Swedish University of Agricultural Sciences
Department of Soil and Environment

Effects of applying biochar to soils from Embu, Kenya

– Effects on crop residue decomposition and soil fertility under varying soil moisture levels

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Cover: Photograph of four of the plots in the field trial on farm 2, planted with beans. To the left, no biochar added to the soil. To the right, biochar added to the soil. Photo by author

Abstract

Global warming is a challenge the world is facing today. All countries won't have the same potential to adapt to future climate. The economic situation is determining on how well the country can adapt. Therefore, this will be a bigger challenge for developing countries. Many of these countries are situated near the equator and are relatively dry. They are also predicted to become warmer and dryer in the future. Due to high weathering rates and erosion soils in these countries are poor in nutrients. Fertilizers are expensive and therefore in limited use. In many areas also infrastructure is limiting the availability of fertilizers. Rapid decomposition of organic matter causes carbon content rarely to be maintained in soils. Carbon is important for water and nutrient holding capacity and is therefore affecting crop yields. If crop residues are combusted in absence of oxygen a part of that carbon remains as biochar. This biochar is more stable than crop residues and can thereby be added to soil for improving soil properties. Research on biochar is conducted in many countries over the world, inspired by the black Terra Preta soils in Amazonas. Several field studies are run by *Swedish University of Agriculture* in collaboration with *International Center for Tropical Agriculture, Tropical Soil Biology and Fertility* (CIAT-TSBF) in Kenya. I performed my field studies in one of these experiments, at Embu, close to Mount Kenya. I studied the effects of biochar on plant growth and decomposition of crop residues under varying soil moisture levels. This study was conducted in pots in a greenhouse. The results indicate a positive effect of added biochar on plant water supply and nutrient availability after application of biochar. Plants grown in soils not containing biochar suffered from nitrogen deficiency and drought. Plants grown in presence of biochar had higher biomass and showed less signs of nutrient deficiency and drought stress. Biochar could be produced on the farms using organic materials that are commonly available. Therefore, biochar could be an option for improving soil fertility. The implementation of this technology could even become more important for food security in the future due to climate change.

Key words: Biochar, plant growth, decomposition, soil amendment, Kenya, soil moisture, climate change, drought.

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1 Introduction

1.1 Kenya

The republic of Kenya is a developing country, located on the east coast of Africa (Figure 1) with neighboring countries; Tanzania, Uganda, Sudan, Ethiopia and Somalia. The land area is 580 367 km^2, the population 41 070 934 million and the growth rate is 2,462 %. Kenya was colonized by United Kingdom in 1895 and became independent in 1963 (Central Intelligence Agency, 2010).

Figure 1 Map of Kenya's location on earth (The World Bank, 2011).

The GNP per capita in Kenya is 1 600 USD compared to Sweden which has a GNP per capita of 39 000 USD (Central Intelligence Agency, 2010). 50 % of the population in Kenya lives in poverty but with current economical conditions in the country it would be possible to reduce poverty. Since extensive corruption is widely spread it opposes the development towards this direction. Corruption is a large obstacle towards development (Sida, 2010). Agriculture is the most important industry, since 75 % of the population is depending on it for food and income. Only one third of the total land area is suitable for agriculture due to limitations by topography and climate. In the northern and eastern part rainfall is 200-400 mm per year, whereas in the western part it can be as high as 1,600 mm (WRI, 2007). The varying topography divides the land area into different regions. The climate is humid in the highlands, sub-humid in the lake region`s and the western part, semi-arid in the north and north-eastern part (fao.org; 2006). About 80 % of the land area is arid or semi-arid (FAO Land and Water Division, 2005). There are two rainy seasons; long rains in March-June and short rains in October-November. In between these there are dry seasons (Camberlin, 1997).

1.2 Farming systems in Kenya

Generally, farming is small-scale and the farms are usually run by family members. Most common crops cultivated for food are maize, cassava, sugar cane, beans, sweat potatoes, potatoes, sorghum, fruits and vegetables. Main cash crops for exportation are coffee, tea, vegetables, fruits and flowers (CIA, 2010). Major challenges for African agriculture are the low content of nutrients in the soil, caused by population growth and lack of fallow. To compensate for nutrient depletion caused by cultivated crops and to maintain soil fertility, nutrients need to be applied continuously. Since fertilizers are expensive most farmers can't afford to maintain the soil fertility and nutrient content. Generally, fertilizers are applied to cash crops, coffee and tea for example. Cultivation strategies such as crop rotations, intercropping and fallow are important for keeping soil fertility (Sanchez et al., 1997).

1.3 Project description

This thesis is a part of a project about biochar as a soil amendment in collaboration between the Research program Tropical Soil Biology and Fertility at the institute of CIAT (CIAT-TSBF) and the Department of Soil and Environment at the Swedish University of Agriculture (SLU). Within this project a field experiment is ongoing to investigate effects of application of biochar in the fields. The main aim of my project was to study the effect of biochar and soil moisture on plant growth and decomposition of crop residues (in this case maize leaves). The soils used for this project has been collected in Embu and was performed in parallel with another student, Camilla Söderberg, who studied a soil from Kisumu in Western Kenya using the same method.

2 Background

2.1 Climate and climate change

Today the world is facing a challenge due to global warming, believed to be caused by increased levels of greenhouse gases. The greenhouse effect is essential for life on Earth and if it were not for this effect the average temperature on Earth would be -18°C. Some believe the increase of greenhouse gases in the atmosphere is created by anthropogenic activity. Since the Industrial Revolution the combustion of fossil fuels has increased and still increases. Greenhouse gases such as CO_2, CH_4 and N_2O are long-lived and they absorb and prevent the infrared radiation from Earth leaving the atmosphere. There is a debate whether present climate changes are natural or caused by human activity (Campbell & Reece, 2008). The effects of global warming will be different in different parts of the world. It is projected that areas near the equator will get a warmer and drier climate which could affect farming in a negative way. One of these countries is Kenya (naturvardsverket.se, 2008). A country's ability to cope with climate change is depending on its economic situation. Therefore it will be a bigger challenge for developing countries to adjust to the changes in climate (svt.se, 2007). Observed climatic trends in Kenya are inconsistent rain pattern and increased natural weather disasters resulting in cyclic droughts and floods etc (UNEP, 2007). According to UNEP (2009) the mean annual temperature in Kenya has increased with 1˚C since 1960. The temperature could increase 2.8 degrees by 2060 and by 4 degrees in 2100. Kenya is considered a water deficient country. Water shortage in already dry areas is expected in the future (NEMA, 2009). Kenya usually experiences two rainy seasons per year but in 2009 the short rain falls didn't appear. It's likely that there will be tremendous changes in rain fall patterns in the future (Harding & Devisscher, 2009).

2.2 Soil properties from cultivation aspects

2.2.1 Soil types

In humid climates precipitation is higher than evaporation which results in nutrient leaching. In arid climate it's the opposite, precipitation is lower than evaporation which will lead to a desert climate and high amounts of salts in the ground caused by weathering. In tropical humid climates typical soil types are oxisole and ultisole. These represent the final stage of soil formation. Oxisoles and ultisols are highly weathered and have a yellowish to red color caused by Fe- and Al-oxides (sesquioxides). Because of the weathering and leaching these soils are poor in nutrients. Field capacity is low due to poor sandy like structure caused by sesquioxides which are bound together in strong micro aggregates. Particle size of sesquioxides is clay, whereby they contribute to a high quota of non-available water in the soil. This means the soils can't hold a lot of water available to plants. In climates with high precipitation and high temperature, like in Kenya, there's a high decomposition of organic material, see 2.5 Decomposition. To make these soils able to cultivate there must be carbon added, for example by adding crop residues, see chapter 2.4. In more arid climate aridisole and entisole are the most common soils. These are young, slightly developed soils, due to dry environment. Aridisoles are typical in deserts where there are only short periods with water in the top soil and high amounts of salts due to the shortage of water. This is a tough environment for plants why only drought and/or salt resistant plants are occurring. But these soils have a high chemical fertility since there's no leaching. With irrigation they can be turned into good cultivating land but it also require a good drainage system to leach the salts (Wiklander, 2005).

2.2.2 Soil erosion and land degradation

One of the main reasons for food insecurity in Kenya is land degradation (Harding & Devisscher, 2009). Erosion becomes a problem on cultivated land, since the soil isn't protected by natural vegetation. Most cultivated soils in Africa have been exposed to far gone erosion and/or nutrient depletion. This has made the soils poor and impaired their capacity to hold water and nutrients. Erosion is caused by intense rainfalls and wind mainly during dry seasons (Wiklander, 2005).

2.2.3 The functions of organic carbon in cultivated land

Organic particles have a large surface area in proportion to their volume, because of the small size of the particles. Since nutrients and water are binding to the surface, organic particles, generally, can hold more water and nutrients than mineral particles can. Soil organic matter also (SOM), generally, has a higher capacity to adsorb cations (CEC) than mineral particles have. The content of (SOM) is therefore important for the capacity of holding water and nutrients. Nutrients as nitrogen, phosphorus and sulfur are also bound in organic material and get available when decomposing. SOM can improve the structure in mineral soils and together with clay forms aggregates. That will lead to soils less sensitive to disturbances, for example cultivation. A good structure provides more air to circulate in the soil and higher capacity for holding water. This will lead to a better root environment that provides more roots to develop. This makes it possible for the plant to get more water and nutrients, which will enhance plant growth and thereby increasing the yields (Wiklander, 2005).

2.2.4 Decomposition

The rate of decomposition is affected by temperature and moisture. Low temperatures and extremely high or extremely low amount of water will reduce the rate. Decomposition is also dependent on evaporation and pH. Microorganisms are important for decomposition since they convert organic material to CO_2. pH affects the microbial climate; low pH will inhibit bacteria and benefit some fungus species. In the current climate of Kenya there is a rapid decomposition which contributes to low amounts of organic carbon in soils. Influence of carbon on soil properties will thereby be low. Crop residues from harvest are not always enough to maintain the content of carbon in the soil (Wiklander; 2005). C/N ratio has an impact on decomposition of organic material. Higher quota than 25 means there’s a high competition for nitrogen among plants. The rate of decomposition will decrease and plants suffer of nitrogen shortage (SLU, 2007).

2.3 Biochar

2.3.1 Production

Biochar is made through thermal decomposition (pyrolysis), a process where organic material is combusted in the absence of air. As a byproduct from production of biochar oil and gas can be produced. These byproducts can be used as fuel, clean and renewable energy (IBI, 2011). At a temperature of 120˚C and above, all organic materials will start to undergo thermal decomposition (Lehman & Joseph, 2009). The nutrient composition of biochar depends on the material it is made of as well as the duration and temperature during the pyrolysis (Major, J. 2010). The content of ash is important for the physical properties of biochar and high ash content might deteriorate the structure, wherefore the biochar becomes less stable (Lehman & Joseph, 2009). Materials that can be used for production of biochar are crop residues, animal manure, and food and forestry waste among others (IBI, 2011).

2.3.2 Climate and environmental aspects

Nowadays organic wastes are burned or left to decompose. This will release CO_2 and CH_4 to the atmosphere and might also pollute local ground and surface water due to leaching of nutrients and chemicals (IBI, 2011). Biochar can improve quality and quantity of these waters by binding the substances, functioning as pollutions in water. These substances will thereby stay in the soil, where they can have a positive function as nutrients, instead of leaching into water and cause pollution (IBI, 2011). Biochar can maintain carbon in the soil for hundreds of years. This carbon would have been released to the atmosphere as CO_2 if combusted in absence of oxygen or decomposed. This means, the total CO_2-emissions to the atmosphere from organic material is decreasing if biochar is produced. Since carbon is bound in soil the system becomes “carbon negative” or in other words a carbon sink. Since biochar also improve soil fertility and stimulate plant growth, plants will consume even more CO_2 and thereby decrease CO_2-emissions to the atmosphere even more (IBI, 2011).

2.3.3 Effects of biochar on soil properties

Biochar has beneficial effects on soil properties like increased water holding capacity, enhanced cation-exchange capacity (CEC), higher pH, increased water retention, reduced leaching of nutrients and adding nutrients by itself etc (Lehman & Joseph, 2009 and IBI, 2011). However, a study by Novak et al. (2009) on soils where biochar has been added showed no significant effect of biochar on water holding capacity. Similar results were reported from a study by Chan et al. (2007). Enhanced CEC, as a consequence of the large surface area of biochar particles, improves soil fertility. It may also prevent nutrient leaching. pH affects nutrient uptake and plant availability of nutrients. Biochar may thereby give higher yields with the same amount of fertilizers (Lehman & Joseph, 2009). Biochar carbon is in a stable form and is not easily digested by microbes. The large surface of biochar particles are, on the other hand, beneficial for biological activity, water and air circling in the soil (Lehman & Joseph, 2009). Biochar can be used to increase food security and cropland diversity in areas with poor soils, soils with low carbon content and deficient water and fertilizer supplies (IBI, 2011).

2.4 On-going field experiments of SLU/CIAT-TSBF

The purpose of the project is to determine the effect of applying charcoal to soils in central and western Kenya. The field experiments were initiated in November 2006 at four locations within these regions. The trials consists of three main treatments; black fallow, crop and crop+fertilizers with two sub-treatments; with and without application of biochar (5 kg charcoal/m2). Size of plots is 4x6 m. During the long rainy season maize is grown and during the short rainy season soya beans are cultivated. Seasonal analysis is made on yield and soil properties (K. Röing de Nowina et al, 2010).

2.5 Site

The two farms, from where the soil samples were taken, are situated in the village of Kibugu, located approximately 8 km north of Embu. The district of Embu is located in the south of the eastern province, on the foot of Mount Kenya, 1100-1500 meters above sea level. Approximately one third of the area has a favorable climate and fertile soils. Annual precipitation is 600-1800 mm. In areas with the highest precipitation, tea and coffee are cultivated (National Coordination Agency for Population and Development-NCAPD, 2005). From now on the two farms will be referred to as farm 1 and farm 2.

Figur 2 Location of Embu (Maps of the World, 2011).

3 Material and metods

The study consists of two parts; 1) field work 2) laboratory work and greenhouse trial. Field work was conducted in the Embu and the experimental part took place in the greenhouse and laboratories of ICRAF/CIAT-TSBF in Nairobi. The greenhouse trial went on for four weeks and was divided into two parts; a plant growth experiment and a decomposition experiment.

3.1 Field work in Embu

3.1.1 Soil sampling

Each of the two farms contained 18 plots. Biochar had been applied to nine of these and the other nine was used as control. For these 18 plots there were three different treatments with three replicates of each treatment. The treatments were as follow; Control, Biochar, Biochar and PK-fertilizer, PK-fertilizer, Biochar and NPK-fertilizer, NPK-fertilizer. In this project soil samples was taken from the three plots treated with biochar and the three control plots. Table 1 gives the plot number in the field for each treatment and farm.

Table 1. Treatment for each plot number and farm.

	Biochar	Control
Farm 1	5, 11, 16	6, 12, 15
Farm 2	5, 10, 15	6, 9, 16

Soil samples were taken for measuring bulk density, chemical analyses and for using in a pot trial in greenhouse.

For bulk density samples were taken with a cylinder (volume ca 95.4 cm^3) from the top soil at a depth of 7.5-12.5 cm. Two samples were taken from each plot and an average bulk density for these plots was calculated.

Approximately 10 kg of soil was collected with a soil auger. This soil was taken on a depth of 0-20 cm randomly within each plot. The soil was mixed well where after 0.5 kg soil was put into small bags to prepare for analysis. The rest of the soil was put into plastic bags to be used in the greenhouse experiment.

3.1.2 Interviews

This project is a Minor Field Study founded by SIDA. To learn about the country during the stay there is one requirement from SIDA to receive this Scholarship. In Embu interviews were held with the owners of the two farms to be introduced to the farming system in Kenya. These interviews will therefore not be declared in this project report further than this brief mention.

3.2 Laboratorial work

3.2.1 Preparation of soil samples for analyze

The soil samples taken in Embu were put into paper bags and dried in a dryer room. When dry, the soil was sieved (2 mm) and pieces of charcoal and soil were ground.

3.2.2 Soil analyze

Soil samples was sent to Crop Nutrition Laboratory Services for analyze of content of carbon, potassium, phosphorus and nitrogen and for pH, Cation Exchange Capacity and C/-quota. Phosphorus was extracted using Olsen P metod and Potassium was extracted using Mehlich 3.

3.2.3 Bulk density and dry matter

The fresh weight of each sample was measured; thereafter samples were placed in an oven over night at 105˚C. When dry the weight was measured again. From this we calculated bulk density and gravimetric water content.

3.2.4 Field capacity and calculations of soil water content

Field capacity was estimated for the soil from each plot. A pot was filled with 800 g dry soil. Water was added to saturate the soil. This was repeated a couple of times during the day. In the evening more water was added and perforated plastic was placed over the pots to minimize evaporation from the surface and to be sure that all pores were filled with water. Surplus water was drained through holes in the bottom of the pots until drainage equilibrium. The next morning the pots were weighted. From the weight differences between dry and wet soil field capacity was calculated. Also, the amounts of water the soil would contain for 90 %, 70 %, 40 % and 20 % of the field capacity. Raw data is shown in appendix 2. Approximately 20 % was recorded in this soil when samples were taken. 40 % is estimated to be a likely water amount in the field when not end of dry season. 90 % water in the soil is optimal for crops, except in an early phase when 70 % is to prefer.

3.3 Green house experiment

3.3.1 Plant growth experiment

Soil collected from plots on the two farms was dried on a tarpaulin in the sun and sieved with a 2 mm sieve. Aggregates and biochar pieces larger than 2 mm were ground and sieved again. 12 pots were filled with 800 gram of soil. Water was added to 70 % of field capacity three hours before planting the seed to reduce risk of air bubbles which may affect germination. Three maize seeds were placed at a depth of 2 cm in each pot. Three seeds were planted to guarantee that at least one would germinate. All pots were kept at 70 % of field capacity until maize plants was 5 cm high. Thereafter the water content was adjusted to 90 % and 40 % for the rest of the four weeks. See Figure 3 for a sketch of the trial. The same water level could be held throughout the experiment by weighing each pot and add water until it reached the weight for the specific water level. Watering schedule can be seen in appendix 4. This weight included weight of water, 800 g soil and pot. In practice water was added to compensate the weight of plant material. Estimated weight of plants was made by using weight of maize in the same development stage grown beside the experiment. When the maize plants were about 10 cm high two of the three seedlings in each pot were removed. Only the healthiest seedling was kept for the experiment. After four weeks height of plants was measured. Thereafter plants were harvested 1 cm above the soil surface. Both green weight and dry weight was measured.

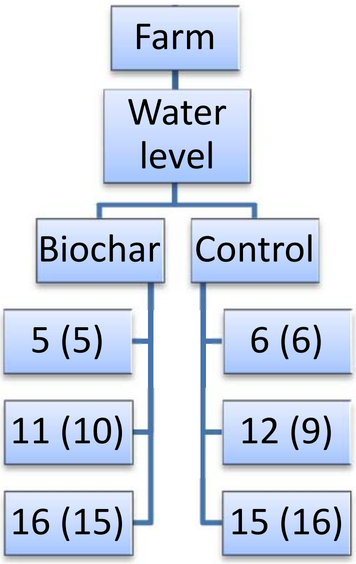

Figure 3. Sketch of plant growth trial. The sketch is the same for each farm and water level. The numbers referred to plot numbers in field explained in chapter 3.1.1. Numbers without brackets are plot numbers on farm 1 and numbers within brackets are plot numbers on farm 2.

3.3.2 Decomposition experiment

Dried maize leaves were cut into a size of around 1x1 cm. The leaves were put into nylon mesh bags with the size 4x6 cm and with mesh-size of 1mm. Each bag contained 0.50 g of leaves. Three bags were placed in each pot containing 800 gram of soil, 2 cm from the bottom. The bags were placed vertically in a triangle, with the same distance to the wall of the pot and to each other, see Figure 4.

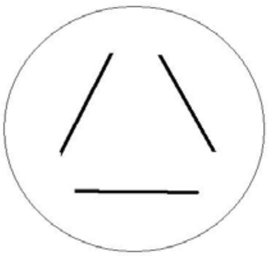

Figure 3 Sketch of the allocation of litterbags in pots, seen from above.

Water was added to 20 %, 40 % and 90 % of field capacity. Figure 5 shows a sketch of the experiment. 0.5 gram of maize leaves was ground and sent for analysis of Nitrogen, Phosphorus and Potassium. The pots held on water level 90 %, 40 % and 20 % of field capacity throughout the experiment by weighing each pot and add water until it reached the weight for the specific water level. Watering schedule can be seen in appendix 4. This weight included weight of water, 800 g soil and pot. In practice additionally a couple of gram was added considering weight of bag and maize leaves.

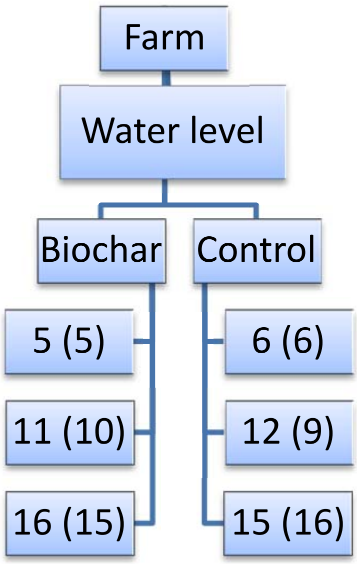

Figure 4. Sketch of decomposition trial is the same for each farm and water level. Numbers refer to plot numbers in field explained in chapter 3.1.1. Numbers without brackets are plot numbers on farm 1 and numbers within brackets are plot number on farm 2.

Seven days after starting the experiment the first nylon bag was taken out of the soil. The maize leaves from each nylon bag were placed in a paper bag and dried in an oven at 60˚C over night. Each paper bag with the content of maize leaves was weighted. The three replicates of each treatment were ground together and sent to the laboratory for analyze of N, P and K. After another seven days the next bag was taken up and 14 days after that the last bag was removed from the soil.
All bags were treated as the first bag, described above.

3.4 Statistical analysis

T-test for two independent variables assuming equal variances was made, using Microsoft excel, to determine whether there are significance in the results. Significance is set to be less than 5 % for two-tailed graph.

4 Results

4.1 Analysis of soils

Application of biochar did significantly decrease bulk density after application of biochar on farm 2 but not on farm 1 (Fig. 6A). Soil water content at field capacity was significantly higher after the additions of biochar on both farms (Fig. 6B). Raw data for calculations of bulk density and field capacity are presented in appendix 2 and 3, respectively.

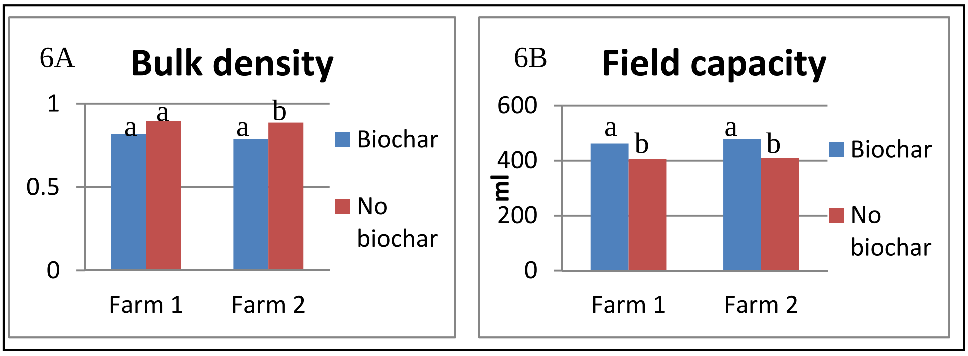

Figure 6. Bulk density and field capacity as affected by charcoal treatment at the tow farms. Different letters indicate significant differences between treatments.

Soil analyses revealed significantly increased soil carbon content, pH and CEC after applying biochar. Potassium concentrations increased significantly only on farm 2 while there were no significant differences were observed for phosphorus and nitrogen. Soil C/N-ratio was higher after application of biochar only on farm 1.

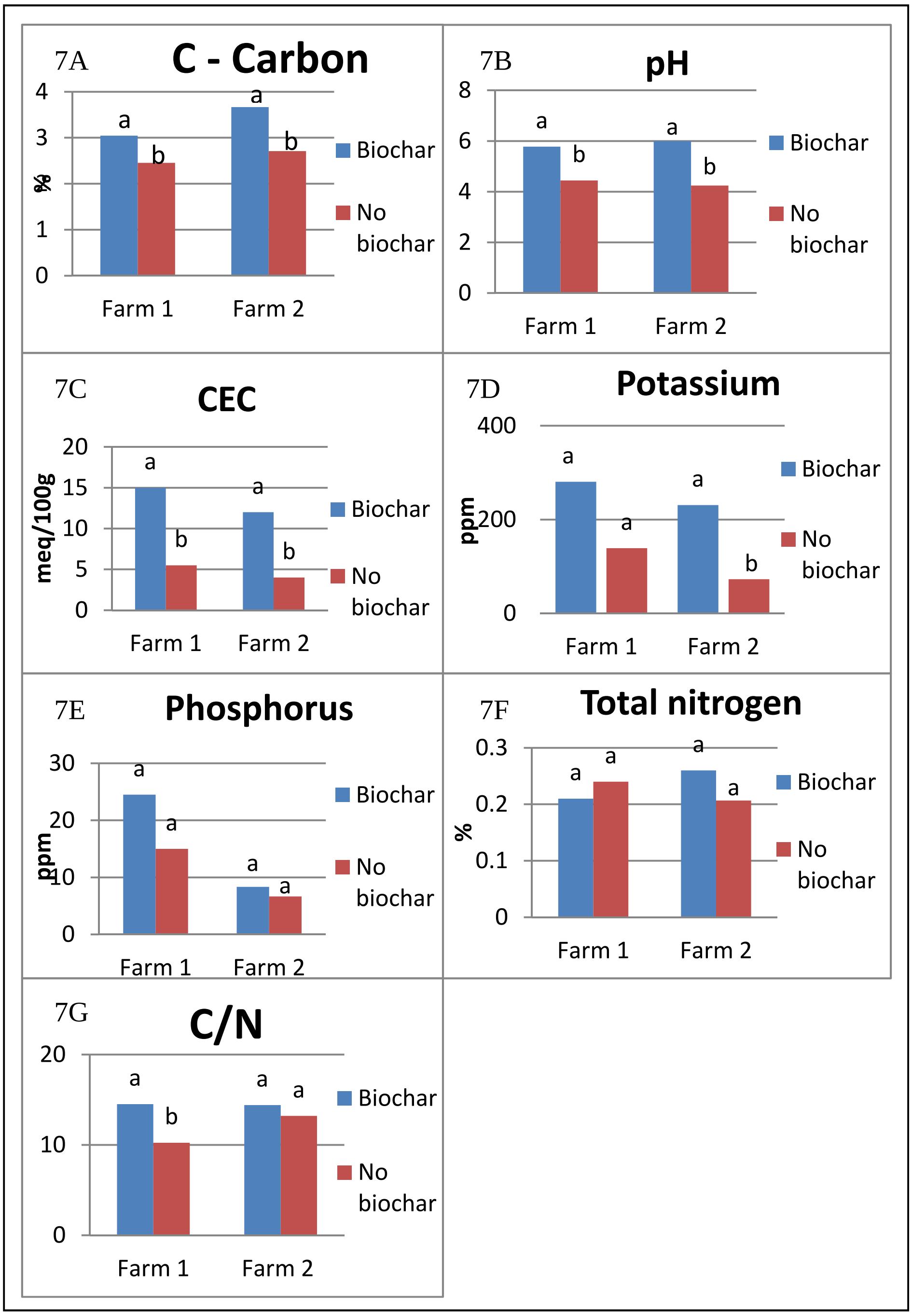

Figure 7 A-G. Chemical soil properties as affected by charcoal treatment. Different letters indicate significant differences between treatments..

Most soil properties have been affected similarly in the soils from the two farms. Field capacity was increased with more than 10 %, carbon content with about 20 %, pH with approximately 1.5 units and CEC with more than 60 % on both farms.

Table 2. Significant increases in soil properties relative to those in untreated soil in percentage.

	Farm 1	Farm 2
Bulk density	-	11.3
Field capacity	12.4	14
C (%)	19.4	26.1
pH	1.33 units	1.76 units
CEC	63.3	66.7
K	-	68.5
P	-	-
N	-	-
C/N	29.4	-

Probably replicates number 15 and 16 from farm 1 had been interchanged between biochar amended and non-amended soil. Therefore, these replicates had been excluded from the results. Results of soil analysis and plant growth were based on two replicates from farm 1 and on three replicates from farm 2.

4.2 Plant growth experiment

Figures 8-9 show the condition of plants treated at 90 % of field capacity at the end of the experiment, right before harvesting. Figures 10-11 show conditions of plants treated at 40 % of field capacity. In Figures 12-13 these photos are complemented with measurements of fresh and dry biomass as well as plant height. Water content was calculated from fresh and dry weight.

Figure 8. Maize plants grown in soils collected from farm 1, treated at 90 % water of field capacity for four weeks. Left: control. Right: biochar. The two plants in the back have been excluded from the results due to a possible interchange.

Figure 9. Maize plants grown in soil collected from farm 2, treated at 90 % water of field capacity for four weeks. To the left: control. To the right: biochar.

Figure 5 Maize plants grown in soil collected from farm 1, treated at 40 % water of field capacity for four weeks. To the left: control. To the right: biochar. The two plants in the back have been excluded from the results due to a possible interchange.

Figure 6 Maize plants grown in soil collected from farm 2, treated at 40 % water of field capacity for four weeks. To the left: control. To the right: biochar.

According to Figure 8-9 differences in plant growth condition between the pots with and without biochar are obvious. This is most clear in figure 9. Plants grown without biochar were smaller and have a yellowish-green color which is an indicator for nitrogen deficiency. Plants grown in soil without biochar were seriously damaged by drought and some of them died (figure 10-11). Damages from drought were also observed on plants grown in soils amended with biochar but not as serious. Plants grown in biochar amended soil from farm 2 (figure 11) were relatively prosperous while plants grown in biochar amended soil from farm 1 (figure 10) were damaged by drought.

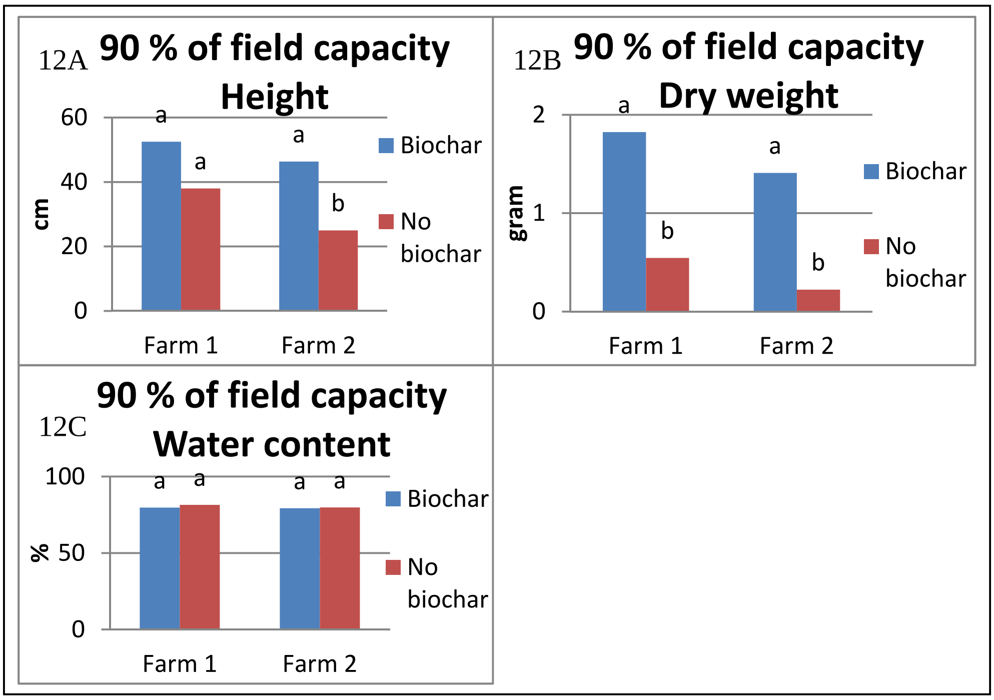

Figure 12 A-C. Height, dry weight and water content for plants treated at 90 % of field capacity. Different letters indicate significant differences between treatments..

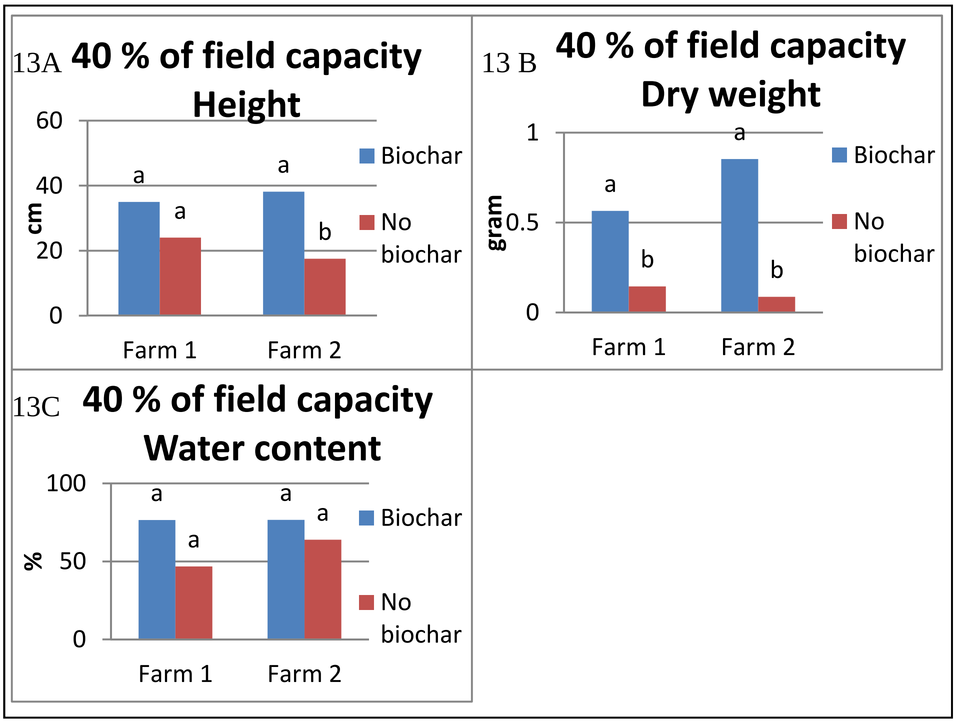

Figure 13 A-C Height, dry weight and water content for plants treated at 40 % water of field capacity. Different letters indicate significant differences between treatments.

Plant height increased significantly only when grown in soil from farm 2 after application of biochar (Figs. 8-11 and 12-13). Dry weight was significantly higher for plants grown with presence of biochar at both water levels. No significant differences in water content between plants grown in biochar amended soil were observed, neither at water level 90 % nor at 40 %.

4.3 Decomposition experiment

During planning of the methodology for decomposition part of the project we missed the determination of ash-content. Therefore, changes in mass could not be attributed to decomposition only since samples were heavily contaminated with soil.

5 Discussion

Soil analyses showed that biochar had a significant increasing effect on field capacity, carbon content, pH and CEC. Increased CEC could be explained by the molecular properties of the biochar applied, see chapter 2.2.3. According to Lehmann et al. (2011), biochar significantly increases CEC and pH in soils. In a report from 2006 Lehmann states that the CEC frequently increases with up to 40 % of initial CEC and pH increases up to one pH unit after application of biochar. In soils from Embu used for this project the CEC increased with 63.3 % respectively 66.7 % by applying biochar and pH increased with 1.33-1.75 unit which is more than reported from Lehmann (2006). Lehman et al. (2011) argued that the extent of impact biochar will have on a soil is dependent on the production conditions of the biochar used. According to the study reported by Lehman et al. (2006), availability of major cations, phosphorus and total nitrogen increased after application of biochar. Results of soil analyses in this project showed significant increase only for potassium on farm 2. The effect on nitrogen and phosphorus was not significant in this experiment. Lehman et al. (2006) explained higher nutrient availability with the direct nutrient additions by the biochar, greater nutrient retention and changes in soil microbial dynamics.

Decreased bulk density from application of biochar can be explained by biochar having a lower bulk density than mineral particles. Moreover, biochar addition to soil may also increase porosity due to interaction with parent soil mineral and organic particles (Lehmann et al., 2011). Increases in meso- and macropores resulted in elevated water holding capacity but also contribute to decrease bulk density. Due to the extremely high C/N ratio of bichar, C/N ratios are expected to increase even though the increase was only significant on farm 1. Since biochar has been through pyrolysis the carbon is in a form that is more resistant to decomposition than soil organic matter in average.

Signs of nitrogen shortage for plants treated at 90 % water of field capacity were most distinct on farm 2 which can be explained by the lower nitrogen content in soil from farm 2 than in soil from farm 1. Soil nitrogen concentrations were not significantly different between treatments (Figure 7) since biochar usually contain very low amounts of N. Most of N is lost during pyrolysis (Lehman et al., 2011). Plants treated at 40 % of field capacity were draught damaged and worst damaged was plants grown without presence of biochar even though the water content of these plants was not significantly differ between treatments. Probably the number of plants is not enough to show statistical significance. Plant available water content increased due to the application of biochar since field capacity was significantly higher in the biochar amended soils. I did not measure the wilting point in the soils but if repeating this study it would be interesting to determine the plant available water content. Dry weight is a measure on crop production. For plants treated with 90 % of field capacity, nitrogen was the limiting factor for plant productivity and at 40 % of field capacity the limiting factor was water. According to Lehman et al. (2011), effects on soil fertility by adding biochar have been observed, which may be explained by increased pH or CEC. Also effects have been observed on biota communities which may impact on nutrient cycles and soil structure which indirect will affect plant growth. In a report written by Lehmann et al (2003a) increases in yield directly connected to the addition of biochar have been observed. Immediate benefits of charcoal addition are explained by nutrient availability. As long-term benefits stabilization of organic matter, slower nutrient release from applied organic matter and better retention of cations are the factors mentioned with largest impact on the yield (Lehmann et al., 2006). The small number of plants in this experiment is not enough to give a scientific result of the effect by application of biochar. If repeating this project a larger number of plants should be used.

For a successful soil management in the humid tropics maintaining the level of organic matter and biological cycling of nutrients is crucial according to Lehmann et al. (2006). Compost, manure, cover crops and mulches are carbon resources in the tropics and need to be applied each season. Biochar provide the soil with carbon in a long-term perspective. In addition to the impact of biochar on water and nutrient availability, biochar is a carbon sink which reduce the total release of greenhouse gases. In the production process of biochar, oil and gas are may be produced thereby replacing fossil fuels. The economic viability of using biochar as a soil amendment is dependent on the costs for producing biomass for biochar production, costs related to the production process, transport and value of carbon offsets (Roberts et al.; 2010). The potential for economical profitability is probably highest when wastes are used as biomass source. In laboratory and commercial production, biochar has an average recovery of 54 % (Roberts et al.; 2010) carbon if produced by woody biomass. Biochar produced in earthen pits and mounds are likely containing 30-50 % of carbon. Biochar production from crop residues is more carbon effective than shifting cultivation (Lehmann et al., 2006). In many shifting cultivation systems 2-3 years of cropping are followed with 10 years of fallow (Nye & Greenland 2006). In a biochar system the number of cropping seasons before fallow can be increased extensively. Continued cultivation for more than 40 years with acceptable yields is practiced in the Amazonas basin where biochar rich soils has been developed (Petersen et al, 2001). Biochar could be an important strategy for handling drought to be able to support people in the tropics with food in the future. My own experiences from Kenya tell me that biochar is already used as a soil amendment. There are also NGOs working with implementing biochar to farming systems in Kenya. Many farmers are familiar with the practices for producing biochar and it’s already practiced by many farmers for producing charcoal for the local market or for own use as cooking fuel.

6 Conclusions

Biochar is a soil amendment which may have positive effect on plant water and nutrient availability. In the tropics soils are often poor in nutrients with low water and nutrient holding capacity and droughts are commonly recurring. Biochar together with drought resistant crops, proper water management, conservation tillage practices and/or nutrient recycling might be a future alternative for coping with drought and currently poor soils. Biochar can be produced both at large and small scale and the needed knowledge for producing biochar exists among farmers today.

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Appendix 1– Soil analysis

Results of chemical soil properties from the lab.

Crop Nutrition Laboratory Services
Healthy, Profitable Farming

Client TSBF-CIAT
Farm Embu
Analysis Soil
Crop Maize
Date #####

TSBF-C
Embu
Soil
Maize
####

Sample Number	Label	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/100g	%	%	%	%	%	%	%	%	%
CT042SA1768	AE 1.5	6.032	30	346	1945	242	15.23	16	3.11	0.22	61.38	12.75	5.6	0.42	5.34	14.52	4.82
CT042SA1769	AE 1.11	5.519	19	215	1445	150	16.20	14	2.98	0.20	51	8.82	3.89	0.5	6.36	29.43	5.78
CT042SA1770	AE 1.16	5.110	19	179	802	168	12.55	12	2.56	0.20	34.59	12.1	3.96	0.47	7.18	41.7	2.86
CT042SA1771	AE 1.6	4.532	15	160	283	60	14.19	6	2.45	0.23	22.12	7.8	6.41	0.97	8.34	54.36	2.83
CT042SA1772	AE 1.12	4.350	15	118	208	40	12.67	5	2.46	0.25	19.98	6.44	5.82	1.06	8.7	58	3.11
CT042SA1773	AE 1.15	5.806	35	337	2709	341	23.18	24	3.39	0.34	57.3	12	3.66	0.43	5.79	20.82	4.77
CT042SA1774	AE 2.5	6.564	10	264	1650	113	18.98	11	3.82	0.32	73.5	8.36	6.03	0.74	4.84	6.54	8.79
CT042SA1775	AE 2.10	5.606	8	220	1281	95	24.30	12	3.68	0.22	54.57	6.71	4.81	0.9	6.19	26.82	8.13
CT042SA1776	AE 2.15	5.829	7	209	1573	115	29.78	13	3.50	0.24	61.47	7.46	4.18	1.01	5.74	20.13	8.24
CT042SA1777	AE 2.6	4.156	8	71	140	35	25.00	4	2.63	0.20	15.89	6.55	4.13	2.46	9.09	61.88	2.43
CT042SA1778	AE 2.9	4.172	6	57	154	37	26.99	5	2.70	0.23	16.82	6.82	3.18	2.56	9.06	61.56	2.47
CT042SA1779	AE 2.16	4.396	6	90	117	27	16.96	3	2.80	0.19	18.07	6.85	7.11	2.28	8.61	57.08	2.64

Explanation: **Label**
A = analyze
E = Embu
First number = farm number
Second number = Plot number in field

For more details of plot numbering see chapter 3.1.1.

Appendix 2 – Dry matter and bulk density

Raw data of soils used in the experiment. From fresh weight and dry weight dry matter (DM) and average dry substance was calculated for each plot. Two samples for bulk density were collected in each plot for which an average was calculated. Methodology of soil sampling and analyzing is explained in chapter 3.1.1 and 3.2.3.

Plot	Fresh weight (g)	dry weight (g)	Bulk density (g)	Average, bulk density (g)	DM (g)	Average, DM (g)
E1.5a	92.86	75.95	0.7959	0.8110	0.8179	0.8081
E1.5b	98.74	78.83	0.8261		0.7984	
E1.11a	88.97	71.53	0.7496	0.8231	0.8040	0.8093
E1.11b	105.03	85.55	0.8965		0.8145	
E1.16a	99.39	80.96	0.8484	0.8270	0.8146	0.8130
E1.16b	94.71	76.86	0.8055		0.8115	
E1.6a	112.13	91.38	0.9576	0.9400	0.8149	0.8184
E1.6b	107.08	88.01	0.9223		0.8219	
E1.12a	98.88	79.1	0.8289	0.8534	0.8000	0.8033
E1.12b	103.86	83.77	0.8779		0.8066	
E1.15a	103.91	83.97	0.8800	0.8721	0.8081	0.8100
E1.15b	101.58	82.47	0.8643		0.8119	
E2.5a	94.46	76.03	0.7968	0.7847	0.8049	0.8058
E2.5b	91.38	73.72	0.7726		0.8067	
E2.10a	98.23	79.07	0.8286	0.7976	0.8049	0.8113
E2.10b	89.47	73.15	0.7666		0.8176	
E2.15a	98.01	78.68	0.8245	0.7786	0.8028	0.8053
E2.15b	86.55	69.92	0.7327		0.8079	
E2.6a	115.3	94.04	0.9855	0.9402	0.8156	0.8115

E2.6b	105.77	85.39	0.8949		0.8073	
E2.9a	105.51	82.46	0.8642	0.8633	0.7815	0.7923
E2.9b	102.47	82.3	0.8625		0.8032	
E2.16a	100.79	80.41	0.8427	0.8570	0.7978	0.7999
E2.16b	103.68	83.15	0.8714		0.8020	

Plot
E = Embu
First number = farm number
Second number = Plot number
a/b = two samples per plot

Appendix 3 - Field capacity

Raw data for calculating field capacity for the soils and weights of pots for different water levels, explained in chapter 3.2.4.

Plot	Pot+bag (g)	Dry weight of soil (g)	Drainage equilibrium+ pot +bag (g)	Drainage equilibrium	Field capacity (g)	90 % of f.c (g)	70 % of f.c (g)	40 % of f.c. (g)	20 % of f.c. (g)
E1.5	22,25	785	1279,35	1257,1	472,1	424,89	330,47	188,84	94,42
E1.11	21,74	800	1274,54	1252,8	452,8	407,52	316,96	181,12	90,56
E1.16	22,07	800	1254,76	1232,69	432,69	389,421	302,883	173,076	86,538
E1.6	22,31	800	1222,98	1200,67	400,67	360,603	280,469	160,268	80,134
E1.12	21,82	800	1231,59	1209,77	409,77	368,793	286,839	163,908	81,954
E1.15	22,14	800	1283,58	1261,44	461,44	415,296	323,008	184,576	92,288
E2.5	21,56	800	1309,52	1287,96	487,96	439,164	341,572	195,184	97,592
E2.10	21,69	800	1285,06	1263,37	463,37	417,033	324,359	185,348	92,674
E2.15	21,67	800	1303,65	1281,98	481,98	433,782	337,386	192,792	96,396
E2.6	22,33	800	1234,13	1211,8	411,8	370,62	288,26	164,72	82,36
E2.9	22,39	800	1232,02	1209,63	409,63	368,667	286,741	163,852	81,926
E2.16	22,68	800	1233,5	1210,82	410,82	369,738	287,574	164,328	82,164

Plot
E = Embu
First number = farm number
Second number = Plot number

Appendix 4– watering schedule

Schedule used for daily watering of plant growth and decomposition experiment as described in chapter 3.3.Weight of plant material in plant growth experiment and weight of bag and maize leaves are not included in these weights but water was added to compensate for their weights in practice.

Weight of pot+soil	Plot	Water level 90%	Water level 70%	Water level 40%	Water level 20%
823	E1.5	1247.89	1153.47	1011.84	917.42
823	E1.11	1230.52	1139.96	1004.12	913.56
823	E1.16	1212.421	1125.883	996.076	909.538
823	E1.6	1183.603	1103.469	983.268	903.134
823	E1.12	1191.793	1109.839	986.908	904.954
823	E1.15	1238.296	1146.008	1007.576	915.288
823	E2.5	1262.164	1164.572	1018.184	920.592
823	E2.10	1240.033	1147.359	1008.348	915.674
823	E2.15	1256.782	1160.386	1015.792	919.396
823	E2.6	1193.62	1111.26	987.72	905.36
823	E2.9	1191.667	1109.741	986.852	904.926
823	E2.16	1192.738	1110.574	987.328	905.164

Plot
E = Embu
First number = farm number
Second number = Plot number

Appendix 5 - Plant harvesting protocol

Raw data from harvesting of plants at the end of the plant growth experiment. Height, fresh weight and dry weight were determined and general condition was noted. Diagram from these data can be seen in chapter 4.2.

Water level 90 %

Plot	Height (cm)	Fresh weight (g)	Dry weight (g)	General condition
E1.5	53	8.66	1.78	Cyano colored stem and leaf veins. Oldest leaf yellow.
E1.11	52	9.33	1.87	Cyano colored stem and leaf veins.
E1.16	50	6.62	1.48	Cyano colored stem and leaf veins. Yellow leaf tips.
E1.6	42	4.1	0.67	Cyano colored plant. Yellow leaf tips.
E1.12	34	2.03	0.42	Cyano colored stem and leaf veins. Oldest leaf yellow.
E1.15	51	10.13	2.3	Cyano colored stem and leaf veins.
E2.5	46	6.48	1.37	Cyano colored stem and leaf veins. Yellow leaf tips. Necrocis
E2.10	47	5.93	1.16	Cyano colored stem and leaf veins.
E2.15	46	7.9	1.7	Cyano colored stem and leaf veins. Yellow leaf tips.
E2.6	27	1.28	0.28	Cyano colored stem and leaf veins. Yellow leaf tips.
E2.9	24	0.8	0.16	Cyano colored stem and leaf veins. Wilting leaf tips.
E2.16	24	1.23	0.23	Cyano colored stem and leaf veins. Yellow-green plant.

Plot
E = Embu
First number = farm number
Second number = Plot number

Water level 40 %

Plot	Height (cm)	Fresh weight (g)	Dry weight (g)	General condition
E1.5	35	2.49	0.62	Cyano colored plant. Wilting leaf tips.
E1.11	35	2.31	0.51	Moderate cyano colored. Slouched. Oldest leafs wilted.
E1.16	32	1.44	0.37	Cyano colored plant. Wilting leaf tips.
E1.6	21	0.11	0.13	Dead
E1.12	27	0.65	0.16	Cyano colored stem. Very Slouched, wilting leaf tips.
E1.15	38.5	2,77	0.63	Cyano colored plant. Wilting leaf tips.
E2.5	40	4.78	1.13	Cyano colored leafs. Oldest leafs wilted.
E2.10	37	2.95	0.68	Cyano colored leafs. Oldest leafs wilted.
E2.15	37.5	3.22	0,75	Cyano colored leafs. Oldest leafs wilted.
E2.6	17	0.16	0.07	Dead
E2.9	17	0.29	0.09	Cyano colored stem. Wilting leafs and leaf tips
E2.16	18.5	0.3	0.1	Cyano colored stem. Yellow. Wilting leaf tips.

Plot
E = Embu
First number = farm number
Second number = Plot number