm)	Fresh weight(g)	Dry weight(g)	Observations
K1.3	34,5	3,22	0,58	Cyano coloured stem and leaf veins. Yellow leaf. Oldest leaf wilted.
K1.12	37,5	2,95	0,56	Cyano coloured stem and leaf veins. Yellow leaf. Oldest leaf wilted.
K1.18	44	4,67	0,79	Cyano coloured stem and leaf veins. Yellow leaf. Oldest leaf wilted.
K1.4	44	4,9	0,92	Cyano coloured plant. Yellow leaf tips.
K1.11	37	3,04	0,59	Cyano coloured plant. Yellow leaf tips.
K1.17	42,5	3,85	0,75	Cyano coloured stem and leaf veins. Yellow leaf tips.
K2.4	42	5,29	0,95	Cyano coloured stem and leaf veins. Yellow leaf. Oldest leaf wilted.
K2.12	45	5,59	0,96	Cyano coloured stem and leaf veins. Yellow leaf tips.
K2.16	54,5	7,72	1,68	Cyano coloured plant. Oldest leaf wilted.
K2.3	39	2,99	0,54	Cyano coloured stem and leaf veins. Oldest leaf wilting.
K2.11	40	2,49	0,49	Cyano coloured plant.
K2.15	48	5,41	0,98	Cyano coloured plant. Oldest yellow and wilted.

40 % of field capacity

Plot	Height(cm)	Fresh weight(g)	Dry weight(g)	Observations
K1.3	22	0,32	0,11	Cyano coloured stem. Wilting leaf tips.
K1.12	19	0,33	0,12	Cyano coloured stem. Wilting leaf tips.
K1.18	25,5	0,45	0,17	Cyano coloured stem. Wilting leaf tips.
K1.4	21	0,12	0,14	Dead
K1.11	19	0,08	0,08	Dead
K1.17	23	0,14	0,13	Dead
K2.4	29	0,92	0,27	Cyano coloured stem and leaf veins. Wilting leaf tips.
K2.12	31	1,39	0,34	Cyano coloured plant. Wilting leaf tips.
K2.16	28,5	0,61	0,21	Slouching plant. Wilting leaf tips.
K2.3	23,5	0,47	0,15	Wilting plant.
K2.11	27,5	0,18	0,15	Dead
K2.15	30,5	0,42	0,22	Dead