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SOIL AND LAND USE EVALUATION FOR SUSTAINABLE AGRICULTURE IN THE FOREST SAVANNAH TRANSITION ZONE OF GHANA

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ABSTRACT

The conversion from natural to agricultural lands by smallholder farmers affects soil nutrient status. A variety of traditional farming systems are being used in the Ejura-Sekyedumase District in response to rapid population growth. The main goal of this study was to investigate differences in soil nutrients of the different land use types within Ejura-Sekyeredumasi in order to enhance knowledge to improve rural income and food self-sufficiency. Soil samples were divided into three landuse types; forested land (non-cultivated), savannah regrowth (fallow) and cultivated land (arable). A variety of soil parameters were analysed from a total of 68 sites, divided into several depth intervals. The forest reserve recorded the highest averages for soil carbon, total nitrogen, soil pH, base saturation and carbon stocks, followed by savannah regrowth, but lowest in the cultivated land. Total carbon stocks within the three land use types were 10.05, 6.75, and 5.89 kg/m^2 for the forest reserve, savannah regrowth and cultivated land respectively. The cultivated land was the most degraded in terms of soil nutrient depletion with a Degradation Index of 53.42%, followed by the savannah regrowth with 64.86%. Conversion from forest to agricultural land and the adoption of rudimentary methods by smallholder farmers has depleted soil nutrients in the study area by about half.

Keywords: Land use, sustainable agriculture, soil organic carbon, soil fertility and smallholder farmer.

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1. INTRODUCTION

Methods that are used to grow and raise animals were developed in the Middle East about 10,000 years ago (Miller 2002). These farming systems gradually spread across the world (Buringh 1989). Rapid population increase has caused extraordinary changes in land use during the last few decades, which has resulted in increasing loss of soil carbon through agronomic activities (Davidson & Ackerman 1993).

Soils are fundamental to life on earth (Brady & Weil 1996). Soil organic matter is a critical component of any soil-plant ecosystem and it changes with land use management practices (Ghani et al. 2003). Soil management, including the decision to convert land from natural vegetation to agricultural use, can produce significant changes in soil organic matter status (Szajdak & Maryganova 2009). Soil organic carbon (SOC) content is an essential component affecting soil quality (Doran et al. 1994). The impact of SOC on soil fertility includes the ability to hold and slowly release nutrients to plants during and after decomposition. Several studies in the 1990s indicated that soil fertility decline is a problem in most tropical countries (Hartemink 1997; Brand & Pfund 1998; Folmer et al. 1998; Henao & Baanante 1999; Omotayo & Chukwuka 2009).

In Ghana, continuous cropping has led to soil fertility decline. This has resulted in the application of fertilizers to increase crop yields. However, it was estimated by MOFA (2010) that only 7.42 kg/ha per year was used in Ghana. This is the lowest fertilizer application in Sub-Saharan Africa. The reason for such limited use can be traced to the removal of government subsidies on the prices of fertilizers as a result of the abolishment of the structural adjustment policies in the early 1990s (Gerner et al. 1995; Bekunda et al. 2010). This situation therefore suggests the need to identify sustainable land use strategies that allow continuous cultivation while overcoming soil fertility decline on smallholder farms in Ghana and Sub – Saharan Africa.

1.1 Problem statement

The major cause of declining soil quality is inappropriate land use. Anthropogenic activities such as unsustainable agricultural practices, overgrazing, overharvesting of fuel–wood, uncontrolled bush fires, reduction in length of fallow period and settlement expansion, have led to land degradation with its attendant negative effects on soil quality and crop productivity in Sub-Saharan Africa (Nandwa 2001; Bationo et al. 2007, Bekunda et al. 2010). This pressure is mainly brought about due to increased population pressure. In Ghana, the situation is similar. Agriculture is the main economic activity and employs over sixty percent (60%) of the rural population and declining soil productivity in cultivated lands means not only is less food grown, but also production of cash crops and income are adversely affected (MOFA - Ghana 2010).

Land degradation together with desertification is a growing threat on Earth. It is manifested by soil erosion, loss of vegetation cover, loss of biodiversity, breakdown of natural ecosystems and other such manifestations which mean adverse changes in the natural environment. In Ghana, according to Gyasi et al. (2011), 23% of the land is prone to very severe sheet and gully erosion, 46% to severe erosion and 31% to moderate to slight erosion. Soil erosion is common in areas of extensive vegetation removal in all the major ecological zones: forest, savannah, and forest-savannah mosaic zones (Gyasi et al. 2006). Furthermore, rampant bush fires cause significant damage in all the ecological zones. It is noticeable in the savannah, where the bush is burned to hunt for bush meat and to clear the land for farming (Nsiah – Gyabaah 1996; GNADO 2004).

In order to improve soil quality long fallow periods have been used by farmers. However, with increasing population and scarcity of land, fallow periods have been reduced considerably, while cultivation of marginal lands has increased (Henao and Baanante 2006; Omotayo and Chukwuka 2009). Furthermore, urban migration, particularly from the vulnerable regions of Northern Ghana, to the Ashanti region in search of greener pastures has increased pressure on Ashanti land. This is particularly manifested in areas where there are extensive farming practices of which the Forest Savannah Transition Zone (FSTZ) is no exception. Figure 1 illustrates the relationship between population growth and land degradation.

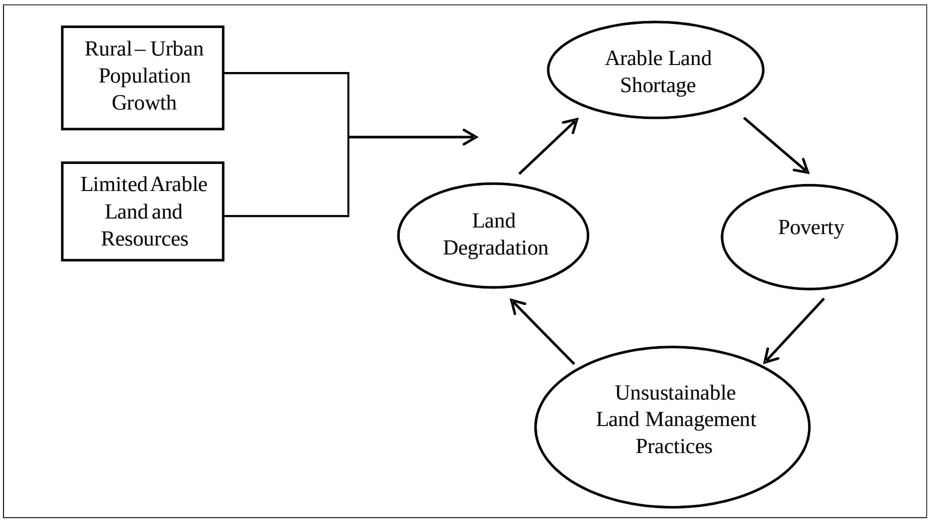

Fig. 1. *Conceptual framework illustrating the associated relationship between land use, population growth, poverty and land degradation. (Source: Mbagwu, 2003).*

Maintaining quality of tropical soils has become a constant challenge for smallholder farmers and agronomists due to poor management and the fragile nature (physio-climatic factors) of these soils, which can lead to rapid loss of nutrients through erosion and leaching (Hossner & Juo 1999; Omotayo & Chukwuka 2009). Soils in most parts of Ghana are inherently low in fertility and do not receive adequate nutrient replenishment (Bationo et al. 2007; Fening et al. 2009) and Ejura - Sekyedumase is not an exception.

The increasing population of the study area has resulted in encroachment on forest and other marginal lands and their conversion into cultivated lands in order to increase food production. The depletion of soil nutrients is reflected in the continued decline in crop yield on these farm lands (cultivated lands). Annual yields are relatively low despite the high potential for improvement; hence Sub - Saharan Africa (SSA) is the only region in the world where food production has been stagnant over the last 40 years although population has strongly increased (Sanchez 2002).

1.2 Objectives of the study

The main goal of the study was to investigate differences in soils of the different land uses within the Ejura-Sekyeredumase area in Ghana. The information gained is aimed to provide background information to help improve rural income and food self-sufficiency through improved techniques.

The main objectives of this study were to:

i. Determine soil fertility decline in Ejura-Sekyedumasi District (FSTZ),
ii. Identify the various forms of soil fertility decline,
iii. Explore measures to mitigate soil fertility decline,
iv. Recommend land - use management strategies to sustain crop production.

The key research aim was:

i. To investigate differences in key soil parameters in soils of the Ejura-Sekyeredumasi district under three different land use types: forest reserve, cultivated land and savannah regrowth.

These soil parameters were % carbon, total nitrogen, soil pH, C:N ratio, bulk density, cation exchange capacity, base saturation, potassium, phosphorus and total carbon stocks.

2. LITERATURE REVIEW

The first part of the literature review focuses on the various types of land degradation and land use options in Ghana. The review also highlights constraints and possible solutions to the major agro-ecological zones and the importance of holistic and participatory approaches for soil management and productivity improvement issues in Ghana.

2.1 Soils

Soils are often divided into four important major components: mineral solids, water, air and organic matter. When mineral and organic particles clump together, aggregates are formed creating pore space which helps to store water and enhancing gas exchange as oxygen enters for the use of plant roots and soil organisms (Magdoff and Van Es 2009). A soil suitable for agriculture is a porous soil. Some soils are exceptionally good for growing crops while others are inherently unsuitable; most are in between.

Most soils have limitations, such as low organic matter content, texture extremes, poor drainage, or layers that restrict root growth (Bekunda 2010). Recent research findings stress that the combined use of mineral and organic fertilizers (recycling rice straw, crop residues, compost and manure) helps in restoring soil nutrients on smallholder farms (Fening et al. 2005; Hasegawa et al. 2005; Yan et al. 2007).

Farming activities by small scale farmers are often the most destructive form of land use. These traditional farming systems cause harm to vegetation and soils after a few years of cultivation by depleting soil nutrients with negative effects on soil micro-organisms (Pimentel et al. 1995; Sanchez et al. 1997). Also, the lower infiltration capacity of degraded soils reduces the amount of water that is available to plants and increases run off.

2.2 Land use management strategies

Agricultural soils usually contain less organic matter and other nutrients as compared to soils of the same type with little or no human interference (Brady and Weil 1996). Management of land affects soils and its functions. The introduction of various forms of land use to improve soil fertility and the adoption of simple agricultural practices affects food production. These practices include low tillage, crop rotation, and utilization of fallow periods, the use of cover crops and the introduction of organic amendments (Omotayo & Chukwuka 2009).

Tillage is necessary for land preparation and when reduced to a minimum, improves soil structure, aeration and the breakdown of organic materials, making it available to plants (Brady & Weil 1996). Crop rotation is often important in soil management practices due to the effect it has on pest control (Peoples & Craswell 1992; Giller & Cadisch 1995). The introduction of crop rotation with cereals (maize), legumes (soybean, cowpea, and groundnut) and root tubers (cassava) are essential in soil nutrient management and thus helps restore soil organic matter and improve soil physical structure (Peoples & Craswell 1992).

Grain legumes in rotation assist farmers to increase food production and to improve the amount and quality of crop residues annually (Giller & Cadisch 1995). Rotating cereals with grain legumes provides different environments for different soil micro-organisms which in turn directly affects biodiversity and crop residue left on farmlands after harvesting. Crop residues protect the soil from water erosion and high temperatures (Mogdoff and Van Es 2009).

Organic amendments such as manure, compost and the introduction of cover crops sustain soil nutrient levels for plants. Manure and compost contain nutrients such as nitrogen and phosphorus (Bationo and Buerkert 2001). The quality of compost can be improved by adding tithonia, phosphate and fresh manure during composting which lower the carbon: nitrogen ratio, which in turn increases the rate of decomposition by soil microbes (Misra et al. 2003).

Furthermore, farmers have knowledge of the challenges associated with soil fertility (Mairura et al. 2007). However, the depletion of soil resources occurs as a result of the traditional slash and burn methods of land preparation, including reduction in fallow periods (Makokha et al. 1999). The introduction of nutrient management strategies such as matching nutrients available in the soil to plant requirements, erosion prevention, and restriction of tractor movement on farms to decrease compaction, intercropping with legumes, introduction of cover crops, and the use of organic and mineral fertilizers (Nandwa 2001) can improve yield. Finally, there is the need to distribute information about how to improve soil fertility to farmers and the society.

2.3 Soil organic carbon as an indicator of soil fertility

Soil organic carbon (SOC) is the carbon associated with soil organic matter (SOM). Soil organic matter is the essence of a fertile and productive agricultural soil. It is made up of living and dead plants and animals. The process and rate of decomposition of organic matter depends on factors such as soil temperature, soil moisture, aeration, and soil pH. Larson and Pierce (1994) states that SOM improves soil structure and drainage, holds soil moisture, improves aeration and provides nutrients to plants as well as being an important contributor to cation exchange capacity (CEC). In the tropics, the warm and wet climatic patterns increases the rate of organic matter breakdown (Baker et al. 2001; Alhamd, et al 2004).

Biologically, soil organic carbon affects a diverse microbial community which leads to greater biological control of plant diseases and pests (Rice et al. 2007). It also serves as a buffer against harmful chemical substances and their effects on plants, animals and humans (Lal 2004). Furthermore, soil organic carbon controls various environmental processes (see Fig. 2) governing the formation of soil-based environmental services (Vanlauwe 2004).

Fig. 2. *Importance of organic carbon to soil. (Source: Rice et al. 2007)*

2.4 Soil organic carbon as sink for atmospheric carbon

The activities of man since the 1750s have resulted in the release of carbon dioxide into the atmosphere through fossil fuel burning and land use change. Intensive tillage of agricultural soils has led to substantial losses of soil C which is estimated as 30% to 50% of soil organic carbon (Davidson & Ackerman 1993). Carbon loss from soils has increased the amount of carbon dioxide in the atmosphere, amplifying global warming and climate change.

SOC forms part of the natural carbon cycle. It is the largest terrestrial carbon pool and holds twice the amount of carbon in the atmosphere and the vegetation. The estimated amount of organic C stored in world soils is about 1100 to 1600 petagrams (Pg), more than twice the C in living vegetation (560 Pg) or in the atmosphere (750 Pg) (Sundquist 1993). Increasing the levels in soils for a long time would assist in reducing greenhouse gas levels in the atmosphere, thus helping to reduce global warming and climate change.

3. METHODOLOGY AND PLANNING

3.1 Ecological zones of Ghana

Ghana lies along the Gulf of Guinea in West Africa, between 4° and 12°N latitude and 4°W and 2°E longitude. It covers an area of 238,500 km^2. Half of the country lies below 152 meters of elevation and the highest point is 883 meters (Mount Afadjato) and is found in the

Akwapim-Togo Ranges in the Volta Region. The 537 km coastline is mostly a low, sandy shore with plains and scrub and connected by several rivers and streams, most of which are navigable only by canoe.

The climate is tropical. Ghana is divided into three broad ecological zones; forest, forest-savannah transition and savannah zones. These zones are subdivided into the coastal savannah, rainforest, semi-deciduous forest, forest-savannah transition, Guinea savannah and the Sudan savannah. In between the forest and the savannah zones lies the forest-savannah transition zone, which is a blend of the forest and savannah zones. Figure 3 illustrates the study area in the transition zone.

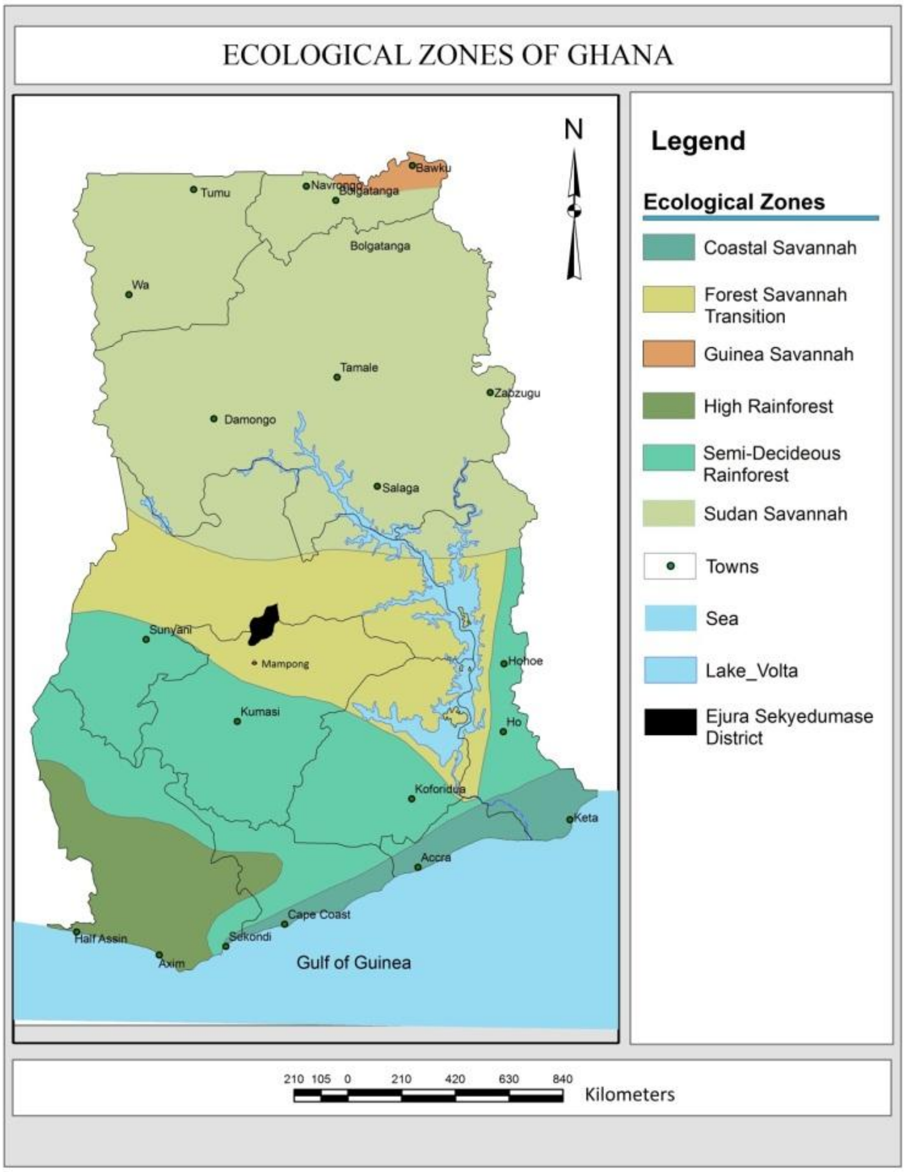

***Fig. 3.** Ejura Sekyeredumasi is located in the forest savannah transition zone on the map.*

3.2 Ejura-Sekyedumasi District: Location and size

The Ejura-Sekyedumasi district is located in the Ashanti region within 1° 5´ W and 1° 39´ W longitude and 7° 9´ N and 7° 36´ N latitude. It is about 1,782.2 km^2 of which 1,335 km^2 is arable. The district had a population of 60,997 (1984), 81,115 (2000) and about 101,826 in 2010 (Ghana Statistical Services 2010).

3.3. Climate

According to Dickson and Benneh (1988), the climate in Ghana is controlled predominantly by the tropical continental air mass (the north-east trade winds) and the tropical maritime air mass (south-west monsoon winds). The variation in seasons experienced in Ghana is a result of the movement and position of the Inter-Tropical Convergence Zone (ITCZ) between the two air masses (Folly 1997). Figure 4 illustrates the monthly rainfall and temperature distribution at Ejura Sekyeredumasi. Rainfall and temperature data on Mampong, which is the closest meteorological station, were used to represent the rainfall and temperature pattern in the study area.

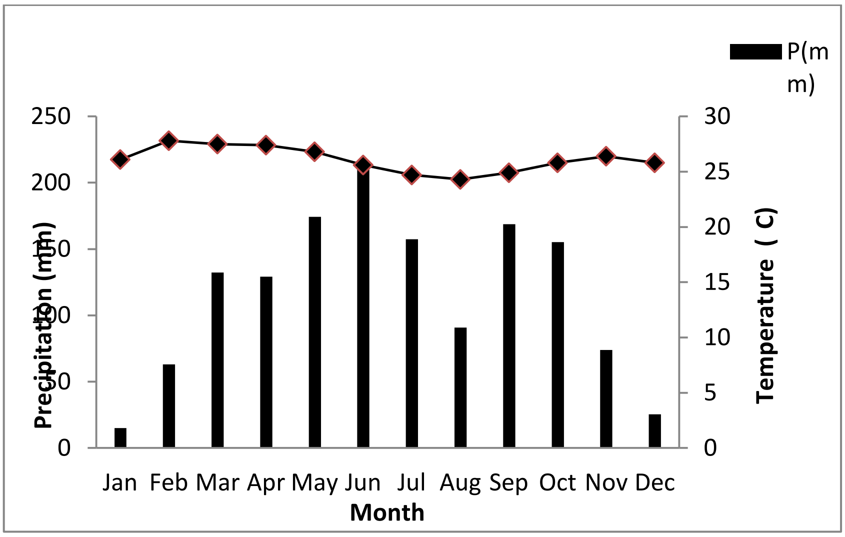

Fig. 4. *Mean monthly precipitation and temperature measured at Mampong climate station, 1961-1999 (based on data from Ghana Meteorological Services Department 2000).*

Ejura, which lies within the transitional ecological zone between the Guinea Savannah to the north, which is characterized by a single rainy season, and the forest vegetation to the south, characterized by two rainy seasons. The study area experiences the equatorial climatic regime, hence the tropical monsoon climate (Am) according to the Koppen Classification (Koppen Climate Classification, as cited in Complete Dictionary of Scientific Biography 2007).

Annual rainfall varies between 1200 mm and 1700 mm. The rainfall pattern is bimodal, characterized by two rainy seasons, which are separated by two dry seasons. The main rainy season starts from mid-March to mid-July with a peak rainfall in June. The minor rainy season starts in the middle of September and lasts to the end of November. August experiences a minor dry season (Fig. 4). The long major dry season occurs from November until the end of March or mid-April.

During the main dry season there is often a severe drought characterized by the withering Hamattan wind which blows in from the north. Most plants shed their leaves and rivers and streams dry up completely or shrink into intermittent pools. Some months of this period are noted for little or no rain and bushfires become widespread. The beginning and the end of the rainfall seasons varies and great differences exist in the total monthly and annual rainfall amount. These uncertainties are factors that influence the activities of farming (Smith 1962; Adu & Mensah-Ansah 1995).

Temperatures within the area are high throughout the year with a yearly average of around 33°C maximum and 20.2°C minimum (Kasei 1993). The mean monthly temperatures are highest in February, March and April. The lowest mean monthly temperatures occur in August, while the lowest recorded minimum temperatures occur in the nights of December and January during the Hamattan periods (Dickson & Benneh 1988).

Relative humidity across the country decreases northwards. During the wet months of June to September, mean monthly figures may be around 80% at mid - days and are lowest in the Hamattan months with recordings of about 70% in the mornings and 40% at mid-day (Walker 1962; Dickson & Benneh 1988).

3.4. Geology and soils

The project area falls within the Voltaian Sandstone Basin with the underlying geology consisting entirely of sedimentary rocks, mainly fine-grained sandstone which is massive, thin-bedded, flaggy, impure, ferruginous and locally interbedded with shale and mudstone. These sedimentary formations are of Devonian or early Carboniferous age (Junner & Hirst 1946). The Voltaian formation covers about 45 percent of the country (Smith 1962).

Figure 5 illustrates soils found in the Volta Basin of Ghana. These are predominantly acrisols, fluvisols, gleysols, leptosols, lixisols, luvisols, and plinthosols (FAO-WRB Classification; IUSS working group WRB 2006).

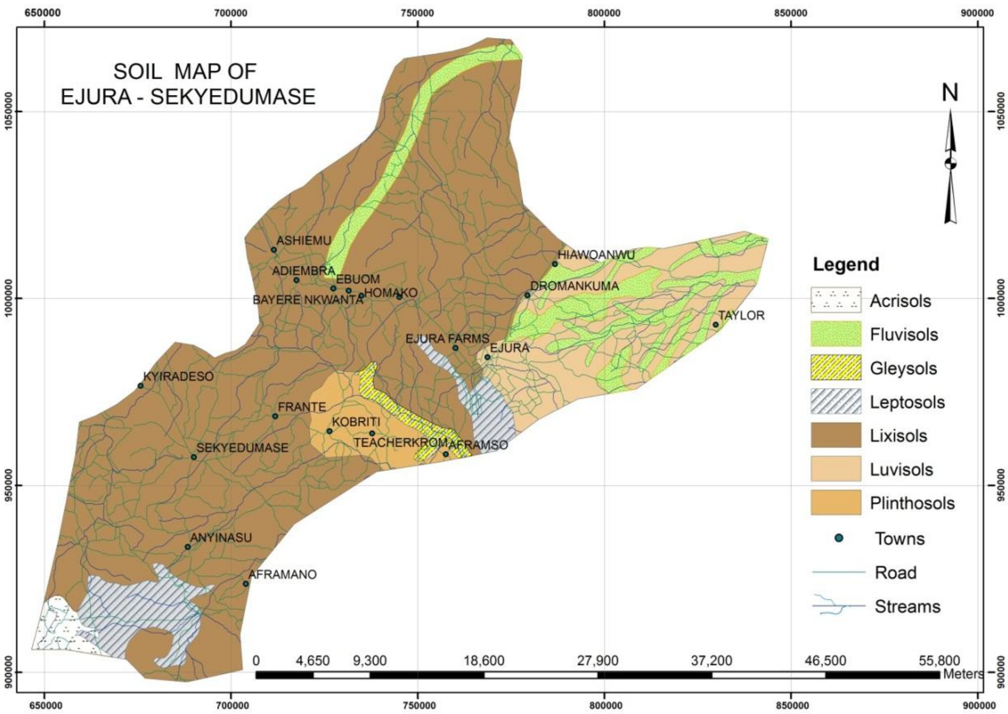

***Fig. 5** The soil map of Ejura Sekyedumase District. (Source: authors own map built on data from Soil Research Institute – Kumasi, Ghana with reference to FAO/WRB Soil Classification System).*

The soils, formed from the Voltaian sediment, vary widely in terms of soil texture and productivity but generally have low inherent soil fertility compared to the granite derived soils. Different hydrological conditions along the slopes have led to the development of different soils from upland to lowland, resulting in various soil associations (such as kpelesawgu-changnalili association, damongo-murugu, bediase-sutawa and ejura-sene soil associations) in the study area (Adu and Mensah-Ansah 1995).

These soils are generally well drained, deep, light in colour, well aerated and rich in organic matter. They have a high water retention capacity which makes it easy for food and cash crop production. Soil erosion is frequent and continuous cropping, using unsuitable soil management techniques, has resulted in depletion of the soils and the resultant reduction in the soil.

3.5. Relief and drainage

The project area is undulating with valleys and peaks in the southern part of the district which ranges between 135 m in the valleys to about 315 m. The northern part is fairly undulating and fairly flat with heights ranging from 150-300 m. Ejura, which is the district capital, is located at an altitude of about 225 m (Smith 1962). The district is well drained by a number of rivers and streams with their tributaries forming a dendritic drainage pattern which has a west-east and north-west – south-east directional flow. Yaya, Baba, Chirade, Afram and Akobaa are some major rivers in the district. During the peak of the rainy seasons in June and July and in September and October, the low lying areas may be waterlogged.

3.6. Vegetation and land use

The natural vegetation is classified as Guinea Savannah Woodland. It consists of deciduous, fire-resistant trees, often widely spaced, and a ground flora made of different species of grasses of varying heights (Taylor 1952). The original vegetation has been degraded through intensive human activities such as fuel wood harvesting, charcoal production, agriculture, settlement, lumbering and annual bush fires, which have resulted in little of the original climax vegetation remaining. The major tree species within the project area and its environs include *Butyrospermum parkii, Borassus aetiopum, Parkia clappertoniana, Anogeissus leiocarpus, Afzelia africana, Lophira alata.* The main grass species, as described by Brand and Brammer (1956), are *Andropogon gayanus, Pennisetum purpureum, Imperata cylindrica.*

The high population of Ejura and its environs has subjected the area to intensive agriculture and other uses for decades (see Fig. 6). The growth of the savannah vegetation is largely a result of the increase in shifting cultivation and bush fallowing. The majority of farmers practise the traditional slash and burn method of land preparation, which has led to an increase in soil erosion and leaching of soil nutrients. Charcoal production is a major activity which has resulted in the logging of trees in the area. Game hunting and fishing in the streams of the study area are also important.

The climatic condition of the district, together with the general topography of the region, provide favourable conditions for the cultivation of food crops such as maize (*Zea mays*), cassava (*Manihot esculenta*), yams (*Dioscorea spp*), sorghum (*Sorghum bicolor*), cashew (*Anacardium occidentale*), mango (*Mangifera indica*), vegetables (such as pepper and tomatoes, okro, etc.) and legumes such as groundnut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*).

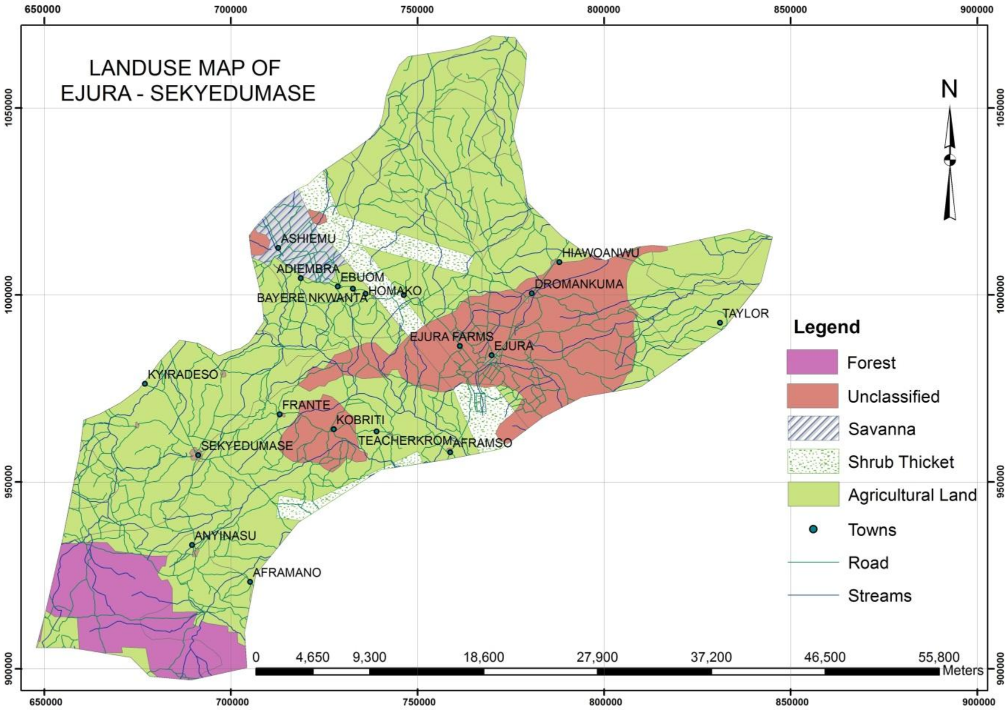

Fig. 6 *Land use map of the district.* ***(****Source: authors own map built on data from Soil Research Institute, Kumasi – Ghana and Centre for Remote Sensing and Geographic Information Systems - University of Ghana, Legon).*

3.7. Soil sampling and analysis

Soil samples were obtained from 68 sites. For each site, land use type was identified. Table 1 shows the land use types. Soil samples at each location were sampled using an auger along the catena spanning from the summit to the valley. At examination points, soil cores (5cm diameter) were taken to identify and describe soil type. Soil depth, texture, drainage and coarse fragments (gravel and stones) were parameters considered in the field to characterize soil types according to the local classification system. The soils were also classifield based on the FAO classification (FAO-WRB Classification; IUSS Working Group WRB 2006). Information about vegetation, climate and land use was also considered in the field.

Table 1. *Land use types identified in the study area.*

Land Use Type	Number of Soil Sites	Mean Depth of soil samples(cm)
Forest Reserve	20	170
Cultivated Land	24	208
Savannah Regrowth	24	228

GPS co-ordinates were taken at each observation point. This assisted in mapping the distribution of the different soil types identified (Table 2). A digital soil map of the area, obtained from CSIR-Soil Research Institute, was overlaid on the data collected with GPS to check the accuracy of the identified soil types using ArcGIS 10 software. Soil samples taken to the lab were air dried and sieved (2mm) and analysed for soil pH, organic carbon, total nitrogen, carbon:nitrogen ratio, bulk density, cation exchange capacity and available phosphorus and potassium.

Table 2. *Soil distribution in the Ejura Sekyedumasi District with reference to the FAO/WRB 2006 classification.*

Soil Series (FAO Classification)	**Area (km^2)**	**Area (%)**
Acrisols	22.9	1.3
Fluvisols	156.0	8.8
Gleysols	22.9	1.3
Leptosols	104.5	5.9
Lixisols	1213.6	68.3
Luvisols	190.4	10.7
Nitisol	1.8	0.1
Plinthosols	68.4	3.8
Total	**1780.44**	**100**

Soil reaction (pH) was determined by glass electrode and pH meter (Thomas 1996), total nitogen (N) determined using the rapid dichromate oxidation method (Walkley and Black 1934), soil bulk density (BD g/cm^3) was determined with the core method (Blake & Hartage 1986), available phosphorus (P) determined colorimetrically after extraction with Bray's P1 solution (Bray 1945), available potassium (K) by flame photometry after extraction with Bray's P1 solution (Bray 1945), and cation exchange capacity (CEC) was determined by ion extraction with ammonium acetate solution and subsequent determination of the extracted cations (Thomas 1982).

Soil organic carbon (SOC) was determined with Walkley and Black's wet combustion method as described by Jackson (1973). Base saturation (% BS) was determined as the ratio of basic cations in CEC. A weighted average was calculated for the top 20 cm for soil pH, N, %C, BD, BS, CEC, P, and K. Total carbon stocks (kg/m^2) based on the IPCC (2003) method were calculated for each profile and with the assumption that there were no coarse fragments (>2mm). The Degradation Index for carbon for each land use type was also determined using the forest reserve soils as a reference. Statistically, data were analysed using Microsoft Excel and R statistical software.

4. RESULTS

The results for soil parameters for each of the land use types are presented in Tables 3a and 3b. The numbers are averages for the top 20 cm of soils (weighted average). There is a marked difference in pH between land use types with pH being highest in the forest soils (6.4) but lower in the cultivated (5.8) and savannah soils (5.9). Organic carbon followed a similar trend from 0.9 to 1.1 and 1.7 in the cultivated land compared to savannah regrowth and the forest reserve respectively. Total nitrogen measured as; 0.1, 0.1 and 0.2 in cultivated land, savannah regrowth and forest reserve in that order. The C:N ratio was lower in the cultivated land (9.9), compared to the forest reserve (11.4) and the savannah regrowth (11.7), all numbers with a high standard deviation. Bulk density was similar in all land use types, 1.3-1.4 g/cm^3.

Table 3a. *Average values (mean±standard deviation) for soil pH, % organic carbon (C), nitogen (N), C:N ratio and bulk density (BD).*

Land Use Type	**Sample Size**	**Average in top soil (0 – 20 cm)**				
		pH	**% OC**	**% N**	**C:N**	**BD(g/cm^3)**
Forest Reserve (FR)	20	6.4±0.6	1.7±0.3	0.2±0.1	11.4±2.7	1.3±0.0
Cultivated Land (CL)	22	5.8±0.9	0.9±0.6	0.1±0.2	9.9±4.4	1.4±0.1
Savannah Regrowth (SR)	20	5.9±0.7	1.1±0.6	0.1±0.2	11.7±4.0	1.4±0.0

Table 3b shows that CEC in the top 20cm decreases from 13.9 to 10.4 to 6.1 in the forest reserve, cultivated land and the savannah regrowth, respectively. The % BS also decreased from 95.4 to 72.4 to 64.6 in the forest reserve, savannah regrowth and cultivated land in that order. With respect to available P, savannah regrowth recorded 8.4, forest reserve 8.3, and 5.2 in the cultivated land. For available K cultivated land recorded the least with 0.6; the forest and savannah regrowth recorded the highest with 0.9.

Table 3b. *Average values (mean±standard deviation) for cation exchange capacity (CEC), base saturation (BS),phosphorus (P) and potassium (K) of soils in the Ejura-Sekyedumase district.*

Land Use Type	**Sample Size**	**Average in top soil (0–20 cm)**			
		CEC	**% BS**	**P**	**K**
Forest Reserve (FR)	20	13.9±6.4	95.4±8.9	8.3±1.2	0.9±0.2
Cultivated Land (CL)	24	10.4±13.4	64.6±24.1	5.2±1.7	0.6±0.2
Savannah Regrowth (SR)	24	6.1±3.1	72.4±13.6	8.4±0.9	0.9±0.1

4.1 Distribution of % C within land use types in Ejura-Sekyeredumase.

The variation in carbon content observed within land use types is displayed with box plots. The box plots for each land use portrays the mean, standard error and standard deviation for percentage carbon in the forest reserve, cultivated land and the savannah regrowth. The plot box in Figure 7 shows that organic carbon content was highest in the forest reserve, but considerably lower in the savannah regrowth and the cultivated land.

4.2 Carbon stocks

Total carbon stocks for each profile (from top to bottom) were determined using bulk density and carbon values. The soil profiles are up to 228 cm deep. Within the land use types (Table 4), carbon stocks decreased from 10.1 to 6.8 and to 5.9 for the forest reserve, savannah regrowth and the cultivated land, respectively. Figure 8 also illustrates a boxplot for carbon stocks within the three land use types.

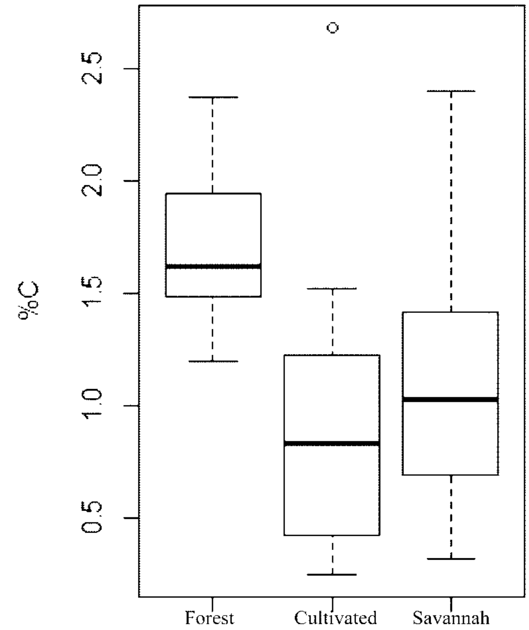

__Fig. 7__ Box plots displaying variability in organic carbon between land use types. Forest Reserve (n=20), Savannah Regrowth (n=22) and Cultivated Land (n=20). Mean values are shown as bold lines, the boxes represent 25% and 75% percentiles, the whiskers the show the range of the data for each land use type, and the open circles represent outliers.

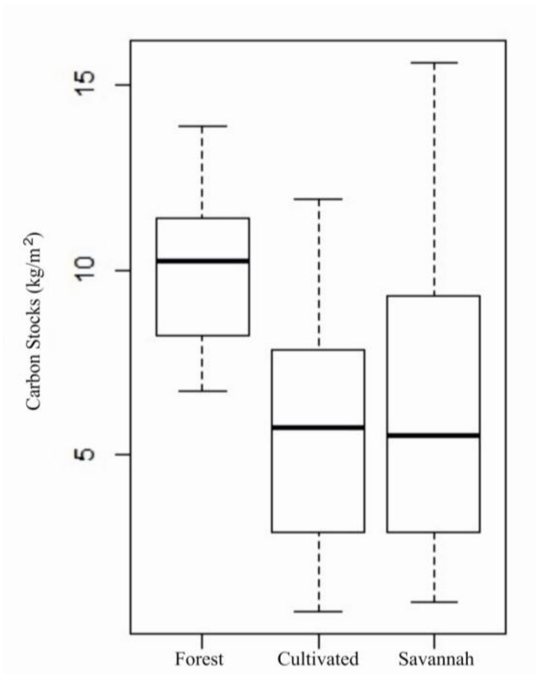

__Fig. 8.__ Box plots displaying variability in organic carbon stocks between land use types. Forest Reserve (n=20), Savannah Regrowth (n=22) and Cultivated Land (n=18). Mean values are represented as bold lines, the boxes represent 25% and 75% percentiles and the whiskers show the range of the data for each land use type.

***Table 4.** Average values (mean±standard deviation)* for *carbon stocks for the each land use type in the Ejura-Sekyedumase district.*

Land Use Type	Sample Size	Carbon Stocks (kg/m^2)
Forest Reserve (FR)	20	10.1±2.2
Cultivated Land (CL)	24	5.9±3.5
Savannah Regrowth (SR)	24	6.8±4.4

Lixisol is the most commonsoil type in the District (see Table 2) and it was also the most commonly sampled soil type with 22 sites (see Table 5), while acrisol was recorded the least common with only two soil sampling sites. Nitisol recorded the highest carbon stock (8.8 kg/m^2) and fluvisol on the other hand recorded the lowest (3.7 kg/m^2). Figure 9 shows a bar graph with error bars indicating the variation of carbon stocks between the soil types.

4.3 Degradation Index for carbon (%)

The Degradation Index for carbon was also tabulated among land use types. The forest reserve served as a control (100%). The Degradation Index (see Table 6) was calculated as 64.9% in the savannah regrowth and as 53.4% in the cultivated land.

Table 5. *Average carbon stocks(kg/m^2) and amount of soil carbon (%) distribution for each soil type in the Ejura-Sekyedumase District with reference to FAO/WRB 2006 classification.*

Soil Series (FAO Classification)	**Number of sites**	**SC (kg/m^2)**
Acrisols	2	8.7
Fluvisols	3	3.7
Gleysols	11	6.5
Leptosols	9	10.0
Lixisols	22	7.2
Luvisols	9	6.4
Nitisol	7	8.8
Plinthosols	5	7.0
Total	**68**	**58.4**

Table 6. *Degradation index for carbon for each land use type with the forest reserve as control.*

Land Use Type	**Sample Size**	**Degradation Index for carbon (%)**
Forest Reserve (FR)	20	100
Cultivated Land (CL)	22	53.4
Savannah Regrowth (SR)	20	64.9

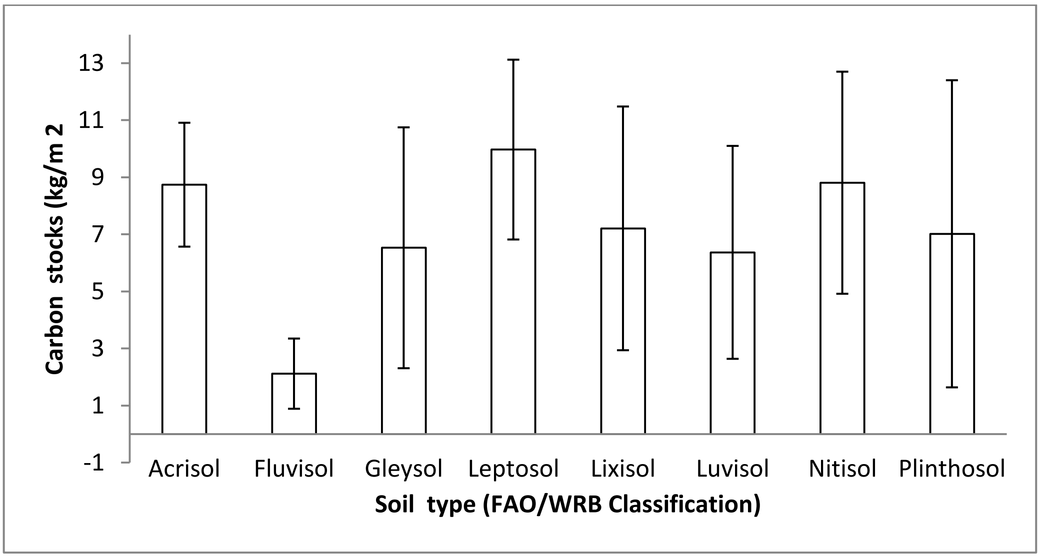

Fig. 9. *A bar graph with error bars illustrating carbon stocks (kg/m^2) within soil types in Ejura-Sekyedumase.*

4. 4 Regression analysis

Generally, there was a positive weak correlation between the cation exchange capacity and carbon percentage of the soils under forest reserve and savannah regrowth, with the exception of the soils in the cultivated area in which there was no correlation between the CEC and % carbon (see Figure 10).

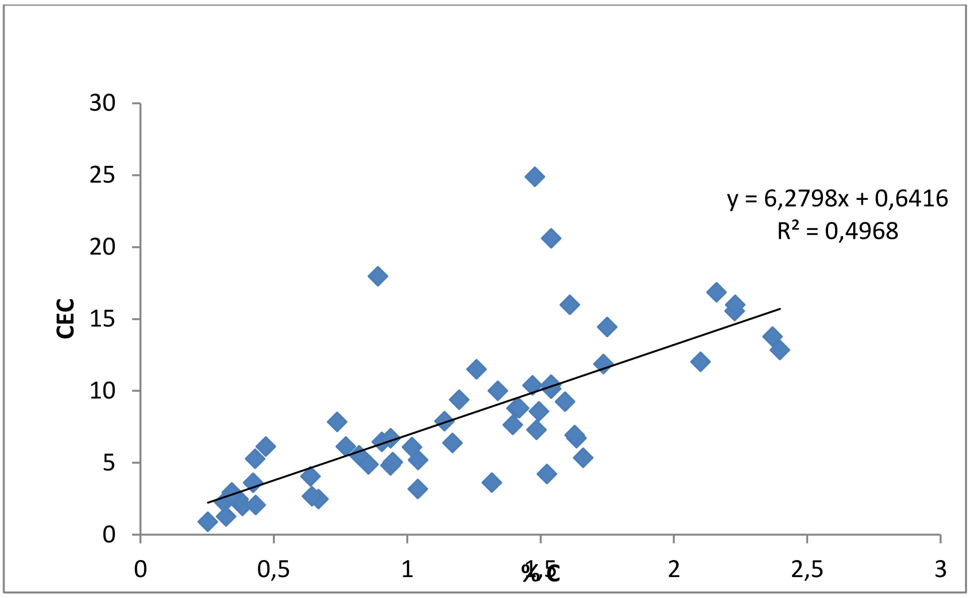

Fig.10. *Regression analysis for cation exchange capacity (CEC) and carbon (%C).*

Though not significant, there was a positive correlation between base saturation and pH in the forest reserve, cultivated land and savannah regrowth (see Figure 11). This implies that the higher the pH, the higher the base saturation.

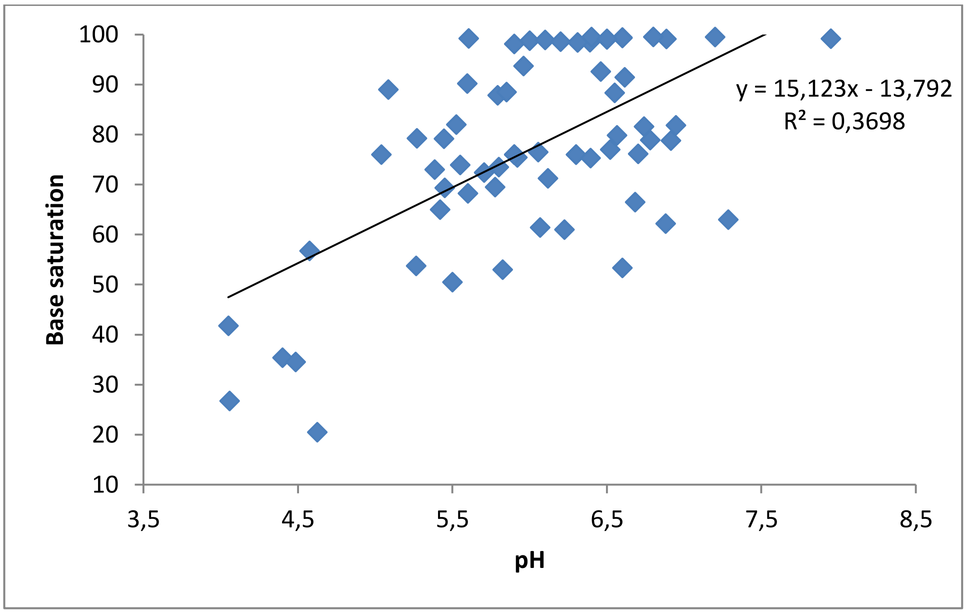

Fig. 11. *Regression analysis for base saturation (BS) and soil pH.*

5. DISCUSSION

5.1 Organic carbon and nitrogen

The results showed that there was more organic carbon in the forest reserve than in the cultivated land (Table 3a and Fig. 7). The high organic carbon content observed in the forest reserve is attributed to the decomposition of fallen leaves and dead branches by soil fauna in the soil medium. In the forest reserve, the micro-climate needed for nutrient transformation is very favourable, and for that reason, the decomposition of organic material is enhanced.

Additionally, the numerous fine roots in forests are known to be the main source of carbon additions to soils, whether through root turnover or via exudates to associated mycorrhizal fungi and the rhizosphere (Price et al. 2012). Under forest conditions, organic carbon is stabilized by the soil's inherent chemical properties, through production of secondary microbial compounds, by physical separation from microbial breakdown and by molecular interactions with metals or other bio-molecules (Price et al. 2012).

It was generally observed that organic carbon, nitrogen, pH, P, K, and CEC content were lower in the savannah and cultivated soils than in the forest reserve soils. Price et al. (2012) had a similar observation and noted that carbon is lost from surface organic matter as CO_2 by microbial respiration, and therefore, by mixing and incorporation of surface organic matter into mineral soil horizons by soil fauna and by leaching of dissolved organic matter (DOM) of which dissolved organic carbon (DOC) is an important constituent. This trend may also be due to the decrease in decomposition rates with land use.

The pH of the forest soil was found to be higher than in the other land use types (Table 3a). In a similar study, Michalzik et al. (2001) reported that the concentration of DOC in leachate from the forest floor to the mineral soil was positively correlated with the pH. This suggests that more basic conditions favour microbial decomposition and DOC production. The relatively lower supply of organic materials, coupled with moderate to few root distribution in soils in the cultivated land, accounted for the moderate accumulation of organic matter and hence carbon reduction in the cultivated land.

In all, the organic carbon content in the cultivated soils (Table 3a) was appreciably lower than in the forest reserve soil. Human activities and physio-climatic factors are among the principal factors affecting the productivity potential of the soil resources in the study area. In similar studies, Bekunda et al. (2010) and Girmay et al. (2008) in Ethiopia also identified indiscriminate activities in direct relation to the soil, often carried out by smallholder farmers, as having resulted in the low content of organic carbon in the cultivated land. These include continuous cropping by smallholder farmers, indiscriminate logging, vegetation removal, and uncontrolled bush burning practices (the slash and burn method of land preparation). As a result of continuous cropping, the mineralized organic carbon, together with other soil nutrients such as N, P, K, have been mined by growing plants and thus led to greater removal than addition.

Comparatively, the amount of nitrogen stored in the soils was of the order: forest reserve > cultivated land > savannah regrowth (see Table 3a), following the amount of organic carbon in these soils. This is expected, as total soil N is mostly associated with organic matter (Brady & Weil 1996). It must be emphasized that there was no significant difference between % N found in the soils of the cultivated land and savannah regrowth. An increase in the decomposition of organic matter increases N mineralization, which in turn decreases % N in the soil, while C:N ratios may be comparatively low and favourable until the carbon reserve is depleted. Higher C:N ratios in the forest reserve may imply that falling leaves and litter are an essential component of soil fertility restoration.

5.2 Soil pH

Soil pH is an important factor in determining the fertility status of soils. pH values in the soils studied were in this order: forest reserve>savannah regrowth>cultivated land (Table 3a and Fig. 11). Continuous cropping has resulted in a decrease in soil pH. The low pH values observed in the cultivated land may have been due to the application of nitrogen based fertilizers. Application of ammonium based fertilizers has the tendency to decrease the pH of the soil. When ammonium based fertilizers (e.g. $(NH_4)_2SO_4$,) are applied to the soil, there are principally two fates of the NH_4^+ released. Firstly, NH_4^+ undergoes the process of acidification through which H^+ ions are released. Nitrification is the conversion of NH_4^+ ions into nitrate ions through an intermediate process. The process is a 2-step reaction (eq. 1.3a and 1.3b).

$$2\,NH_4^+ + O_2 \xrightarrow{\textit{Nitrosomonas}\text{ and }\textit{nitrococcu}} 2\,NO_{2^-} + 2H_2O + 4H^+ \qquad \text{(eq. 1.3a)}$$

$$2\,NO^{2-} + O_2 \longrightarrow 2\,NO_3^- \qquad \text{(eq.1.3b)}$$

The release of H^+ ions in the first reaction causes an increase in soil acidity, and therefore the pH of the soil is lowered. Under low pH, the availability of most nutrients (e.g. phosphorus) is limited.

5.3 CEC and % C, base saturation and soil pH

Organic matter (carbon) has the tendency to form soluble complexes with cations in the soil medium. The availability of nutrients in the soil solution therefore has the tendency to increase with higher CEC of the soil. The order of the strength of correlation observed under the different land use systems can be explained by the fact that organic matter under savannah regrowth and forest reserves is relatively higher than that of the cultivated land, and this accounts for the relatively higher CEC in the savannah regrowth and forest reserve than in the cultivated land.

This implies that the higher the pH, the higher the base stauration. Soil pH is an important factor in determining the base saturation of tropical soils. Soils in the tropics are characterised by a variable charge system, and the charge on the exchange complex is determined by soil pH. At a higher pH there is a creation of negative charges on the exchange complex which gives the soil the propensity to attract positively charged basic ions (Hooda 2010). The higher the pH, the higher the negative charges created, and the higher the basic cations absorbed by the soil. The more cations absorbed implies a higher percentage saturation.

Soils under the forest reserves and savannah regrowth have relatively higher pH compared to soils in cultivated land. There is leaching of basic cations in the latter, and this gives rise to a relatively lower pH, and for that matter, a lower base saturation in the cultivated land. The forest reserve and savannah regrowth have enough vegetation cover to check the possibility of leaching of basic cations in those soils. This therefore gives rise to a relatively higher pH and, hence, a higher base saturation.

5.4 Land use management options identified for the study area

There are huge benefits associated with simple farming practices which enhance soil fertility renewal in terms of cost; smallholder farmers can then adopt new and simple modern techniques in addition to the traditional system of farming in order to increase the fertility of soils in the study area.

In order to integrate conservation of organic and inorganic resources into soil fertility management options (use of compost, manure, plant residue, etc.) organic residues can be prepared and stored for use in the cropping seasons. Also, by accessing the plant nutrient requirement or demand, appropriate simple farming practices, which should involve the growing and management of crops and fertilizer placement (at the base of each plant) on an extensive scale (Poulton et al. 2006), can complement soil nutrient management and thus enhance soil fertility restoration.

The intensification of ‘enhanced marketing pathways and strategies’ (Bekunda et al. 2010) by the government of Ghana should focus on addressing issues concerning post-harvest losses during peak seasons, land fragmentation (land tenure) and management. The ability of small scale farmers to conform to bylaws governing land is important for restoring soil fertility. The adoption of the participatory approach to project management and implementation is likely to yield good results as smallholder farmers engage in practices that conserve organic stocks on their farmlands.

Finally, smallholder agricultural activities for food production should also be integrated into the world produce market by policy makers (Bekunda et al. 2010), as is now done for the small scale cocoa farmers who enjoy these incentives (access to external resources and markets) in the country, hence making Ghana a renowned high quality cocoa producing country in the world market. According to Bingen et al. (2003), investing in human capital (similar to the ‘farmers heal the land policy’ of Iceland) can assist a great deal in the dissemination of information to small farm holders in Ghana and SSA, if, and only if, these sustainable restoration processes targeting soil fertility and food production by farmers is backed by policies and measures by African governments and the international community (UN, WTO, etc.).

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Conversion from natural (FR) to agricultural ecosystems (CL) changes the amount of soil organic carbon pool which also affects soil fertility in the study area. Comparison of the average carbon stocks of the forest to cultivated lands showed that there has been a significant loss of soil nutrients in the cultivated fields and hence a decline in soil fertility. The Degradation Index for the cultivated land (53.4%) as compared to the forest reserve and the savannah regrowth (64.86%) also proves that soil fertility has declined.

6.2 Recommendations

Accurate and reliable large scale determination of soil organic carbon stock depends on SOC densitiy determination at the local level (Su et al. 2006) which can serve as a measure for soil fertility restoration in Ghana and SSA with the associated environmental and financial benefits. It has also been shown in this research that land use affects the soil organic carbon status (soil fertility) and subsequently the fertility of soils also influences the sustainability of crop production.

Therefore, for further studies in this area, it is recommended that:

- Extensive soil organic carbon research should be conducted at the local level to provide an accurate baseline (database) for a national soil carbon inventory for Ghana (at the district, regional and national levels, respectively). Further, research should be conducted at depths 0 – 5 cm, 5 – 10 cm, 10 – 20 cm, etc., which will in the long term prepare Ghana for the on-going carbon sequestration projects under the Clean Development Mechanism (CDM) of the Kyoto Protocol, 2006.

- Awareness creation among small-holder and large scale farmers on the benefits of sustainable land use management practices which would in the long term increase yield and improve the fertility of soils. Hence, the role of SOC in contributing to climate change mitigation and the financial, economic, environmental and societal benefits associated with the carbon trade which involves developing countries such as Ghana.

- Implementation of socio-economic incentives such as subsidation of fertilizer and other packages to encourage small-scale farmers to engage in food crop production, as compared to their counterparts in the cocoa farm business where the government subsidizes fertilizer and other agro-chemicals to boost cocoa production. This will in the long term affect food crop production which would promote sustainable land use management practices available to small scale farmers in the rural communities of Ghana.

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ABBREVIATIONS

AEZ	Agro – Ecological Zone
CDD	Clean Development Mechanism
CERGIS	Centre for Remote Sensing & Geographic Information Systems
CL	Cultivated Land
CSIR	Council for Scientific and Industrial Research
DOC	Dissolved Organic Carbon
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
FR	Forest Reserve
FSTZ	Forest Savannah Transition Zone
GHG	Green House Gasses
GIS	Geographic Information Systems
GMSD	Ghana Meteorological Services Department
GNADO	GIA/NABIO Agro-forestry Development Organization
GSS	Ghana Statistical Service
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFDC	International Fertilizer Development Centre
MOFA	Ministry of Food and Agriculture
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SR	Savannah Regrowth
SRI	Soil Research Institute
SSA	Sub – Saharan Africa
UNFCCC	United Nations Framework Convention on Climate Change
UNU – LRT	United Nations University – Land Restoration Training Program
WRB	World Reference Based
WTO	World Trade Organisation
UN	United Nations
IPCC	Inter-governmental Panel on Climate Change