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Soil physical properties and erosion risks at smallholder farms in Embu, Kenya

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Abstract

The soils ability to produce food is important in all parts of the world. The soils used for food production in Kenya are threatened by different factors, such as soil degradation due to erosion, lack of nutrients, and scarcity of water. The aim of the study was: (1) to obtain background information related to Kenyan small hold farming, focusing on the farmer's experience of productivity and erosion, and (2) to measure soil physical properties and field characteristics as part of a field study conducted over a short period of time.

This study was conducted on eight farms in the Embu district, in central Kenya. The study was divided into three parts: study of farming in the Embu district, study of soil physical properties and their correlation to productivity, and a study of soil erosion. The first study was done through observation and interview. It showed that farming was done with simple methods. The most common crops were: maize, beans, bananas, coffee and tea. The farms were small, around one hectare with small fields of about 1300 m^2.

The following soil physical properties were compared between fields with high and low productivity, respectively, within the farms: soil texture, plant available water capacity and infiltration capacity. The carbon content was also compared. There were no statistically significant differences in the mentioned physical properties and carbon content between the high/low producing fields. The reasons for this might be that: farms are small and the soil physical properties homogenous, yield data was too uncertain or other soil properties affect the productivity. The texture was rich in clay and the plant available water had an average of 21% of the soil, which is ideal for maximal root growth and function. The average carbon content for the area was 2.0%, which is good for African soil and the average infiltration capacity was 330 mm/h, which is rapid. This showed that infiltration and plant available water was not limiting for the crops.

The erosion study compared sites on the farms which had much and little erosion, respectively. The compared factors were: silt content, slope steepness and infiltration capacity. There were no statistical significant differences in the mentioned factors between the sites with much and little erosion. The average soil loss for the region was calculated to 80 ton ha^{-1} $year^{-1}$ using the Revised Universal Soil Loss Equation (RUSLE).

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Introduction

Kenya is situated in east Africa (see Fig. 1) and is a country with old soils (Wambeke, 1992). Kenya has an annual population growth of 2.67 % (CIA, 2008). Agriculture is of great importance as 75% of the people rely on farming for food and income (Orodho, 1997). The agriculture has to face and solve several problems to make it possible for the local farms to produce enough food for the people. Deteriorated soils, lack of nutrients and soil erosion are some of the obstacles that prohibit the farms from meeting the needs of the people. Kenya is also one of the countries which suffer from insufficient freshwater supply; with a growing population the water scarcity will increase. Seventy percent of the freshwater withdrawal is used by agriculture, and hence, the scarcity in freshwater is a limitation to the agriculture (Millstone & Lang, 2008). Research is important to determine what problems agriculture is facing and how they can be solved.

Figure 1. Map of Africa. Kenya is marked with black. (NACAA, 2009)

The studied area has an average annual precipitation of 1100 mm, which comes down in two rain periods, Long rain between March and May and Short rain in October and November. The average daily temperature differs between 21°C and 17°C in a year (worldclimate, 1990).

This report focuses on the soil physical properties that may affect the productivity and on the factors that may affect the erosion risk.

There were three aims of the study. The first aim was to obtain a general idea of what constitutes small hold farming in central Kenya. The second aim was to clarify if and if so which soil physical properties affect the productivity on Kenyan smallholder farms. The third aim was to study if erosion is a problem, and if so the reason for erosion on the mentioned farms.

The study will also be used to complement a project managed by Dr Kristina Röing de Nowina at the Swedish University of Agricultural Sciences (SLU) in cooperation with the Tropical Soil Biology and Fertility Institute of Centro Agricultura Tropicale (CIAT-TSBF), Nairobi. It is a study of soil carbon management in Kenyan small holder land use systems, with focus on carbon sequestration, greenhouse gas emissions and socio-ecological dynamics.

The second aim was to explore to what extent a positive relationship could be found between productivity of the soil and the following factors; the clay content, the organic carbon content, the plant available water and the infiltration capacity (Eriksson *et al.*, 2005).

The hypothesis for the third aim was that erosion is a problem on the farms and that soil with a high content of silt and low infiltration capacity placed in a large slope has a high risk of erosion (Eriksson *et al.*, 2005; Omuto, 2008).

Background

Erosion is a natural phenomenon which occurs in all types of soils. Erosion is when soil particles are removed from its origin by water, wind or ice. Soil erosion has several negative effects on the environment, both under and above ground. Climate, topography, soil properties, vegetation characteristics and land management are the main factors effecting soil erosion (Fangmeier *et al.*, 2006; Omuto, 2008). Erosion affects in its turn different factors negatively in and on the soil (Pimentel, 2006). It is therefore hard to separate the factors starting the erosion from the erosion effects as such.

Climate

Erosion occurs when soil is exposed to the energies in water and wind (Pimentel, 2006). The climate effects erosion through rain, temperature, wind, humidity, and solar radiation. These factors are not independent and do not effect erosion equally (Fangmeier *et al.*, 2006). As is obvious from erosion prediction models such as the Revised Universal Soil Loss Equation (RUSLE; Renard *et al*., 1997), the amount and intensity of rainfall are the most important climate factors that effect soil erosion by water. According to Norman (1995), erosion runoff is highly probable when the soil is hit by rainfall with a higher intensity than the infiltration capacity of the soil. This is the usual situation when rainfall exceeds 20-25 mm per hour. This results in about 40% of the tropical rainfall being erosive, while only 5% of the rainfall in temperate climate is erosive.

Topography

The slope length and steepness greatly affect the risk of erosion on cultivated fields. Soil is more easily detached and transported from steep slopes (Fangmeier *et al.*, 2006).

Soil properties

Soils can be degraded because of erosion, but already degraded soils have a higher erosion risk. It is therefore difficult to separate which is the initial cause. Erosion causes reduction in infiltration- and water-storage capacity, nutrient- and organic matter content, soil depth, productivity, vegetation growth and biodiversity. These factors all interact with each other and it is almost impossible to separate the impact one has from another. Erosion increases water runoff which results in reduced water infiltration. Erosion also reduces the water-storage capacity of the soil as there will be less soil to hold the water. This will lead to eroded soils being more susceptible to drought conditions (Pimentel, 2006).

Other soil properties that effect or are affected by erosion are: water retention, bulk density, aggregate stability, soil structure and texture. Poorer water retention leads to less water being retained and the runoff and erosion during rainfall increases. Higher bulk density leaves less space for channels in the soil where the rain can infiltrate just as a poor soil structure does. A good aggregate stability increases the resistance to mechanical, physical or chemical destructive forces. If the texture includes a large percentage of silt the risk of erosion is increased (Fangmeier *et al.*, 2006; Omuto, 2008).

Organic matter has a very positive impact on the soil quality and structure through for example stabilising soil aggregates and thereby increasing soil porosity. Increased water-holding capacity which also leads to increased resistance to seasonal drought is another good result of increased organic matter content. All this together with improved infiltration through root channels lessens soil erosion (Stocking, 1994). Eroded soil has unfortunately higher organic matter content than the remaining soil because the content of organic matter is higher in the topsoil and topsoil is most eroded. Organic matter content is improved through vegetation growth, which in its turn is diminished when the conditions for plant growth is degraded by the erosion (Pimentel, 2006).

Important plant nutrients like nitrogen, phosphorus, potassium and calcium are carried away with the eroded soil, leaving the soil poorer in nutrients and overall productivity decline. Eroded soil has a higher nutrient content than the remaining soil, of the same reason as eroded soil has a higher organic matter content than the remaining soil (Pimentel, 2006).

Biological diversity in the soil is closely related to the amount of living and dead organic matter. The activity of the biota improves the quality of the soil as they recycle nutrients, mix soil components, enhance aggregate stability, etc. When soil and organic matter is lost through erosion, biota is also lost, which is unfortunate as biodiversity decreases (Pimentel, 2006).

To summaries; soils with medium to fine texture, low organic matter content, weak structural development and low water infiltration rates are most easily eroded (Pimentel, 2006).

Vegetation characteristics

Living plants cover the soil with their canopy, which harmlessly absorbs the kinetic energy in the rainfall by intercepting the raindrops. The water that reaches the soil is safely transported either by stem flow or by forming new droplets which have little chance of picking up speed. Therefore, these droplets cause much less erosion hazard to the soil, especially in close-growing vegetation. Organic litter on the soil also serves this purpose. Altered and improved vegetation is the easiest way of decreasing erosion. There is also an economically beneficial aspect since greater vegetation cover gives higher yields and production (Stocking, 1994).

Larger plants like banana trees serve as barriers reducing the erosive forces on sloping cropland. Roots decrease the soil water when water is adsorbed into the plant, which results in increased storage capacity and less runoff. A layer of organic matter on the soil is an effective protection from erosion and can easily be achieved by leaving crop residue on top of the soil instead of removing, burning or burying it. This requires reduced or minimum tillage. The crop residue has a remarkable effect on decreasing soil erosion (Stocking, 1994; Fangmeier *et al.*, 2006).

Land management

Agricultural activity increases soil erosion compared to soil of natural ecosystems. Agriculture stands for approximately three-quarters of the soil erosion worldwide. Erosion increases when farms are established and forest is cut down to make room for crops. Cultivation and leaving the soil bare between harvest and planting also enhance the soil erosion as plant coverage has a protective effect on the soil (Pimentel, 2006). Erosion can have great destructive consequences and sometimes farmland has to be abandoned as it can become useless (Eriksson *et al.*, 2005).

Productivity

There are several soil physical properties that affect production. Water is scarce in Kenya and even if the studied area in central Kenya is not the worst afflicted, climate change is making rain unpredictable. The soils ability to hold plant available water is an important factor if yields are to be sustained and increased (Millstone & Lang, 2008). The soil texture affects the soils ability to give good yields in several ways. Soil with high clay content is good at holding nutrients and water. Clay also gives the soil a good structure, which is good for soil aeration. High silt content makes the soil more susceptible to erosion which is negative for production. Sandy soils are low in nutrients and do not hold water well during drought (Eriksson *et al.*, 2005). Carbon content is also an important factor which affects soil fertility as carbon rich soils often are richer in organic matter and nutrients, than soils with less carbon (Persson *et al.*, 1994). A high hydraulic conductivity often indicates that the soil has a good structure which is important for making a soil fertile (Keller & Rydberg, 2007)

Thus, the aim of the current study was to obtain background information related to Kenyan small hold farming based on the farmer's experience of productivity and erosion matched by analysis of soil characteristics.

Material and methods

Eight Kenyan farmers were interviewed and studies of different physical soil properties on their farms were conducted during a two months period. The following factors were studied: soil texture, soil water content at permanent wilting point and soil water content at field capacity (pore water pressure of -100 hPa), plant available water content, slope-length measurement with GPS as well as an infiltration study using simplified falling-head technique which yields the hydraulic conductivity for the soil. Carbon content and pH had already been determined in a separate study by Dr Kristina Röing de Nowina, covering all fields on the eight farms. These data were included in the current analysis.

Two interviews were held with the farmers. The first was a general interview with the purpose to obtain data to attain the first aim, *i.e.* to get a general idea of farming in central Kenya. The second interview was conducted to complement the infiltration study and to achieve the third aim *i.e.* to give answers about the experienced erosion.

Selection of study objects

The eight farms included in this study are all positioned in the Embu district, in central Kenya (see Fig. 2). The farms were situated on the slopes of Mount Kenya and the area was considered to have medium production potential. The elevation varied between 1550-1790 meters above sea level. All farms were lying on a slope. Six of the farms were positioned on a steep slope leaning down towards a small stream. The soil type is Lixisol/Nitisols which includes a high content of clay (Bationo *et al.* 2006).

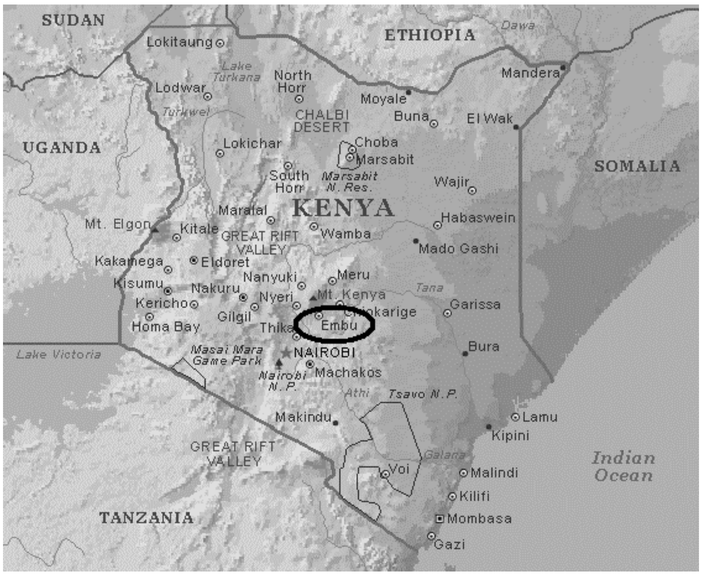

Figure 2. Map of Kenya. The town nearest the farms is encircled. (sandwatch, 2007)

The contact with the farms was already established with through CIAT - TSBF (Tropical Soil Biology and Fertility of CIAT) researchers before the study began. The farms had been given identity numbers which were used in this study. They were indexed “Farm 1”, “Farm 2” etc. through to “Farm 8”. Two fields per farm were selected for sampling. On four of the farms (Farm 1, 3, 5 and 6), the fields were selected through interviews in a previous study, during which the farmer had shown which fields he/she thought had the highest productivity and which field had the lowest productivity. Earlier studies on the farms have also included determination of the carbon content and the pH for all fields. The field with the highest carbon content and the field with the lowest carbon content were selected for the research on three other farms (Farm 2, 7 and 8). This was not possible on one farm (Farm 4) as the field with the highest carbon content was newly planted with vulnerable beans and the farmer did not allow soil sampling there. The field with the third highest carbon content was chosen instead at this farm.

During the erosion interview farmers were asked to show where on the farm they experienced most and least erosion, respectively. These sites were used for the infiltration study, to see if the infiltration capacity determines whether a site is easily eroded or not. An *in situ* simplified falling-head technique was used to determine hydraulic conductivity on these sites. GPS measuring on the highest and lowest spot above sea level were used to help determine the slope-length factor.

In situ

Fieldwork methodology

The fieldwork was divided into three visits. The first visit included an introduction to the farmers, soil sampling on the selected fields and general interview questions about the yield and fertilisation practise. The second visit included completing questions of the first interview as well as more soil sampling and interview questions about the risk of erosion on the farm. Photos of the sampling sites and the farmers were taken during the first two visits. The third visit provided feedback to the farmers and they were also given the photos taken during the first and second visit. The GPS measuring was done three months after the feedback.

First visit – soil sampling

The fields were divided into two parts during the first visit. One part was named Left and one named Right, because when facing east the field part called Left was on the left side and vice versa for the Right. Soil was sampled with a soil auger 10 to 40 times per field half, depending on the size of the field. The collected soil was put in a bucket, bulked and mixed thoroughly (Carter & Gregorich, 2008). Approximately one kg was put in a plastic bag and used for particle size analysis and soil water content at permanent wilting point. This soil sampling was done between 2^{nd} and 4^{th} September 2008.

First visit – interview

A structured interview method with closed-end questions was used for the first interview (see appendix 1). The interview was carried out with the help of local assistants who translated into local language, when necessary. A sketch of the farm, including fields and crops, was drawn after the interview. The sketch was corrected and completed with the help of existing measured data. The interview was complemented with own observations and assistance from the local associates as well as literature.

Second visit – soil sampling and infiltration study

The sampling for soil water content at field capacity and the infiltration study (using simplified falling-head technique) was conducted during the second field visit. Both these studies were conducted on both the Left and the Right side of the selected fields. The infiltration study was also done on areas on the farm which the farmers thought was most eroded or at the highest risk of erosion, as well as areas where no or little erosion took place. Sampling for bulk density was conducted on these extra sites to determine the field water content. The result from the productivity study could be used for the erosion study when the sites coincided. These samples were all collected between 22nd and 24th September 2008.

The infiltration study was performed *in situ* using simplified falling-head technique (Bagarello *et al*., 2004). It required a metal cylinder, water and a stop watch. The metal cylinder had a diameter and height of 14.5 cm and was pushed about 10 cm down in the soil. 500 ml of water was poured into the cylinder and onto the soil. The time from when all the water had been poured until all the water had infiltrated was measured with the stop watch. This procedure was repeated 3 to 4 times per site.

Three metal core ring soil samples were obtained from either side of the selected fields on two of the farms (farm 1 and 2) *i.e.* six samples per field and twelve samples per farm. Two core rings per field side were sampled on the rest of the farms (*i.e.* farms 3-8), *i.e.* four samples per field and eight samples per farm. The metal rings had a 5 cm diameter and were 5 cm high and put in the soil at approximately 3-8 cm depth. Lids were put on either side of the metal core rings after the rings were removed from the soil. The soil samples containing the sampled soil were put in plastic bags, which kept them from drying, as these samples were used to establish the field water content in these fields. The samples were also put in a sample box with padding to keep them from shaking (Carter & Gregorich, 2008).

Second visit - interview

The second interview was divided into two parts. The purpose of the first part was to clarify some of the answers from the first interview. The second part of the interview was a separate part where the farmer was asked questions about his/her experience and observation of soil erosion on the farm (see appendix 2). The farmers were asked to show a site on their farm where they experienced erosion and one where there were no or little erosion. One farmer did not have any erosion and showed the site where there would be erosion if prevention practices were not used. These sites were marked on the earlier constructed maps and the sites were used for the infiltration study and GPS measuring for slope and length.

Third visit – feedback

The farmers each got a folder with the texture analysis results for their farm and the crop rotation for the last four seasons as well as photos of themselves. They also received a map of their farm showing the fields with the highest/lowest productivity alternatively highest/lowest carbon content as well as the sites where they experience most and least erosion. The farmers were also given the opportunity to ask questions about the study. The feedback took place on the 20th of October 2008.

Laboratory work

Soil texture analysis

The sampled soil for the soil texture analysis was left to air dry in a soil drying room with a heater fan during 3-5 days, depending on how wet the collected soil was. The samples were thereafter sieved through a 2 mm sieve. The large aggregates were crushed with a wooden stick and sieved again. The aggregates and organic matter which did not pass through the sieve the second time were thrown away. Approximately 50 g of soil was weighed and put in a 400 ml beaker. Approximately 125 ml of de-ionized water was added to the samples. The organic matter in the soil was digested by putting the samples in an 85 degree water bath. Hydrogen peroxide was added to the samples until the foaming ceased. The samples were thereafter left to cool and 10 ml of 10% sodium hexametaphosphate was added to each sample. The samples were left to stand for about 10 minutes and thereafter put into water tight bottles to be shaken over night. The samples were transported to 1000 ml cylinders. Additional de-ionized water was added to the 1000 ml mark. A blank sample was also prepared in a 1000 ml measuring cylinder with 10 ml of 10 % sodium hexametaphosphate and distillate water to the 1000 ml mark. The samples were mixed with a stir stick about 10 times per sample. After stirring, the sample was left for 20 seconds, after which a hydrometer was gently placed in the sample and a reading was done after an additional 20 seconds. This treatment was repeated for each sample. The soil in the cylinders was thereafter let to settle for 2 hours after which another reading was taken. The temperature of the soil mixture was taken when the two hydrometer measuring were done. The hydrometer readings and the temperature were used to calculate the percentage of clay, sand and silt (Carter & Gregorich, 2008).

Water content at permanent wilting point

The same batch of soil as for the soil texture analysis was used to measure the water content at the permanent wilting point (*i.e.*, at a pore water suction of -15000 hPa = -15 bar). Roughly 20 ml of disturbed but unprocessed soil was put into plastic rings, which were placed on a 15 bar ceramic pressure plate. Water was poured onto the ceramic plate allowing the samples to soak until saturation. The samples were left to soak over night in order to let the air out. Two to three pressure plates were put in the pressure chamber and the pressure was set to 15 bar. The pressure chamber procedure was repeated 3 times and the samples were left for 4, 14 and 21 days. The samples were weighed after they had been extracted from the chamber. The samples were thereafter placed in an oven at 105 degrees for at least three days to dry and thereafter weighed again. The weights were then used to calculate the water content at wilting point (Carter & Gregorich, 2008).

Water content at field capacity

The soil samples in the metal core rings, which were collected during the second field visit, were weighed at field moisture content. The field water content was needed for calculation of the field-saturated hydraulic conductivity using the simplified falling-head technique, see below. The samples were thereafter left to soak (*i.e.*, saturated) for 12 days. They were weighed again after they had soaked and thereafter put on a sand bed with the same pressure as the field capacity *i.e.* pF 2 (-100 hPa). They were left to drain for 3 days and weighed again. The samples were then put in the oven at 105 degrees for a week and weighed one last time. The weights were used to calculate the porosity, bulk density and water content at field capacity (Carter & Gregorich, 2008).

Plant available water

Plant available water in the soil was acquired by calculating the difference between the water content at wilting point and the water content at field capacity (Eriksson *at al.*, 2005).

Field-saturated hydraulic conductivity

The infiltration capacity was obtained through using the simplified falling-head technique which yields the hydraulic conductivity (K_{fs}) for the soil. The hydraulic conductivity was calculated from the following equation:

$$K_{fs} = \frac{\Delta\theta}{(1-\Delta\theta)t_a}\left[\frac{D}{\Delta\theta} - \frac{D+\frac{1}{a^*}}{(1-\Delta\theta)}\ln\left(1+\frac{(1-\Delta\theta)D}{\Delta\theta\left(D+\frac{1}{a^*}\right)}\right)\right] \quad \textbf{(1)}$$

Where t_a was the measured time, D was the volume divided by the infiltration area (*i.e.* the area of the bottom of the used cylinder), a^* is a constant with the value of 12 m^{-1} in clay rich soils (Elrick & Reynolds, 1992; Bagarello *et al.*, 2004), and $\Delta\theta$ was the difference in water content in a saturated soil and the field water content (Bagarello *et al.*, 2004).

GPS measuring

The GPS measuring was done in January 2009, on the same sites as the infiltration study. Both elevation and longitude and latitude coordinates were recorded and recalculated into distance between the highest and lowest spot on the site. This was done with a conversion program (Movable Type Scripts, 2007).

Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) was used to investigate the risk of erosion on the farms and in the area in general (Renard *et al.*, 1997). The equation is as follows:

E= R K Lst C P **(2)**

This equation contains several factors where some were measured and some were representative figures from established tables.

E is the estimated soil loss in Mg ha^{-1} $year^{-1}$. The renewable soil formation has been established as 2.2 – 4.5 Mg ha^{-1} per year for the topsoil in this area (Angima *et al.*, 2003). This means that an erosion rate above this is unsustainable and that erosion is a problem (Angima *et al.*, 2003).

R is a rainfall erosivity factor measured in MJ mm ha^{-1} h^{-1} $year^{-1}$. The R-factor was calculated from the mean annual precipitation (P in mm), through the following separate equations (Renard, 1993):

R-factor = 38.46 + 3.48*P* **(3)**

R-factor = 587.8 – 1.219*P* + 0.004105 P^2 **(4)**

An average of the values from the two equations (3) and (4) was used. The mean annual rainfall in Embu was 1100 mm (worldclimate, 1990).

K is the soil erodibility factor which was calculated through the equation (5). The factors determining the soil erodibility are: soil texture (M), organic matter content (a), soil structure (b) and infiltration capacity (c). The mean soil texture for the area was calculated from results from the soil texture analysis. The infiltration factor was retrieved from a table and classified as rapid (value of 1) based on results for hydraulic conductivity. The soil structure was also retrieved from a table and classified as medium or coarse granular, with a value of 3 (Fangmeier *et al.*, 2006*)*. The organic carbon content had already been established through earlier studies and was calculated into organic matter, assuming that soil organic matter contains 58% organic carbon by weight (Follett *et al.*, 1987).

$$\mathbf{K = 2.8 \times 10^{-7} M^{1.14}(12 - a) + 4.3 \times 10^{-3}(b - 2) + 3.3 \times 10^{-3}(c - 3)} \qquad \textbf{(5)}$$

The slope-length factor, Lst, was calculated as described in Fangmeier *et al.* (2006). The values for the slope-length were retrieved from the GPS measurements.

C is the cover management factor and includes the effects of cover, crop sequence, productivity level, length of growing season, tillage practices, residue management and expected time distribution of erosive events. The used figure was estimated from values retrieved from tables in Angima *et al.* (2003) and Fangmeier *et al.* (2006). The values varied most with the kind of cultivated crop as can be see in table 1 and an estimated figure of 0.35 was used.

Table 1. C-factors for different crops (Angima *et al*., 2003; Fangmeier *et al.* 2006).

Crop	C-factor
Coffee	0.394
Bean/Maize rotation	0.343
Banana	0.089
Grass	0.01

P is the conservation practice factor; it declines with improving erosion controlling practices. Examples of such practices are: terracing, contour tillage, and permanent barriers or strips (Angima *et al.*, 2003; Fangmeier *et al.* 2006). The value was estimated as 1 as none of the practices were used in any large extent.

Statistical methods

Data (*i.e.* measured soil properties, as described above) were statistically analyzed using SAS (SAS Institute, 1996). The hypothesis of no treatment effects was tested for each soil property by F-tests using field type (*i.e.* high productivity vs. low productivity; and high erosion risk vs. low erosion risk) as treatment and farm identity as block. .

Results

General interview

The first interview, complemented with observations and literature study, gave the following answers about farming systems in the Embu district:

A year on the farm

The annual precipitation is about 1100 mm which comes down during two rainfall (growing) seasons, in central Kenya (worldclimate, 2009-01-13). This affects the farming as cultivating, planting and harvesting all takes place twice every year. The growing seasons are called the long- and short rain season. The long rain is the first of the year and its duration is between March and September. The rain comes down between March and May during the long rain. Planting takes place in March/April and harvest is in August/September during this season. The short rain season is the second of the year and has its period between September and December. The rain comes down in October and November. September/October is the time for planting and December is the month for harvest during the Short rain season (Angima *et al.* 2003; Rånlund, 2007).

Baseline information about the farms

The farms were between 0.3 - 4.5 hectares in size with an average of 1.0 hectares (see Table 2). The households held between 1-11 people. Most of the labour was done by hand such as planting, weeding, fertilizing and harvesting, on the studied farms in Kenya. The number of fields and field sizes on the farms changes from season to season since the annual crops are easily shifted. During the long rain season 2008 the number of fields varied from 4-10 with an average of 7 fields per farm. The field sizes differed between about 100 m^2 and 14000 m^2 with an average of 1300 m^2 during the long rain season 2008. Most of the farms have been cultivated by the present farmers since Kenya got its independence from the British government in the 1960th.

Table 2. The farm sizes of the eight different farms.

Farm	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8
Farm size (hectare)	4,6	0,34	0,68	0,31	0,72	0,45	0,42	0,86

Crops

Intercropping was practised on all eight farms, in most of the fields. Tea was generally planted as a monocrop, but sometimes other trees, such as banana, were planted in the tea field. Other examples of intercropping were beans and maize planted on the same field or coffee and banana trees. The most common crops were maize (*Zea mays*), beans (*Phaseolus vulgaris*), coffee (*Coffea arabica*), tea (*Camellia sinensis*), banana (*Musa sapientum*) and Napier grass (*Pennisetum purpureum*), the latter crop was used as fodder for the farm animals. Several other crops were cultivated and a selection of these are: avocado (*Persea Americana)*, arrow root (*Maranta arundinacea)* and pineapple (*Ananas comosus)*.

Yields

The yield for maize, tea and coffee, for each farm, can be seen in Fig. 3. The average yield per year was; maize 1800 kg/ha; tea 14000 kg/ha and coffee 5800 kg/ha. On the farms an average of 75 kg of maize per person per year were produced. All numbers are in fresh weight of unprocessed crops.

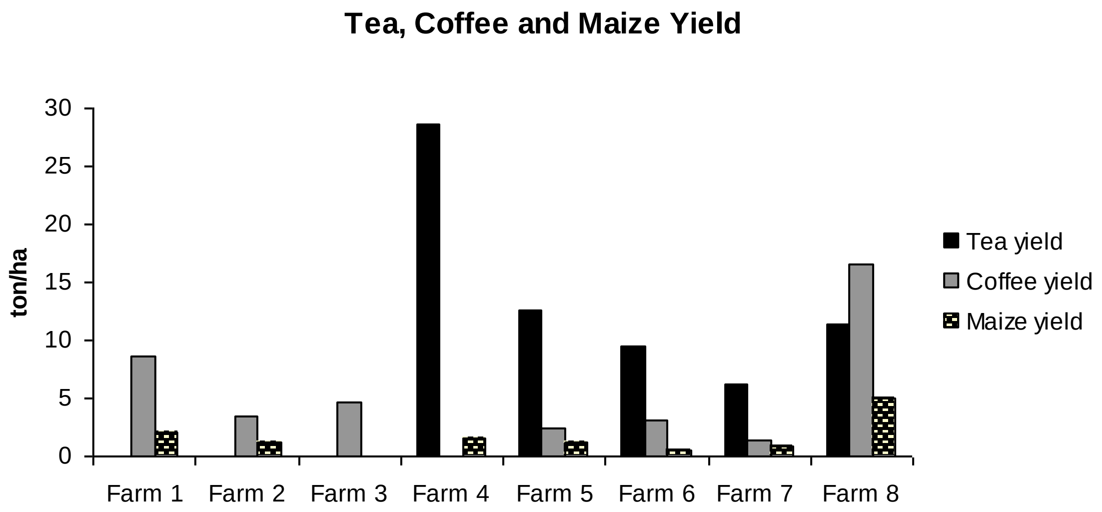

Figure 3. The yield in ton/ha/year for tea, coffee and maize. Not all farmers planted all crops.

Fertilizer and manure

All farmers used fertilizers, but none of them kept track of how much and what kind of fertilizer used nor on where it was applied on the farm. Therefore no reliable estimates on the amount of applied fertilizers could be obtained. The most common used fertilizers were DAP (Diammonium Phosphate), CAN (Calcium Ammonium Nitrate) and NPK (Nitrogen Phosphorus Potassium). Seven of the eight farms used manure. The most common manure was manure from cattle.

Pesticides

Three farmers stated that they used pesticides during the long rain season 2008. Six farmers said they have used pesticides at some time. One farm did not use any pesticides at all but applied ash as a pest repellent

Irrigation

None of the interviewed farmers used irrigation.

Soil analysis

There was also no significant difference between the Left and Right side of field and therefore an average of the field was calculated and used.

Soil texture analysis

The average distribution between the particle sizes were: clay 54.4%, sand 28.4% and silt 17.2%. The results received from the texture analysis can be seen in Figs. 4 and 5. There was no significant difference ($P > 0.05$) in soil texture between the high and low producing fields, or between the high and low carbon content fields.

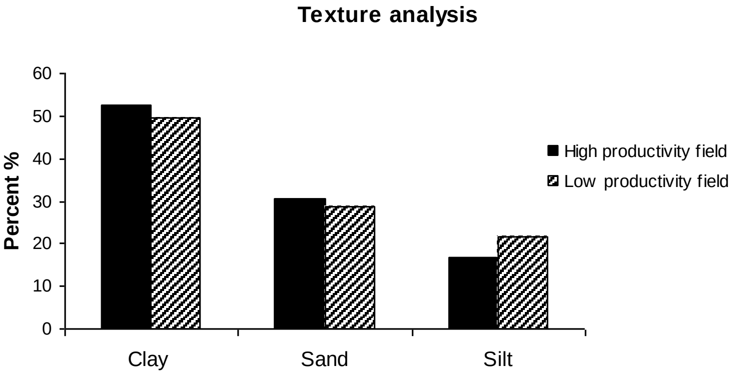

Figure 4. Average percentage of clay, sand and silt in the high/low producing fields.

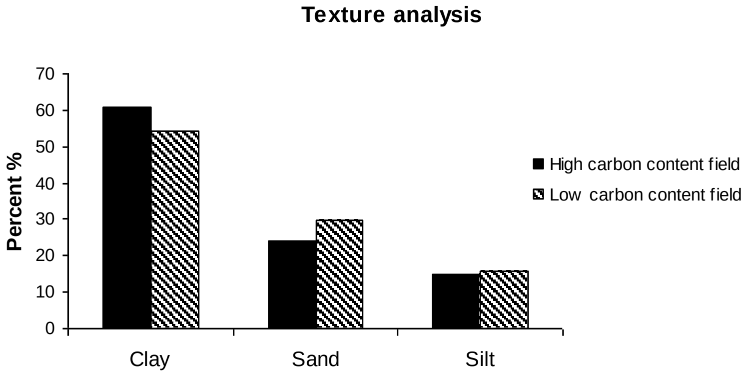

Figure 5. Average percentage of clay, sand and silt in the high/low carbon content fields.

Plant available water

The average percentage of plant available water for the area was 21%. The percentage of plant available water in the high/low carbon content and productivity fields can be seen in Fig. 6. There was no significant difference ($P > 0.05$) in plant available water between the fields with high and low productivity, respectively; nor between the fields with high and low carbon content, respectively. However, there was a tendency of higher plant available water on the fields with higher productivity.

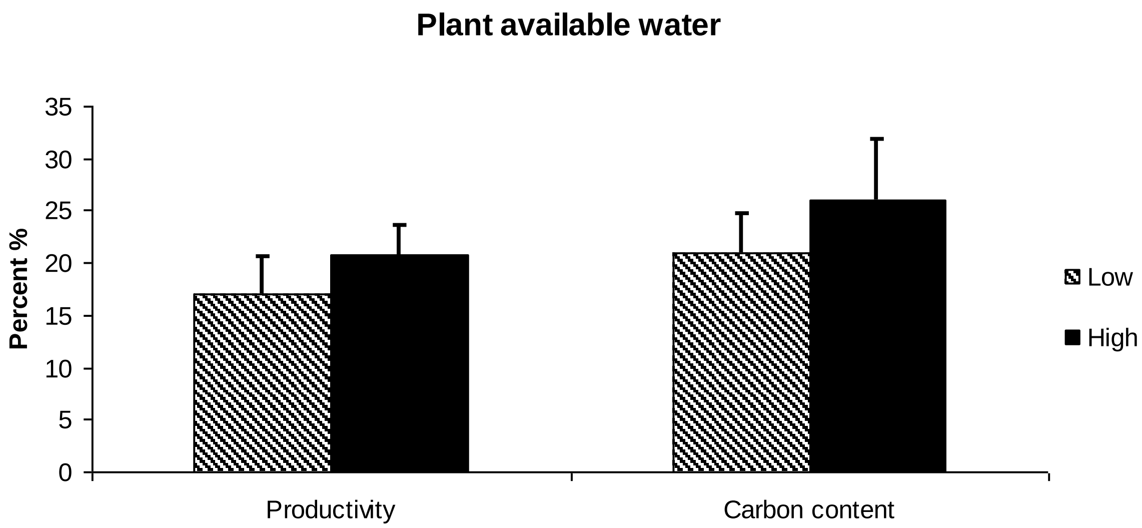

Figure 6. Average percentage of plant available water in the high/low productivity and carbon content field. The error bars indicate standard error of the mean.

Carbon content

The average carbon content for the area was 2.0% and the average percent carbon for the studied fields can be seen in table 3. There was no significant difference ($P > 0.05$) in carbon content between the fields with high and low productivity.

Table 3. The carbon content for the high/low productivity and carbon content fields.

Field	Carbon content (%)
Low productivity	2,29
High productivity	2,30
Low carbon content	1,61
High carbon content	1,99

Infiltration

The average hydraulic conductivity for the area was 330 mm/h, with a coefficient of variation of 71.5%. The average values for hydraulic conductivity on the different sites can be seen in table 4. There was no significant difference ($P > 0.05$) in saturated hydraulic conductivity between the fields with high and low productivity, respectively; nor between the fields with high and low carbon content, respectively.

Table 4. The hydraulic conductivity for both the productivity study and erosion study.

Site	Hydraulic conductivity (mm/h)
Low productivity field	560
High productivity field	335
Low carbon content field	250
High carbon content field	210
Least erosion	380
Most erosion	286

Erosion study

There was no statistical significant difference in the hydraulic conductivity (see above) or silt content between the sites with high or low erosion. The slope steepness was not statistically significantly different when the sites were compared. The slope steepness varied between 2-46% with a medium of 15% for the region.

The soil loss, from the calculations with the RUSLE equation, was on average 80 ton ha^{-1} $year^{-1}$ for the investigated area. The two equations for R-factor (Eqs. 3 and 4) gave two different results, viz. 3850 and 4170 MJ mm ha^{-1} h^{-1} $year^{-1}$. Therefore an average of 4000 MJ mm ha^{-1} h^{-1} $year^{-1}$ was used. All the RUSLE equation factors can be seen in table 5.

Table 5. Values for the factors in the RUSLE equation.

E (Mg ha^{-1} $year^{-1}$)	R (MJ mm ha^{-1} h^{-1} $year^{-1}$)	K (Mg h $MJ^{-1}mm^{-1}$)	L	S	C	P
80	4000	0.012	2.40	1.992	0.35	1

Interview - erosion

The second interview gave the following information about the farmers’ experience of erosion on the farms in Embu:

All farmers had more or less the same definition of erosion, which was: soil and nutrients are carried away with water and/or wind from the farm. Water erosion seemed to have the largest impact in the area. The majority of the farmers answered that they experienced erosion on their farm; one said they only experience a little erosion, and one farmer said there was no erosion at all because of the prevention practices they were using (see Fig. 7).

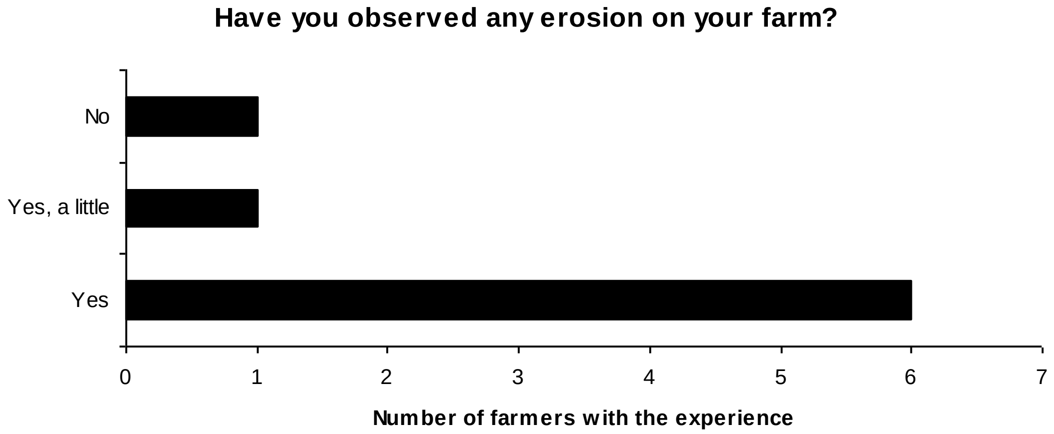

Figure 7. The farmers experience of erosion on their farms.

Erosion was foremost thought as problem because it carries away the topsoil which holds most of the nutrients, manure and fertilisers. Erosion was also thought as a problem because it is destructive to the crop. The farmer who does not have any erosion does not think erosion is a problem.

Figure 8 shows the answers to the question if and how there had been any change in erosion during the years the farmer had been cultivating the land. The number of years differed a little between the farmers, but all farmers had started cultivating in the 1960's or later based on the first interview. The two farmers who answered that the amount of erosion depended on the amount of rain also said that there was less rain now than before, which in length means that there is less erosion now.

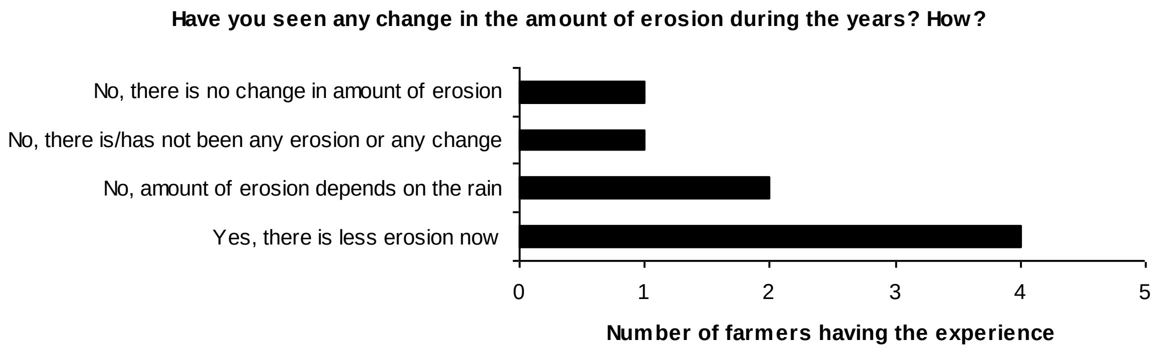

Figure 8. The answers received on the question about the observed change in erosion.

The farmers mentioned both introduction of erosion prevention methods and a decrease in rainfall amount and intensity, as reasons for the reduced erosion. Efficient prevention methods are used and have long been used on the farm which does not have and has not had any erosion. All eight farmers claimed that there is much less rain nowadays. One farmer said that “there is almost no rain now” and another said that “especially this season (Long rain 2008) has been a year of very little rain”. The farmers also thought that apart from less rainfall, the intensity of the rainfall had become less. The erosion in the area is not constant during one year but increases noticeably during rain, especially during the rain in the long rain season. Erosion increases more during intense rain than during less intense rain.

The crop seemed to have effect on the erosion; there was more erosion where maize was planted then where sweet potato or Napier grass was planted. The farmers had different opinions on whether beans caused or prevented erosion, but all agreed that Napier grass helps to prevent erosion and was often planted on the most eroded sites.

The fields are covered with plants during the rains, but the soil was left exposed to rain and wind twice a year, one month before planting for the short rain season in September and one month in January/February before planting for the long rain season.

All eight farmers used erosion prevention methods on their farm. Six of the farmers had dug trenches to lead the water away from the field (Fig. 9) or to slow down the flood during heavy rain (Fig. 10). The perennial Napier grass is another popular erosion prevention method which many farmers adopt (Fig. 11). Small terraces could sometimes be observed where Napier grass and similar grass were planted (Figs. 13 & 14). Other plants that are planted partly to prevent erosion are potato, sweet potato and banana trees. The methods were also combined in different ways, like planting bananas inside a trench to slow down the flooding more efficiently (Fig. 10) or planting potatoes on the trench. Strategies like leaving crop residue (for example leaves) from the tea or coffee plantation, which were carried away by the erosive rain instead of the soil, were also used to prevent soil erosion (fig. 12). The crop residue also intercepts the raindrops before they hit the soil surface which decreases the erosive effect of the rain.

Figure 9. Trench. Photo S. Rosén

Figure 10. Trench and banana trees. Photo S. Rosén

Figure 11. Napier grass. Photo S. Rosén

Figure 12. Crop residue from coffee. Photo S. Rosén

Figure 13. Napier grass. Photo S. Rosén

Figure 14. Small terraces with Napier grass. Photo S. Rosén

The conclusions based on the erosion interview are that there is erosion on farms in the Embu district in central Kenya. Erosion is considered as a problem because it carries away the necessary plant nutrients which the already poor soils lack. Erosion is worst in the maize fields as this row crop is annual and does not cover the soil surface very well. The farmers are trying to limit the erosion with different techniques, especially through planting the perennial Napier grass and digging trenches. The erosion varies during the year and increases during the rain seasons, especially during the long rain season. The erosion has been lessening over the years according to the farmers, because the amount and intensity of rain is declining and also because new erosion prevention practices are introduced on the farms.

Discussion

General about the farms

The first aim of this study, to obtain a general idea of what farming is like on smallholder farms in central Kenya, was achieved, although there is some uncertainty about yield and farm/field sizes. The size of the crop yield can be questioned as there were no reliable records of yields or size of the planted area, especially regarding maize. Records were kept for the yield of tea and coffee as those crops were sold to factories, but the area from where the yield came was not certain. The farmer's answers to how big their farm was did not always coincide with the data that had been obtained in earlier studies. The farms and fields had earlier been measured with a measure tape, which can not been considered as fully accurate. There was therefore an uncertainty when it came to the sizes of fields and farms.

The questions in the first interview were complemented with additional questions in the second interview to get more specific information about the selected fields. The farmers did not have such information, for example: how much yield, fertiliser, manure etc is put on the high/low producing field. Their memory focused on the yield, fertiliser, manure etc. for the whole farm and not for specific fields.

Soil fertility – soil physical properties

The soil properties that were investigated did not show a statistic significant result *i.e.* the plant available water, clay content, carbon content or infiltration was not higher in the high producing fields. Neither was plant available water, clay content or infiltration higher in the fields with higher carbon content. The reason for this can be that other factors than these determined if the soil has a high production capacity or not. Such factors can be cultivation practice (weeding, soil cultivation, planting etc.), soil nutrients, microbiological activity, soil structure, aggregate stability, pH etc.

Another suggestion is that the farmers did not show the correct fields. The possible errors in the site selection can be explained by defects in both methods (i.e. selection through interview and carbon content) for choosing highest and lowest producing field. As stated above, the interview method could not be supported with yield statistics as there was no way of tracking how much each separated field produced. Therefore, the selection was based solely on the farmer's experience. The farmer's selection of fields might be incorrect for different reasons such as memory mistakes or a misjudgement since different kinds of crops were planted on the compared fields and therefore made them hard to compare. The selection with carbon content was more scientific, as high carbon content means high organic matter content, which is good for productivity. Other factors than organic matter content could effect production, which makes also this selection insufficient. However, there may simply be no significant difference in physical soil properties between the fields at the farms. This is a likely reason as the farms are small (around one hectare), and the soil is expected to be rather homogenous within such a small area.

Texture analysis showed that the soil was rich in clay and a high percentage of clay is good for the nutrition state in the soil (Eriksson *et al.*, 2005)

The plant available water capacity, PAWC, was on average 21% (0.21 $m^3\ m^{-3}$), which indicates a good water retention state. In fine-textured soils (such as clay soils), a PAWC ≥20% may be considered "ideal" for maximal root growth and function (see e.g. Reynolds *et al*., 2008). This together with an annual precipitation of 1100 mm/year shows that water should not be a limiting factor on these farms and this is further confirmed with the fact that none of the farmers considered it necessary to use irrigation. The interview indicated that water is becoming more scarce, which is in line with what climate change research shows. The rainfall in eastern Africa has declined with 15% since the 1980s according to NASA-researchers (NASA. 2008).

The average carbon content was 2.0 % which is considered to be good in an African soil (Okalebo *et al.*, 1993).

The average hydraulic conductivity was 330 mm/h, but varied a lot within a small area. The value is high and indicates a rapid infiltration (FAO, 1990). The infiltration capacity can therefore not be considered as a limitation to the production potential.

Erosion study

The information both from the interview and from calculation with the RUSLE equation, show that there is a problem with erosion in the investigated area. None of the factors; silt content, infiltration capacity and slope steepness, were statistically significant between the sites with much/little erosion. Therefore the objective to answer why there is erosion on the farm could not be fulfilled. Although earlier studies show that these factors do affect erosion and can therefore be considered to have an effect on these farms too (Fangmeier *et al.*, 2006)

The infiltration capacity varied a lot between the different fields, which explains why no statistically significant differences were observed. Bad infiltration did not seem to be the cause of erosion as the hydraulic conductivity was very high. The accuracy of the GPS measurements for the values of the RUSLE slope-length factor and the slope steepness could also be questioned as they in some cases did not correlate with reality and were discarded.

Angima *et al.* (2003) has also done a study on erosion using the RUSLE equation, in an area about 7 km from the area investigated in this study. Therefore, the values can be compared as the soil, climate and agricultural practices are likely to be similar. The biggest difference between this study and Angima *et al.* is the R-factor. Angima *et al.* had more information about storm events and used a value of 8500 Mg h $MJ^{-1}mm^{-1}$ (as compared to R = 4000 as used here), which would more than double the calculated soil loss through erosion.

The cover management factor was retrieved from table 3 in Angima *et al.* (2003), where C-factor values for different crops were available. The value was 0.343 for corn/bean rotation and 0.394 for coffee. Corn, bean and coffee were three of the most common crops together with tea. No value for the perennial tea could be found. Fangmeier *et al.* (2006) reported a value of 0.01 for perennial grass, which could be considered similar to tea. Another perennial crop is banana, which had a C-factor value of 0.089 (Angima *et al.*, 2003). However, Banana did not cover a large area. In this study, the RUSLE equation was used to estimate average soil loss at Embu district for a cropping pattern of corn, bean and coffee. Therefore, a value for the C-factor of 0.35 was used. This was an unreliable factor in the RUSLE equation as the background information on effects of cover, crop sequence, productivity level, length of growing season, tillage practices, residue management and expected time distribution of erosive events, was inadequate.

The average loss of soil on the farms was estimated to 80 ton ha^{-1} $year^{-1}$. This value can differ if a steeper or more horizontal slope is used. The value differs between 6-320 ton ha^{-1} $year^{-1}$ when the smallest slope of 2% and the largest slope of 46% on the farms, were used. All these values confirm that there was a problem with erosion as the renewable soil formation has been established as 2.2 – 4.5 ton ha^{-1} per year for the topsoil in this area (Angima *et al.*, 2003). If the value for grass as representative for tea was used instead, a soil loss of 2.3 ton ha^{-1} $year^{-1}$ was obtained. This showed that the kind of crop has a large impact on the loss of soil.

Conclusion

Farming in the Embu district in Kenya was done with simple methods and the most common crops were: maize, beans, bananas, coffee and tea. The farms were small, around one hectare with small fields of about 1300 m^2. The yields differ a lot and the reason was assumed to be unreliable data. The farmer experienced variation in productivity between fields could not be explained by the plant available water, clay content, carbon content or infiltration capacity. There was an erosion problem in the Embu district in Kenya, but the farmers use erosion prevention practices to try to control the erosion. The difference in erosion between sites with much and little erosion could not be explained with silt content, infiltration capacity or slope steepness. The RUSLE calculations showed that the crop has a large impact on the loss of soil, which is in accordance with the farmer’s experience.

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Appendix 1

Interview questions first Embu visit

What year did you start cultivating on the farm?
Who started the cultivation?
How big is your farm?

Do you use irrigation on your farm?
On what crop/fields do you use irrigation?
How much irrigation do you use?
From where do you take the water?
Why do you use irrigation?

Do you use fertilizer on your farm?
What kind of fertilizer do you use?
On which crop/field do you put the fertilizer?
How much fertilizer do you use?
When do you apply the fertilizer?
Why do you apply the fertilizer?

Do you use manure on your farm?
What kind of manure do you use?
On which crop/field do you put the manure?
How much manure do you use?
When do you apply the manure?
Why do you apply the manure?

Do you use pesticides on your farm?
What kind of pesticides do you use?
On which crop/field do you put the pesticides?
How much pesticide do you use?
When do you apply the pesticides?
Why do you apply the pesticides?

Appendix 2

Interview questions second Embu visit -additional questions

Did you use pesticides this season (long rain 2008)?
What is your annual harvest of coffee, maize and tea?
What did you plant on the high productivity/high carbon content field last season (short rain 2007)?
What did you plant on the low productivity/low carbon content field last season (short rain 2007)?
For how long did you allow the manure to lie before you used it on the crops?
Did you put all your manure on the crops?

Interview questions second Embu visit -erosion

What are your thoughts on erosion? What is your definition of erosion?
Have you observed any erosion on your farm?
Where have you seen much/little erosion on the farm?
Where is there no erosion?
Have you seen any change in the amount of erosion during the years? How?
Why do you think there has been/not been a change in the amount of erosion?
Is the amount of erosion constant in one year?
(or does it for example increase with heavy rain?)
How does the amount of erosion change depending on crop (annual/perennial)?
Do you use any practice to prevent erosion on your farm? What?
For how long and when is the soil directly exposed to rain and wind?
Is the soil covered with plants during the rain season?
Has the amount of rain changed during the years?

- Much more rain now
- A little more rain now
- The same amount of rain now
- A little less rain now
- Much less rain now

Has the rain intensity changed?

- Much more intense now
- Little more intense now
- Not changed
- Less intense now
- Much more intense now

How is erosion a problem?