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ASSESSING THE IMPACT OF CULTIVATION ON SOIL ORGANIC CARBON: A CASE STUDY AT KORPA IN ICELAND

Isaac Owusu Ansah
CSIR-Soil Research Institute
Private Mail Bag, Academy Post Office
Kumasi, Ashanti Region, Ghana.
Isaac86owusu@gmail.com

Supervisors:
Dr Utra Mankasingh
University of Iceland
utra@hi.is

Prof. Gudrun Gisladottir
University of Iceland
ggisla@hi.is

Julia Miriam Brenner
University of Iceland
jmb8@hi.is

Maria Svavarsdottir
University of Iceland
mas72@hi.is

ABSTRACT

The conversion of natural vegetation into agricultural land has led to a decline in soil organic carbon storage, such that sustainable land management applications are extensively recommended as an alternative to improve soil organic carbon storage, thereby improving food security, especially in Africa. The main goal of this research was to assess the impact of cultivation on soil organic carbon through a case study at the Korpa Experimental Station in Iceland. This study was carried out in order to relate the situation to the tropics (Ghana) and to propose good land management practices that will improve food security as well as the lives of poor subsistence farmers. Soils were sampled from three land use types; a barley field, a grass field and a shelterbelt (undisturbed). Five samples from each site, totalling 15 samples, were extracted to determine soil moisture, bulk density, % carbon, % organic matter, total nitrogen, texture and C:N ratio. Generally, there was no statistical difference in soil organic carbon and related soil properties among the three land use types. The conservation cultivation practices, as well as the soil type in the study area, had a positive effect on soil organic carbon and related soil properties, leading to no decline in soil fertility.

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1 INTRODUCTION

Agricultural management applications and differences in land use are known to affect soil quality (Walker & Desanker 2004; Raiesi 2006). The current literature has shown that a significant decrease in soil organic carbon (SOC) happens due to differences in land use and to the greatest extent when forest lands are transformed into cultivated lands (Lemenih et al. 2005; Raiesi 2006). SOC decline is also affected by the kind of tillage and arable land practices that are adopted. About 40% of the average global decline in SOC is the result of the use of large farming implements, which turn the soil layer to a depth of 0.3 m (Davidson & Ackerman 1993). Soil forms about 85% of organic carbon across the world (Dixon et al 1994). It holds over 1000 metric tons (Lal 2008), and this stock prompts important awareness about soil because of its potential in carbon storage. Soil fertility decline has been indicated as the only serious significant limitation to food reliability in West Africa, where more than 50% of the people are living in rural areas and are local poor subsistence farmers who directly rely on locally grown crops (Bationo et al. 2007). This has led to pressure on agricultural lands, since these farmers are unable to purchase inputs to replenish the soil as a result of continuous cropping. Additionally, almost half of the population is hungry and more than half of the people are fed on less than US$ 1 per day (Bationo et al. 2007).

The current agriculture in Iceland, as a developed country, is highly centered on livestock. Dried hay, which is harvested and stored for the prolonged intensive feeding time during the coldest season of the year, is generated rigorously on cultivated grasslands (Gudmundsson et al. 2004). Some cultivated grass fields are incorporated in crop rotation, but others are more permanent. The seasonal changes in agricultural management have led to the general acceptance and use of commercial fertilizers, as well as good conservation practices by farmers. With fertilizer subsidies from the government, there is active participation by all farmers to improve and maintain the productivity of farm lands, with the primary motive of monitoring the future progress of soil fertility in Iceland (Gudmundsson et al. 2004).

In the tropics such as in Ghana, agricultural production is carried out on plots managed separately by individual farmers. Soil fertility used to be managed by a small number of farmers through fallowing, in which cultivation is periodically stopped in order for the soil to regain its fertility and to control weeds and other pests (Gladwin 2002). However, in recent times there has been a population explosion in the country and most lands that used to be fallowed are no longer as the system has been changed for commercial purposes. Continuous cropping is the current situation among most farmers in Ghana, which is detrimental to the local ecosystem as savannahs have a low primary production due to declining soil organic matter (OM) levels (Scholes & Hall 1996). This has resulted in a decrease in soil organic carbon levels and fertility in general (Davidson & Ackerman 1993).

In spite of the importance of carbon to soil fertility in agriculture, bad agricultural practices such as continuous cropping, removal of crop residues, deforestation and biomass burning can accelerate SOC decline and result in soil structure breakdown (Gisladottir & Stocking 2005). Unproductive soils in regions used for agriculture directly result in a decline in food production. Careful management and systematic measurement of resources within the farmer household give strong indications on how to improve the system of agricultural output and optimal uptake of nutrients from the soil. It is imperative to assess the impact of cultivation on soil organic carbon in order to propose sustainable land management practices that will maintain soil fertility and optimize food production in Ghana.

The main goal of this research was to assess the impact of cultivation on soil organic carbon using a case study at Korpa in Iceland.

The specific objectives of this project were:

- Identify cultivated and undisturbed sites to compare soil organic carbon content and related soil properties.
- Assess the impact of cultivation on soil quality including bulk density and soil moisture.
- Determine the changes in SOC levels at various sites in relation to the balance of carbon inputs over losses.
- Determine the carbon: nitrogen ratio to ascertain the rate of decomposition among the sites.
- Propose sustainable management practices that would either increase the additions of SOC or decrease the losses of carbon from the soil in the context of Ghana.

2 LITERATURE REVIEW

2.1 Soils

Soil is the genesis for life on Earth, generating a platform for the regulation of the essential functions (energy, nutrients and water) in life that help provide carbon for crop growth as far as soil fertility is concerned. This essential resource (carbon) is not static, but depletes with time as man utilizes the land for survival. Soil is a critical resource that consists not only of minerals and water, but also provides essential connections that maintain the Earth's ecosystems. It takes years for soil fertility to improve, and when land is unproductive, drivers of erosion such as wind and water control surface processes. However, with enough vegetative cover erosion is well checked. Soil erosion modifies the morphological features of the land and can change productive lands into unproductive wasteland (Stocking 2003; Arnalds et al. 2001).

Human activities have transformed nearly every part of the earth, leading to extreme land destruction and almost total collapse of ecosystems (Anarlds 2015; Brady & Weil 2008). Soil loss and decline in fertility are two of the most significant threats now confronting the world (Stocking 2003). Currently erosion has rendered 16% of Africa's cultivable land base unproductive and unsuitable for any agricultural purposes (Bationo et al. 2007).

Andosols are the main soil type in Iceland (Arnalds 2004). Globally, Iceland has the largest land area in terms of Andosols (Arnalds 2004). Andosols are soils that are formed from substances rich in volcanic ash and they are very vulnerable to erosion. These soils have low adhesion but can soak up vast amounts of water and become fully saturated in winter and spring as a result of the frozen surface, which prevents drainage. Additionally, the cold weather comes with an extended period of rainfall. The very young nature of Icelandic volcanic soils makes them distinct among the volcanic soils in the world, as reported by Arnalds (2015). The soils collect vast inputs of sand arising from the action of wind. These particles are made up of dark, fine-grained igneous rock consisting of feldspar, pyroxene and sometimes olivine.

The soils of Ghana are mainly savannah Ochrosols, and forest Ochrosols and Oxysols (Brammer 1962). These are highly weathered soils belonging to the Latosol soil association (FAO/UNESCO 1988). These soils have mostly been influenced as a result of the major climatic differences that have generated two major and well-defined vegetation belts: the forest and savannah. The soils of the forest and savannah belts can easily be differentiated based on their level of organic matter in the top horizon: forest soils have higher OM content due to high leaf fall, as opposed to savannah belts which have grass as the dominant vegetation (Obeng 2000). This, together with human activities, has influenced the soil properties and fertility status in Ghana.

2.2 Organic carbon dynamics in soils

Soil organic carbon is essential for all the three features (chemical, physical and biological) of soil fertility which support the total productivity of the soil (Brady & Weil 2008). Soil organic carbon is the carbon that occurs in the organic matter in the soil. Soil organic matter is the proportion of the soil that consists of decayed organic materials, including microbial organisms which liberate nitrogen, phosphorus and other elements accessible to plants (Wendling et al. 2010). Soil organic carbon improves soil structure by promoting adhesion of soil particles to form firm clusters, thus enhancing soil physical processes such as water holding capacity, water percolation, gaseous exchange, and root development, and overall making cultivation easier (De Gryze et al. 2007).

Soil organic carbon performs a crucial function in the soil food chain by influencing the amount and types of soil dwellers which perform critical roles such as nutrient cycling, root development, utilization of nutrients by plants, creation of tunnels to improve aeration and even the reduction of plant diseases (Turmel et al. 2015). Vegetation acts as a carbon sink because plants convert carbon dioxide via photosynthesis, and this carbon is mostly stored in the soil and has a direct relation to soil fertility. Soil conditions, especially temperature, moisture, texture, structure, tillage and cropping management, all have significant consequences on soil organic carbon transformation (Smith 2008).

The soil carbon to nitrogen (C:N) ratio is an essential soil fertility index because of the direct relationship between SOC and total nitrogen (TN). It states the integration between SOC and TN. The C:N ratio in the organic matter in the arable (cultivated) top layer of the soil often ranges from 8:1 to 15:1, with 12:1 being close to the median (Brady & Weil 2013). In a particular climate, a slight difference appears in the C:N ratio for closely related soils. The soil C:N ratio is usually affected by determinants such as climate (Burke 2004), soil condition (Diekow et al.2005; Galantiniet et al. 2004; Mando & Stroosnijder 2006), vegetation type (Diekow et al.2005; Puget & Lal 2005) and agricultural management (Dala et al. 2011; Liang et al. 2011). Crop residues and crop roots on the soil surface are vital for C:N ratio determination. A C:N ratio >20 reveals a distinct chemical composition and resistance to decay (Torbert et al. 2000). It has been shown that crop residues have a higher soil C:N ratio than roots. Further, remnant absorption can expand the amount of mobile SOC with a lower decay level and a bigger C:N ratio (Lou et al. 2012; Xu et al. 2011).

2.3 Management practices that influence soil organic carbon

It is well documented in the literature that farming operations and land use modifications influence soil qualities (Walker & Desanker 2004). It has been pointed out that farming practices and land tilling have caused changes in carbon storage and transformation (Lemenih et al. 2005; Raiesi 2006). SOC levels are controlled by factors such as precipitation, temperature, vegetation, and soil type, and these are well balanced in a healthy ecosystem (Dixon et al. 1994; Smith 2008). However, the balance is interrupted when land is brought under cultivation. Bringing natural vegetation under cultivation leads to major declines in the SOC levels and further reduction may arise because of management practices. Agricultural practices can leave the SOC unprotected and increase decline by decomposition and runoff (Gregorich et al. 1998; Balesdent et at. 2000; Hamza & Anderson 2005; Stocking 2003). Cultivation practices that make use of unsuitable tools affect the soil, and the resultant decline in the SOC can lead to numerous land destruction issues such as erosion and soil structural losses (Six et al. 2002; Stocking 2003). Most of the decline in SOC happens in the top horizon, 0-10 cm, and for this reason soil carbon levels of cultivated lands are lower than comparable lands in uncultivated vegetation (Islam & Weil 2000). This distinction in SOC shows the possibility for soil carbon storage. Due to rapid population growth, the accessibility of cultivated land in Africa has dwindled, and it is unrealistic to practice prolonged fallow periods to regain soil fertility. The uncultivated season, which would have regained soil fertility and organic carbon, is decreased to levels below soil productivity revival, resulting in unsustainable cultivation practices (Nandwa 2001; Nye & Stephens 1962).

In order to increase SOC levels in soil, it is necessary to adopt a holistic approach to sustainable land management practices that take into account the total environment (biotic and abiotic) as well as the interaction of social and economic restrictions faced by the poor farmers (Stocking 2003). There is a vast span of management choices and cultivation operations that can improve SOC content by either raising inputs or reducing declines. For example, in sub-humid Benin, *Mucuna pruriens* (velvet bean) has been integrated into the soil as green manure mulch, and it has proven to be a well-adopted practice to curb soil fertility losses. Fifteen native farmers adopted this practice through trials in 1987, and by 1996 100,000 farmers were declared to have accepted this practice (Versteeg et al. 1998). Inputs can also be raised through the inclusion of organic materials, compost, manure and other reprocessed organic substances (West & Post 2002). Essentially, any management application that can raise production from a cultivated piece of land should lead to an increase in SOC storage as well. Land users should be made aware of the need to practice conservative methods such as minimizing soil disruption by no-tillage practices, changing from monoculture to multiple crop rotation, and expanding main production by fertilization, which are all ways of improving soil carbon content (West & Post 2002; Deen & Kataki 2003). Kiome & Stocking (1995) reported that, in semi-arid Kenya, poor subsistence farmers have adopted “trashlines” (belts of uprooted weeds and crop remnants) to block deposit and runoff, a technique never encouraged by the consultative services. Yet when the technique was assessed over 10 years due to its usefulness, it had been accepted as the only practice for soil quality enhancement that helps farmers increase their livelihood (Stocking 2003). This application of sustainable land management practices has the possibility to check and eliminate land destruction, hunger, and poverty in West African farming systems through improved levels of soil fertility and the adoption of less expensive technologies in relation to soil quality maintenance (Bationo et al. 2007).

3 METHODOLOGY

3.1 Study area

Iceland is situated near the border between warm and cold ocean currents (Einarsson 1977). The North Atlantic drift passes just south on its course north-eastwards, and one of its branches - the Irminger current - encircles the south, west and north coasts. It is obvious that the oceanographic conditions just described must influence weather and climate considerably, both directly along the coast and also because all air masses arrive in Iceland after having passed over the sea (Einarsson 1977). The study site, Korpa Experimental Station, lies at latitude 64^0 08' N and longitude 21^0 44' W. From 1995 to 2015 the mean annual rainfall was 1237.3 mm and the average temperature was 4.5 °C (Fig. 1; Icelandic Meteorological Office). The soils of Korpa are classified as Gleyic Andosol (Arnalds 2005). According to Arnalds (2004), gleyic Andosols refer to wetland soils with organic carbon (OC) < 12% in the top layer, and they are predominant in many drained wetlands where there is comparatively quick displacement of soil particles by wind.

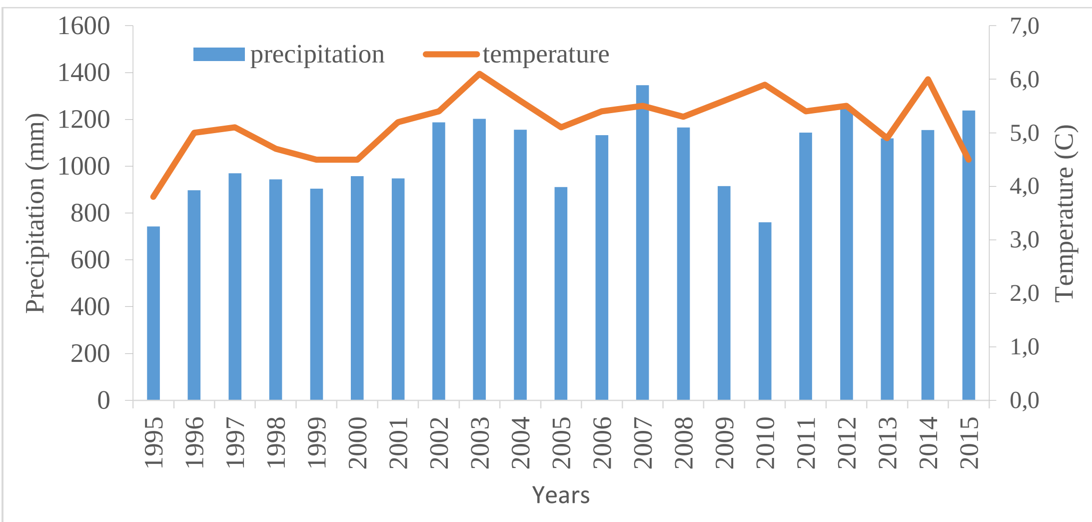

Figure 1. Mean annual precipitation and temperature measured at Korpa from 1995-2015 (based on data from Icelandic Meteorological Office)

The experiment was carried out on three different sites (Figs. 2, 3, 4 and 5), at Korpa Experimental Station. The land is relatively flat and has no slope. The three sites were:

1. The barley site (BAR) which had been ploughed yearly since 1995 and barley grown almost every year (18 out of 21 years). Tractors have been used to plough the field before cultivation and the ploughing depth was 17-20 cm. Two hundred kilograms of seed were used per hectare, seeded around May 1, although this ranged from April 20 to May 11 depending on the arrival of spring and weather conditions during the year. Inorganic fertilizer application at the time of seeding was 60 kg N- 25kg P- 40 kg K per hectare. The crop output was almost the same as the input even though this field was the most intensively cultivated site (J Hermannsson, 8 June 2016, Korpa Research Station, Agricultural University of Iceland, personal communication). Crop residues remaining after harvest were ploughed into the fields to enhance the fertility of the soil (J Hermannsson, 8 June

2016, Korpa Research Station, Agricultural University of Iceland, personal communication).

2. The grass site (GRASS) which was cultivated continuously for 15 years and has been closed and unploughed since 2000. When it was used for barley production, the cultivation practices, the time of seeding, amount of seed used, fertilizer application and crop output after harvest were similar to the barley site (J Hermannsson, 8 June 2016, Korpa Research Station, Agricultural University of Iceland, personal communication).

3. The shelterbelt site (BELT) which was planted with birch trees in 1975 and has never been fertilized since its establishment.

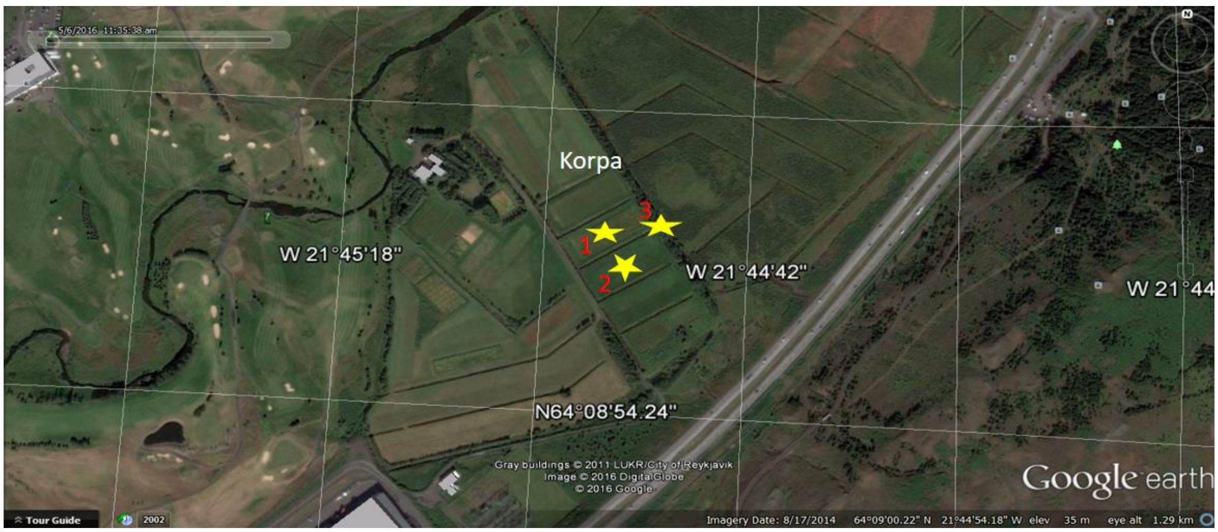

Figure 2. The three sites at Korpa (barley, grass and shelterbelt) indicated with stars 1, 2 and 3, respectively. (Source: Google Earth).


Figure 3. Soil sampling at the BAR site at Korpa (J. M Brenner, 8 June 2016).


Figure 4. Soil sampling at the GRASS site at Korpa (J. M Brenner, 8 June 2016)


Figure 5. Soil sampling at the BELT site at Korpa (J. M Brenner, 8 June 2016)

3.2 Soil sampling and analysis

The three sites were sampled at a depth of 0-10 cm. Each sampling site (BAR, GRASS and BELT) was broken down into 10 quadrats. Five quadrats within each site were chosen using a random number generator. Within each quadrat an X- and Y-coordinate was randomly generated and a 1m × 1m grid was randomly placed around the intersection point of the X- and Y-coordinate. One sample was taken from each corner and one taken from the centre within the grid and pooled into one composite sample, resulting in a total of 5 composites from each site. For bulk density, a 0.5m buffer zone was created outside the grid and one sample (not composite) was taken by pressing a metal cylinder into the soil and the cylinder was removed after extracting a sample of known volume, making a total of 5 samples at each site. In all a total of 30 samples were taken from the three sites: 15 composite samples for soil organic carbon, organic matter and soil morphology (5 composite samples from each site) and 15 individual bulk density samples for soil moisture and soil organic matter determination. Samples were stored in a refrigerator at 4°C until use.

The chemical and physical properties (organic matter, bulk density, moisture and texture analysis) of the soils were determined at the Agricultural University of Iceland Soil Laboratory at Keldnaholt, while soil carbon and nitrogen were analysed at the University of Iceland Soil Laboratory. Soil texture analysis was performed on field moist soils. The textural class of the soils was determined in the field by feeling the sand particles and estimating silt and clay content by flexibility and stickiness (Thien 1979). The soils, with the exception of the bulk density samples, were dried in heated cupboards at <40 °C until well dried. After drying, the samples were then crushed and sieved through 2 mm mesh to remove roots and gravel before being analysed.

For bulk density determination, the moist sample weight was recorded and samples were then dried in an oven at 105 °C, cooled in a desiccator and reweighed in the laboratory. The samples were sieved through a 2mm sieve to separate coarse (>2 mm) fragments from the fine earth fraction (<2 mm). The coarse fragments that were retained were weighed and the density of the rock fragments determined using water displacement to calculate the soil bulk (Grossman & Reinsch 2002).

Soil moisture was determined from the bulk density samples. The moist sample weight was recorded and the samples were placed into porcelain cups and dried in an oven at 105 °C for 16 hours, cooled in a desiccator, and reweighed (Rowell 1999).

Soil organic matter was determined by the loss on ignition (LOI) method. The samples were weighed into crucibles in duplicate and dried at 105 °C for 16 hours. After drying, the samples were weighed and then placed in a furnace at 550 °C for 6 hours. Samples were cooled in a desiccator and reweighed to give a mass of ignited soil. The mass lost by ignition was expressed relative to the mass of oven-dried soil (Rowell 1999).

To determine soil carbon and nitrogen analysis, the soil samples were oven-dried at 40 °C and crushed using a ball mill. The soil carbon and nitrogen were determined by catalytic combustion under excess oxygen supply using a ThermoScientific EA Flash 2000. For the purposes of this study all soil carbon was attributed to soil organic carbon.

3.3 Data analysis

All data were analysed using SAS version 9.4 (SAS 2014) and variance was determined through ANOVA. The results were subjected to Bartlett's test for equal variance for identification of applicable effects and the means were compared using the Tukey's studentized range test ($p < 0.05$). Box plots were used in the presentation of the distribution of all soil properties in order to illustrate the mean, median, minimum and maximum for all soil properties in the BAR, BELT and GRASS sites.

4 RESULTS

The soil textural class for the BELT site was loam, while both BAR and GRASS consisted of clay loam. The soil analytical parameter results for each of the land use types are presented in Table 1, and no significant difference was observed in the soil moisture, BD, OM, C, N and C:N ratio between the 3 land use types. There was a direct relationship between SOC and total nitrogen in terms of their increase with a mean C:N ratio of 14.02, 14.80 and 15.10 in the BAR, BELT and GRASS, respectively.

Table 1. Average values (mean±standard deviation) for soil %moisture, bulk density (BD), % organic matter (OM), % carbon (C), nitrogen (N) and C:N ratio.

Average in top soil (0-10cm)								
Land use type	Sample size	% Moisture	Texture	BD (g/cm^3)	% OM[a]	% C	% N	C:N
BAR	5	81.3±10.6	Clay loam	0.5±0.1	22.7±3.0	9.3±1.6	0.8±0.1	14.0±0.5
GRASS	5	82.4±5.4	Clay loam	0.4±0.1	26.1±5.4	12.5±3.5	1.0±0.4	15.1±1.1
BELT	5	90.2±6.0	Loam	0.4±0.1	26.0±3.8	12.0±3.6	0.9±0.2[b]	14.8±1.4

a: n=30 for % OM only and it was averaged for the 3 land use types
b: n=4 for % N only at the BELT site

4.1 Distribution of % C and related soil properties among land use types at Korpa

The distribution of soil carbon content and related soil properties among land use types are presented with box plots (Figs. 6, 7, 8, 9, 10 and 11). There was an outlier in the BELT site for soil moisture content and the GRASS sites for both nitrogen and C:N ratio contents in their respective box plots.

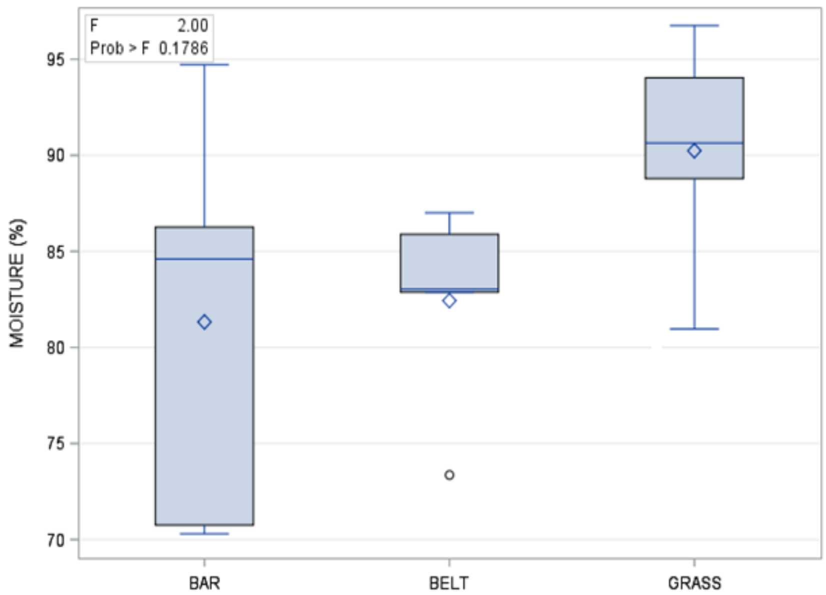

Figure 6. Boxplots showing the distribution of soil moisture among land use types. Horizontal lines and diamond shapes within the boxes give the median and mean respectively. Boxes represent 25% and 75% percentiles, whiskers represent the lowest and highest values of the data for each land use type, and the oval shape outside the whiskers represents an outlier.

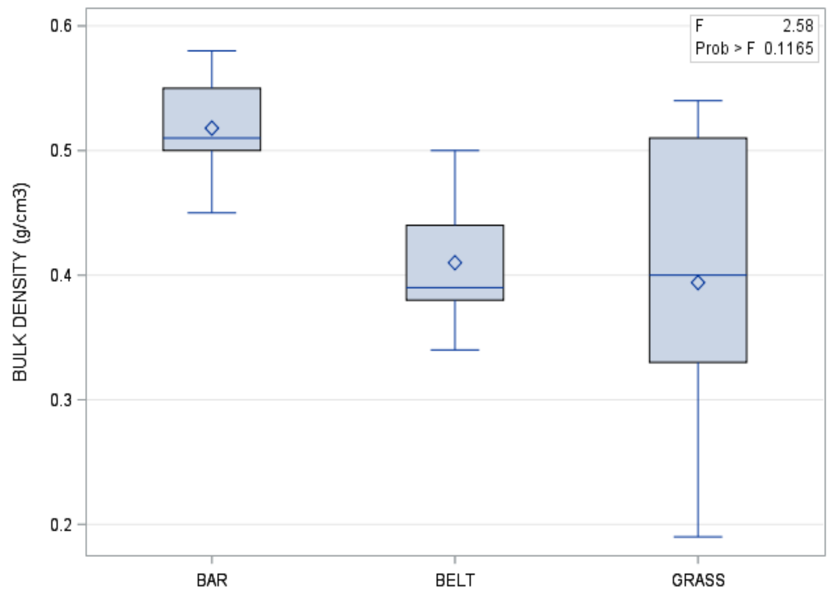

Figure 7. Boxplots showing the distribution of soil bulk density among land use types. Horizontal lines and diamond shapes within the boxes give the median and mean respectively. Boxes represent 25% and 75% percentiles, whiskers represent the lowest and highest values of the data for each land use type.

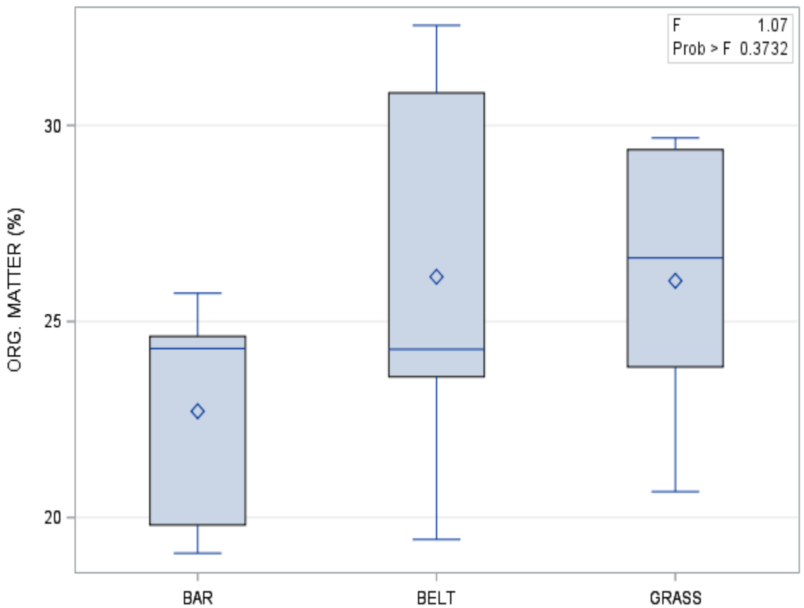

Figure 8. Boxplots showing the distribution of soil organic matter among land use types. Horizontal lines and diamond shapes within the boxes give the median and mean respectively. Boxes represent 25% and 75% percentiles, whiskers represent the lowest and highest values of the data for each land use type.

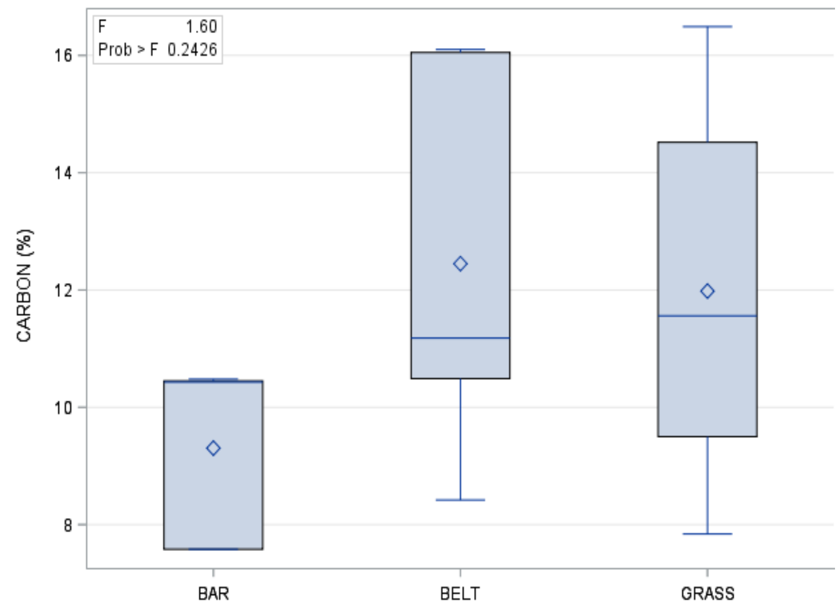

Figure 9. Boxplots showing the distribution of soil carbon among land use types. Horizontal lines and diamond shapes within the boxes give the median and mean respectively. Boxes represent 25% and 75% percentiles, whiskers represent the lowest and highest values of the data for each land use type.

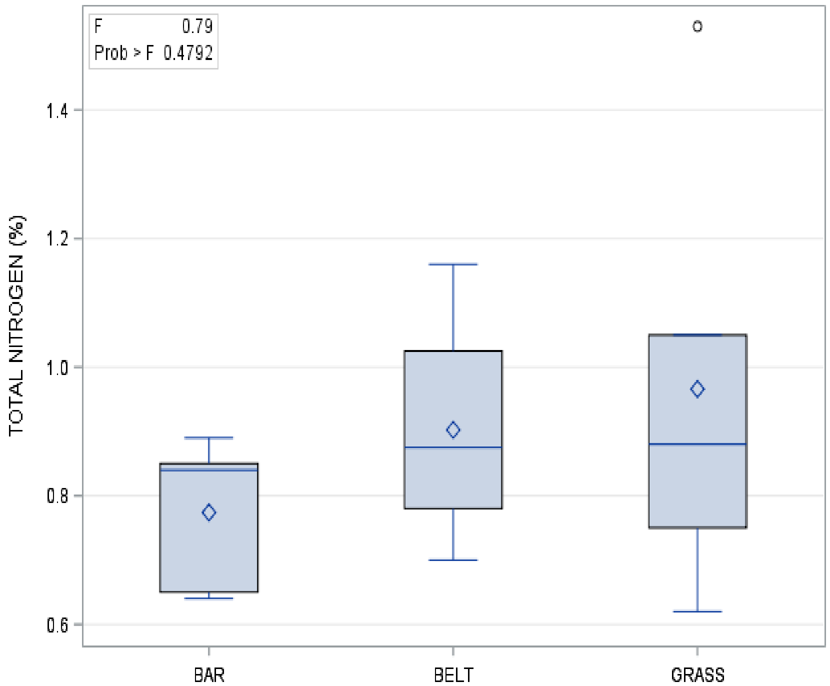

Figure 10. Boxplots showing the distribution of soil total nitrogen among land use types. Horizontal lines and diamond shapes within the boxes give the median and mean respectively. Boxes represent 25% and 75% percentiles, whiskers represent the lowest and highest values of the data for each land use type, and the oval shape outside the whiskers represents an outlier.

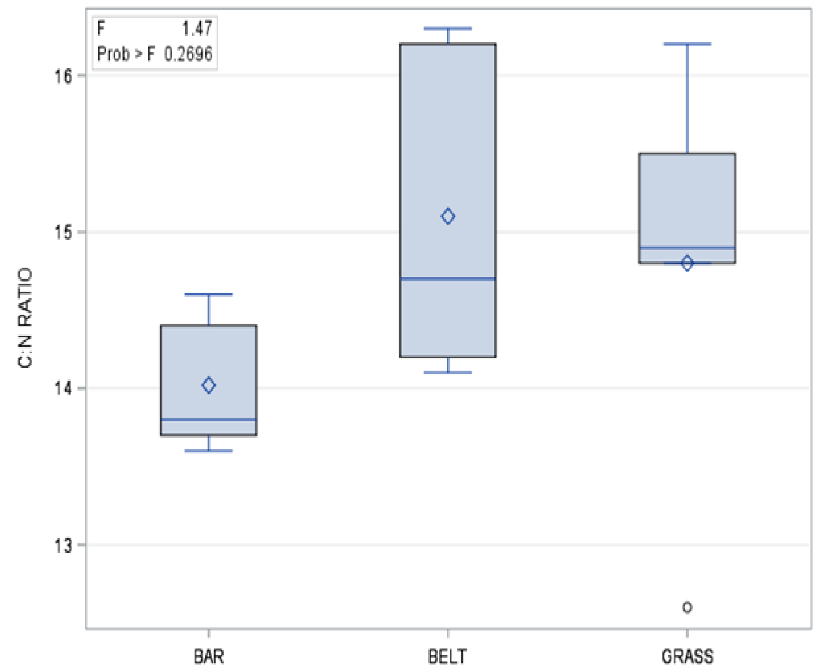

Figure 11. Boxplots showing the distribution of soil C: N ratio among land use types. Horizontal lines and diamond shapes within the boxes give the median and mean respectively. Boxes represent 25% and 75% percentiles, whiskers represent the lowest and highest values of the data for each land use type, and the oval shape outside the whiskers represents an outlier.

5 DISCUSSION

5.1 Soil organic carbon (SOC) and related soil properties as influenced by land use

The analysis of SOC and other related soil properties within the top 0-10 cm of the soil horizon seems to contradict the hypothesis that SOC and related properties are highly influenced by cultivation practices. The results showed no losses in SOC and related soil properties among the three sites. This can be attributed to conservative cultivation practices carried out on the BAR and GRASS sites. Although there was no significant difference between the sites, there was an emerging "trend" that could indicate lower SOC in the BAR sites. If this study is measured again after 10 years, there might be a significant difference, given the same land use.

The present study has demonstrated the soil carbon levels characteristic of Gleyic Andosols (<12%) as reported by Arnalds (2004). The maintenance of organic carbon can be attributed to the generation and accumulation of biomass following the application of fertilizer and the incorporation of plant residues after crop production. The slowed decay may be due to the volcanic origin of materials, which include organic content and allophane, and is resinous to soil masses, thus enhancing the build-up of organic materials (Nanzyo et al. 1993). Additionally, the gleyic nature of the soil creates a condition where the cold climate and absence of oxygen enhance soil organic matter accumulation (Gudmundsson T et al. 2004).

The texture of the sites provides the basis for how to relate SOC and SOM to bulk density in soil quality assessment. Ploughing can result in fragmentation of soil clumps in cultivated lands (Davidson & Ackerman 1993), causing a rise in bulk density. The present study found no increase in bulk density levels of the soil. The soil texture of the three land use types confirmed that there was less sand fraction in the soil compared with the clay content, leading to soils with good SOC and low bulk density (Feller et al. 2001; Davidson & Ackerman 1993). This conforms to the assertion by Lal & Kimble (2001) that soil organic carbon intrinsically has low bulk density and therefore SOC accumulation affects soil bulk density. A decrease in bulk density also confirmed why there was a huge increase in soil organic matter levels among the land use types in this study (Table 1).

5.2 Land use effects on soil fertility in temperate and tropical climates

Based on various conditions (climate, soil type, vegetation and conservative cultivation practices) in the present study, the SOM has been maintained. This has a direct effect on soil quality in terms of SOM decline as reported by Ogle et al. (2005). There has been less pressure on population and land in the study area, which make land available for good cultivation practices, such as crop rotation and improved fallowing, in addition to fertilization. However, higher temperatures in Africa, such as in Ghana (29.8- 37.9^{o}C) (Bonsu et al. 2008), along with other factors, interact to stimulate quick decay of SOC influencing the SOC content of the soil. Continuous cropping with little-to-no fertilization, as a result of the high cost of inorganic fertilizers, coupled with yearly destruction of plant life by fire, especially where the existing biomass is burned and grazed as well, leads to persistent fertility loss (Pieri 1989; Kang 1997; Shepherd & Soule 1998). Such systems inhibit SOC storage in tropical soils and are considered unsustainable.

5.3 C:N ratio and total nitrogen in relation to soil fertility

The C:N ratio for all three sites investigated suggested that both C and N have increased proportionally. The inference is that N has increased by the same margin in terms of percentage as C. The C:N ratio is generally within the range of the arable surface horizon (8:1 to 15:1) (Brady & Weil 2013). There was little variation occurring within the C:N ratio for the similar land use types in this study (Table 1). A high C:N ratio (>20:1) means the decay of biomass can be obstructed if abundant nitrogen is not available in the soil, rendering the soil less fertile. However, our findings indicate that the soil had a greater capacity to bind N in the organic matter. This can be attributed to sustainable cultivation practices such as the regular application of N fertilizers as well as the incorporation of organic residues (Lou et al. 2012; Xu et al. 2011).

5.4 Sustainable land management practices identified in the Ghanaian context

There are multiple advantages associated with simple manageable farming practices (use of compost, manure, crop residue, etc.), which improve soil quality, in terms of fertility regeneration and cost. The poor subsistence farmers in Ghana can blend the current and less complicated techniques with their conventional farming practices for the purposes of soil fertility improvement on cultivated lands.

The modification of the conventional system of land use management and the implementation of conservative cultivation applications are crucial areas to examine in Ghana (Abayie Boateng 1998; Ntiamoa-Baidu 1995; Gyasi 1997). In the past, poor subsistence farmers producing food crops in the middle belt of Ghana depended largely on fallowing for soil fertility conservation in terms of managing their land (Nye & Stephens 1962). This practice enabled phosphorus and nitrogen (highly deficient nutrients) to be refurbished. However, population growth has resulted in scarcity of ideal farmland leading to less "extra" land that can be placed aside and left untouched for a season; all available land is being utilized.

In order to maintain and enhance the soil fertility of tropical soils, there is a need to incorporate the practice of blending organic and inorganic resources into the soil through the use of fertilizer, compost, plant and animal manure, plant residue, etc. (Gudmundsson et al. 2004). The government should subsidize inorganic fertilizers in order to enable poor subsistence farmers to buy and apply enough on their farmlands. Organic residues (e.g. compost, green waste, manure, etc.) can also be gathered and kept for use by farmers during the farming season. The basic properties of the soil essential for cultivation should be improved to control land degradation as a result of erosion, for example changing from a monoculture to multiple crop rotation, increasing remnant retention, and minimizing soil disruption by no-tillage practices (West & Post 2002; Deen & Kataki 2003). Further, fallow land should be replanted with fast spreading leguminous tree types instead of allowing it to restore naturally. Minimizing soil disruption by reduced tilling should be utilized to improve the storage of carbon in cultivated lands. The formation of shelterbelts should be endorsed as agroforestry practices (Bonsu 2007). There is also the need for poor subsistence farmers to conform to bylaws governing land use as far as soil fertility restoration is concerned.

Positive participatory attitudes to project execution and management are likely to warrant a fruitful outcome, as poor subsistence farmers undertake practices that sequester soil organic carbon in their fields. Using humans as a resource, especially involving all stakeholders, would help facilitate the circulation of information, active involvement and all-inclusiveness, especially among subsistence poor farmers in Ghana, if African governments are ready to enact and enforce policies and measures on sustainable restoration processes to ensure and increase soil fertility and food production by farmers.

6 CONCLUSIONS

According to this study, there was no significant difference in soil organic carbon, soil organic matter, the C:N ratio, bulk density and soil moisture among the land use types, therefore demonstrating that soil type, vegetation and conservative cultivation practices in the study area maintain soil fertility. This is in direct contrast to the expectations of the usual tropical (Ghana) land use system where higher temperatures and human activities (e.g. continuous cropping with little-to-no fertilization) have negatively influenced soil properties and fertility.

Based on the results of this experiment, it is recommended that further studies after a long period (10-15 years) would be needed to comprehend the interactive roles of cultivation practices (e.g. farming systems and fertilization) and environmental factors (e.g. climate and vegetation) in controlling soil carbon storage, in addition to the physical parameters (e.g. infiltration and soil consistency) of the soil in the study area. In order to improve food security and carbon storage in tropical soils, such as in Ghana, the following practices are recommended:

- Implementation and enforcement of policy which prevents the yearly destruction of plant life by fire and overgrazing
- Incorporation of crop residues into the soil after cultivation should be encouraged to enhance soil organic carbon storage
- Improved fallow systems, whereby nitrogen fixing plants like *Mucuna* and *callopogonium* are grown when the farmer allows the land to rebuild its fertility after some periods of continuous cropping
- The cultivation of erodible land should be stopped and placed under permanent forests

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