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Impact of Continuous Cultivation on the Soil Physical Properties along the White-Volta River at Pwalugu-Ghana

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ABSTRACT

The study was conducted in irrigation farms along the White Volta River at Pwalugu in the Upper East Region, Ghana to evaluate the effects of continuous cultivation on aspects of the physical properties of the soil in the area. Undisturbed soil cores, taken from 0-10 cm, 11-20 cm and 21-30 cm down the soil profile, were used to evaluate bulk density, soil moisture content, total porosity and particle density. Also, the basic infiltration rates of soils in the selected area were determined. The results indicate that soil under continuous cultivated land within 0-30 cm depth (down the soil) is generally compacted, particularly within the subsoil (21-30 cm), as compared to adjacent soil which has been left to fallow for about twenty years. The overall soil condition in the continuous cultivated land is deteriorating. This may have major adverse effect on agricultural productivity and sustainability. Therefore, strategies to reduce compaction to ensure sustainable soil management should be adopted. The adoption of management practices such as agro-forestry, composting, crop rotation and bush fallowing, which ensure substantial amount of biomass transfer that lead to soil structure stability have been recommended.

Keywords: *Continuous cultivation, Soil physical properties, White Volta, Pwalugu*

INTRODUCTION

Soil is one of the major environmental components that has a direct relationship with agriculture. It is considered to be a renewable natural resource due to the fact that, there is natural process of soil generation albeit slow with regards to time scale. However, if the soil is used at a greater rate than the environment's capacity to replenish it, it becomes non-renewable resource (Khattak, 2008). Soil has a close interconnection with other natural resources, such as water, fauna and flora. In Ghana, major causes of soil degradation are linked to certain agricultural practices, which highly disrupt the soil, particularly, its physical properties (EPA, 2003). The fact that soil has linkage with other natural resources and other environmental components means that, it has a crucial link to other global environmental problems, such as desertification, water management, climate change and loss of biodiversity (Asiamah *et al*., 2000).

During land preparation for agricultural purpose, ploughing helps to reduce bulk density, which facilitates the increment of soil air content and also enhance the rate of organic matter decomposition. However, continuous cultivation affects soil in various ways, particularly, the change in physical properties (Brady, 1990; Mubarak et al., 2005). In soils with high clay content, cultivation may lead to hard pan, below the plough layer that may restrict root penetration and downward movement of water (Singh and Singh, 1996). Cultivation practices alter soil physical properties, such as, water content, aeration and the degree of mixing of soil crop residues within the soil matrix. This affects soil organisms, which play very important role in the soil, such as improvement in soil structure, nutrient cycling and organic matter decomposition (Kladivko, 2001).

Naturally, an ideal soil contains about 50% pore space by volume, with half of the space filled with water and the other half filled with air (Brady, 1990; Camp and Daugherty, 1991). Since pore spaces are filled with both air and water, the amount of air in a soil at a particular time depends largely on the amount of water present in the pore spaces. Immediately after a rain or in waterlogged area, there is more water and less air in the pore spaces. Conversely, in dry periods or arid areas, soil contains more air and less water. Increasing organic matter content usually increases water-holding capacity of soil, but adding undecomposed organic material reduces water-withholding capacity until the material has partially decomposed (Camp and Daugherty, 1991).
Sustainable agricultural production also depends on productive soils, but the land resources of Ghana, particularly, the soils, are being degraded as a result of anthropogenic factors, with poor farming practices being one of the major causes. Soil degradation, in its several forms, is evident in all the agro-ecological zones of Ghana (Asiamah *et al*., 2000; EPA, 2003) and is, therefore, a major constraint to the attainment of the desired growth rate in the agricultural sector (MoFA, 1998; Adomako and Ampadu, 2015). In Ghana, agriculture is not only an economic activity, but also, a way of life for which agricultural land is an indispensable resource upon which the welfare of the society is built, as such its intensification, resulting in the various forms of soil degradation. This phenomenon is more common at places where there is difficulty in acquiring suitable land for cultivation, such as, the Upper East Region of Ghana.

In the Upper East Region of Ghana and in Pwalugu, the study area in particular, most of the inhabitants engage in crop farming and cattle rearing as the main source of livelihood, resulting in intensified agricultural activities on the available lands. The main water resource available in the area (i.e., the White Volta) is a great relief to farmers in Pwalugu, providing suitable agricultural land along its course, as well as providing water for irrigation to support dry season farming. This has however, resulted in continuous cultivation along the river banks as compared to the shifting cultivation system which is usually practiced in Ghana. These lands are hardly left to fallow and this has adverse effect on the inherent physical composition of the soil, their fertility and crop yield. In the process some physical characteristics, notably, porosity and bulk density that influence a multitude of processes in the soil with regards to its fertility are adversely altered.

Currently, farmers in the area are faced with diminishing crop yields that is reducing their income and threatening food security (Personal observation). This situation, in effect, threatens the ecological sustainability of lands in Pwalugu and its environs. There is, therefore, the need to assess the soil to ascertain the effects of continuous cropping on its physical properties, and provide measures for its sustainable management. This study, therefore, aimed at assessing the impact of long term conventional farming as a type of land-use on aspects of the physical properties of soils along the White Volta River at Pwalugu. The specific objectives are: assessing the impact of continuous cropping on soil pore spaces, water content, bulk density and basic infiltration rate in the selected area.

MATERIALS AND METHODS

Study Area

The study was conducted along the White Volta River at Pwalugu in the Talensi District of the Upper East Region of Ghana. The area is located between latitude 10^{o} 15' and 10^{o} 60' north and longitude 0^{o} 31' and 1^{o} 05' west of the Greenwich meridian (Figure 1), and has a total land area of 838.4 km^2 (Census Report, 2010). Pwalugu is situated at about 26.5 km south of Bolgatanga, the regional capital, and falls within the Sudan Savannah woodland,
consisting of short, widely spread deciduous trees and a ground flora of grass, which get burnt by fire or scorching sun during the long dry season (Figure 2). The vegetation is being degraded due to agricultural activities, characterized by prolonged sequences of farming periods with short or no bush fallow.

The study area has two distinct seasons: an erratic wet rainy season, which runs from May to October, and a long dry season that stretches from November to April, with hardly any rains. The mean monthly rainfall ranges between 88 mm and 110 mm and an annual rainfall of about 950 mm. The area experiences a maximum temperature of 45^{0}C in March and April and a minimum of 12^{0}C in December (Census Report, 2010). Pwalugu is drained mainly by the White Volta River and its tributaries, thereby, allowing for intensive dry season irrigation farming (Census Report, 2010). The farming system is a typical mixed and continuous cropping system and livestock production, where grazing animals feed on pasture in fallowed lands. The seasonal erratic rainfall and high temperatures experienced in the area provide conditions for rapid oxidation of soil organic matter, with subsequent chemical reaction leaving a residue rich in iron and aluminium oxides, producing lateritic soils (Amegashie, 2009). These soils exhibit variation in their physical properties in terms of texture, infiltration, transmission and water holding capacity (Nyarko, 2007).

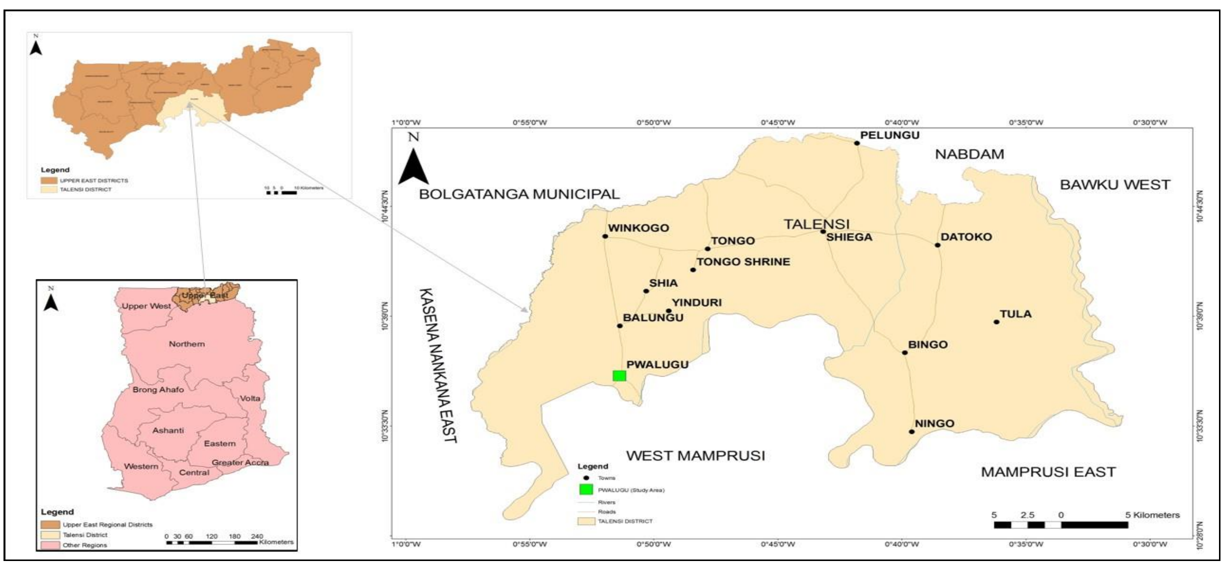

Figure 1. Map of Ghana showing the location of Talensi District and Pwalugu (the study area).

METHODS

Purposive sampling technique was used to select two soil sampling sites of about 1 ha each, lying 100 m apart within the study area. One of the sites labelled plot "C" had been cultivated continuously for about ten years and the other site labelled "F" had been left to fallow for about twenty years (Figure 2). These sites have homogeneous soil type and similar in geologic, topographic and climatic conditions, and were selected based on cultivation history and accessibility. Field observation was used to identify the various land-use types, whilst standard procedure for soil sampling and laboratory analysis were employed to determine soil physical properties, such as, bulk density (core sampler method) (Blake and Hartge, 1986), gravimetric water content (oven drying method) (Hillel, 1980; Brady, 1990) and the particle density; following the soil particle density protocol by GLOBE® (2002). The porosity of each core soil was determined using the values of both particle density and dry bulk density (Hillel, 1980; Brady, 1990; GLOBE®, 2002) which is given as:

$$\text{Soil porosity (\%)} = \left\{1 - \left(\frac{\text{soil bulk density}}{\text{soil partcle density}}\right) \times 100\right\}$$

The study also employed field measurements using the Double Ring Infiltrometer approach (Singh,1992; Diamond and Shanley, 2003; Nyarko, 2007) for the determination of the infiltration rates of the soil. This approach was selected among numerous approaches available in the literature (see Nyarko, 2007) because it reduces lateral flow and overestimation of infiltration rate in the field (Singh, 1992; Nyarko, 2007).

The selected locations provided data that could be used as variables for determining whether or not the continuous cultivation of the farmlands in the area has adversely altered some of soil physical parameters, with the assumption that both sites were in similar conditions before the cultivation began. Important factors, such as depth and sampling intensity per unit area of the sampled site, were considered. As such, separate soil core samples were collected from the plough layer (30 cm thick which is subjected to land preparation e.g. ploughing, harrowing, etc) from (0-10) cm, (10-20) cm and (20-30) cm depths, with a sharp-edged steel cylinder with a volume of 142 cm^3. The steel cylinder was hammered into the soil and dug out carefully with a trowel to get the soil cores to determine the bulk densities, pore spaces and water retention status. Thirty (30) soil cores were taken from each plot (i.e. ten sampling points, three cores from each point). During the collection of samples; growing plants (grasses and shrubs) and dead plants, furrow, pits and wet spots, were excluded. Also, compaction and disturbance to the soil structure were minimized as much as possible. Afterwards, the samples were put in a labelled and air tight plastic bag to protect them from heat, humidity and dust. This was done to minimize the errors emanating from sampling and transportation of samples to the laboratory.

Inferential and descriptive statistics were employed in analyzing the data using the Statistical Package for Social Sciences (SPSS) and Microsoft Excel. A t-test analysis of data generated from soil laboratory test was calculated at 95% confidence level ($\alpha = 5$ %).

RESULTS AND DISCUSSION

Bulk density

Measurement of soil bulk density is required for the determination of compactness, as a measure of soil structure, for calculating soil pore space and as indicator of aeration status and water content (Barauah and Barthakulh, 1997). Mean dry bulk density on both fallowed and continuously cultivated land showed an increasing trend with increasing soil depth

(Table 1). Most often, bulk density increases with soil depth, since subsurface layers have reduced organic matter, aggregation and root penetration, resulting in less pore space as compared to surface layers. In addition, the subsurface layers are also subjected to the compacting weight of the soil above them (Brady, 1990; Ahmed, 2002; Wakene, 2001). Singh and Singh (1996) also stated that in soils with high clay content, cultivation may lead to hard pan below the plough layer that restricts root penetration and downward movement of water. In affirmation to this, there was a considerable variation in the measured soil bulk densities among the various depths under the two land use systems (Table 1). The coefficients of variation within the depth classes were 7.5% and 7.9% for both fallowed and cultivated lands, respectively (Table 1), indicating low variability in the bulk densities. However, t-test results indicated a significant difference in mean bulk densities at 0.05 significant level ($p = 0.016$), suggesting that the land-use system may have effect on the bulk density of the soils.

Table 1: Bulk densities, Particle density, Total porosity and Moisture content of both the Continuous Cultivated and Fallowed lands.

Land Use System	Depth class (cm)	ρ_b (dry) (g/cm^3)		Mean ρ_b(dry) (g/cm^3)	SD Intra-class	CV Intra-class	SD Inter-class	CV Inter-Class (%)	Mean ρ_s g/cm^3	Mean Total porosity (%	Mean Moisture content (%)
		Min	Max								
Fallowed Land	0-10	1.26	1.54	1.37	1.09	6.6	0.11	7.5	2.33	38.57	1.76
	11-20	1.36	1.59	1.45	0.08	5.5			2.29	36.68	3.85
	21-30	1.47	1.71	1.59	0.07	4.4			2.31	31.17	5.39
Continuous Cultivated Land	0-10	1.35	1.74	1.51	1.14	9.3	1.03	7.9	2.33	35.19	1.38
	11- 20	1.46	1.83	1.67	0.10	6.0			2.33	28.32	2.99
	21-30	1.66	1.89	1.77	0.07	4.0			2.46	28.04	4.44

Note: SD = standard deviation; ρ_b (dry) = dry bulk density; CV = coefficient of variation; ρ_s (g/cm^3)= particle density

Within the integral depth of interest (0-30 cm), the highest mean bulk density, 1.77 g/cm^3, was recorded on the cultivated land, which is 10.16% greater than the bulk density of the fallowed land at equivalent depth. The lowest mean value (1.37g/cm^3) was also recorded on the fallowed land, which is 9.27% lower than the bulk density value at equivalent depth under the cultivated land. These ranges of bulk density values observed in the study were in harmony with the research findings reported by Brady (1990) and Tilahun (2007). Thus, the bulk density ranges of values noted under the cultivated land could limit root growth and soil aeration (USDA, 2008). The content and nature of organic matter has been reported to influence dry bulk density, and soils with high amounts of litter usually have low dry bulk density values (Brady, 1990; Amegashie, 2009). According to Brady (1990), the system of crop and soil management employed on a given soil also influences its bulk densities. Brady (1990) further stated that the addition of crop residues or farm manure in large quantities to soil tends to lower bulk densities of surface soils. The higher mean bulk density values recorded under the continuously cultivated land relative to its equivalent on the fallowed land was attributable to soil compaction and organic matter degradation as a result of continuous and intensive cultivation with heavy farm machineries. On the other hand, the smaller difference between the mean bulk density values of the two land use systems might be attributed to constant grazing by livestock on the fallowed land. Although the land has been allowed to fallow, there is a significant degree of disturbance of the land by livestock through trampling and also perennial bush fires (see Figure 2, Plot F).

Soil particle density

Particle density affects soil porosity, aeration and rate of sedimentation of particles (Tilahun, 2007). The highest mean value (2.46 g/cm^3) and the lowest mean value (2.23 g/cm^3) of particle densities within 0-30 cm soil depth were obtained under the cultivated and fallowed land, respectively (Table 1). Student t-test analysis showed that particle density was not significantly affected ($P = 0.305$) by the land-use systems at 0.05 level; implying that tillage has had no effect on soil particle density. This was confirmed by the fact that the mean particle density of most mineral soils is about 2.60 to 2.75 g/cm^3 (Hillel, 1980; Brady, 1990). However, these particle density values under both land use systems increased with increasing soil depth, that is, (0 -10cm) < (11-20cm) < (21-30) (see Table 1). According to Ahmed (2002), the continuous increase in particle densities with increasing depth might be due to the presence of heavy mineral particles and low level of organic matter in the soil.

Soil total porosity

As soil particles vary in size and shape, so do pore spaces vary in size, shape and direction (Foth, 1990). Soil porosity and organic matter content play a critical role in the biological productivity and hydrology of agricultural soils (Aikins and Afuakwa, 2012). The mean total porosity on both fallowed and cultivated lands (Table 1) decreased with increasing soil depth. Soil porosity and bulk density have an inverse relationship; thus, soils with higher proportion of pores to solids have lower bulk densities than those that are compact and have fewer pores (Brady, 1990; Brady and Weil, 1999). The study revealed that total porosity decreased from the surface soils (38.57%: 0-10 cm) through to the last class (31.17%: 20-30cm) under fallowed land, and decreased from 35.19% to 28.04% under the cultivated land at equivalent layers (Table 1). Although this numerical variation was observed, total porosity was not significantly ($P = 0.139$) affected by land-use at 0.05 significant level. However, total porosity values recorded under the fallowed land and the continuous cultivated land were low, as compared to an ideal 50% value suggested by Camp and Daugherty (1991) and Brady (1990) as a satisfactory condition for soil aeration. These results indicated that both lands have had a significant amount of compaction within the depth of interest (0-30 cm), with the continuous cultivated land being the worse affected. The compaction under the cultivated land may be attributed to the use of heavy farm machinery during land preparation and trampling of the soil by grazing animals and perennial bush fires being the cause of compaction in the fallowed land.

Soil moisture

Plants require water for growth and the source is soil moisture, particularly in rain-fed agriculture, which is very essential in guaranteeing good and uniform seed germination and seedling emergence and good yield. The water storage capacity and drainage of a soil is highly dependent on the soil physical properties. Observed mean soil moisture values in all of the soil depth classes in the present study was less than 6% and increased with increasing soil depth under the two land-use systems (Table 1). Thus, soil moisture content was highest under both fallowed and continuously cultivated soil at 30 cm depth. There was no significant difference in the mean values of soil moisture content under the two land-use systems.

The soil moisture content in all of the soil depth classes indicated that the soil was very dry. This was so because the study was conducted in April just at the end of the dry season which started from November (Section 2.0; Figure 2). The relatively dense vegetation as well as increased organic matter content in the fallowed land as compared to the continuous cultivated land prevents swift runoff of rain water, which increases the infiltration rate and reduces the evaporation rate. This may be the reason why relatively high moisture content values were obtained from the fallowed land (Table 1), in agreement with Brady and Weil (1996). As such, organic matter degradation as a result of continuous and intensive cultivation with heavy farm machineries of the continuous cultivated land might account for the relatively low moisture content of the continuous cultivated land as compared to the fallowed land. However, the moisture content of the top layer 0-10 cm of the cultivated land has higher moisture content than the fallowed land. Although, the difference is insignificant this possibly might be due to the presence of irrigated water during the farming season prior to the dry season.

Infiltration

The easiness or complexity with which water can move into and penetrate through the soil profiles is an important and a good determining factor of soil compaction and structural deterioration. The results of basic infiltration rate are summarised in Table 2, and varied between 63.1 and 125.9 mm/h and 31.6 and 44.7mm/h under fallowed and continuous cultivated lands, respectively.

Table 2. Infiltration characteristics of the fallowed and continuous cultivated land use systems

Land use system	Measurement point	Cumulative Infiltration (mm/85min)	Mean of Cumulative Infiltration (mm/85min)	Basic infiltration rate (mm/h)	Mean of basic infiltration rate (mm/h)	cm/min
Fallowed land	First Point	379.0		125.9		
	Second Point	345.8	351.0	63.1	100.4	0.17
	Third Point	328.2		112.2		
Continuous Cultivated land	First Point	135.9		44.7		
	Second Point	87.2	123.1	31.6	36.0	0.06
	Third Point	146.2		31.6		

Table 3. Dingman's Infiltration categories

Class	Infiltration category	Infiltration rate (cm/min)
1	Very slow	< 0.1
2	Slow	0.1 - 0.5
3	Moderately slow	0.5 - 2.0
4	Moderate	2.0 - 6.0
5	Moderately rapid	6.0 - 12.5
6	Rapid	12.5 - 25.0
7	Very rapid	>25.0

Source: Dingman (2002: cited by Nyarko, 2007)

Also, comparison of the measured infiltration values (using t-test) between the two land use systems, showed a significant difference between them at 0.05 significant level (P = 0.04). This clearly shows that the continuous cultivated land has had some significant amount of compaction and deterioration as compared to the fallowed land. As reported by Hillel (2004: cited by Nkeshimana, 2008), gradual deterioration of soil structure can affect soil infiltration rate. A feature of compacted soils is the formation of a pan-layer, caused by tractor tyres driving directly on the subsoil during ploughing of the top soil.

Comparing the mean basic infiltration capacity of both land-use systems (Table 2) to Dingman's infiltration categories (Table 3), one can observe that the fallowed and continuous cultivated lands have slow and very slow infiltration rates, respectively. Similar infiltration rate values were found in the area in an earlier study by Nyarko (2007). The depth of water penetration (cumulative infiltration) in a period of 85 minutes varied among the points (location) of measurement and ranged from 87.2 mm to 146.2 mm and 328.2 mm to 379 mm for continuous cultivated land and fallowed land, respectively.

CONCLUSION AND RECOMMENDATION

The study showed that, in general, the soil under the continuous cultivated land has higher bulk density and particle density and lower total porosity, soil moisture content and basic infiltration rates, as compared to soil under the fallowed land. However, in most cases, the difference in the soil physical properties observed between the two land-use systems was not significant.

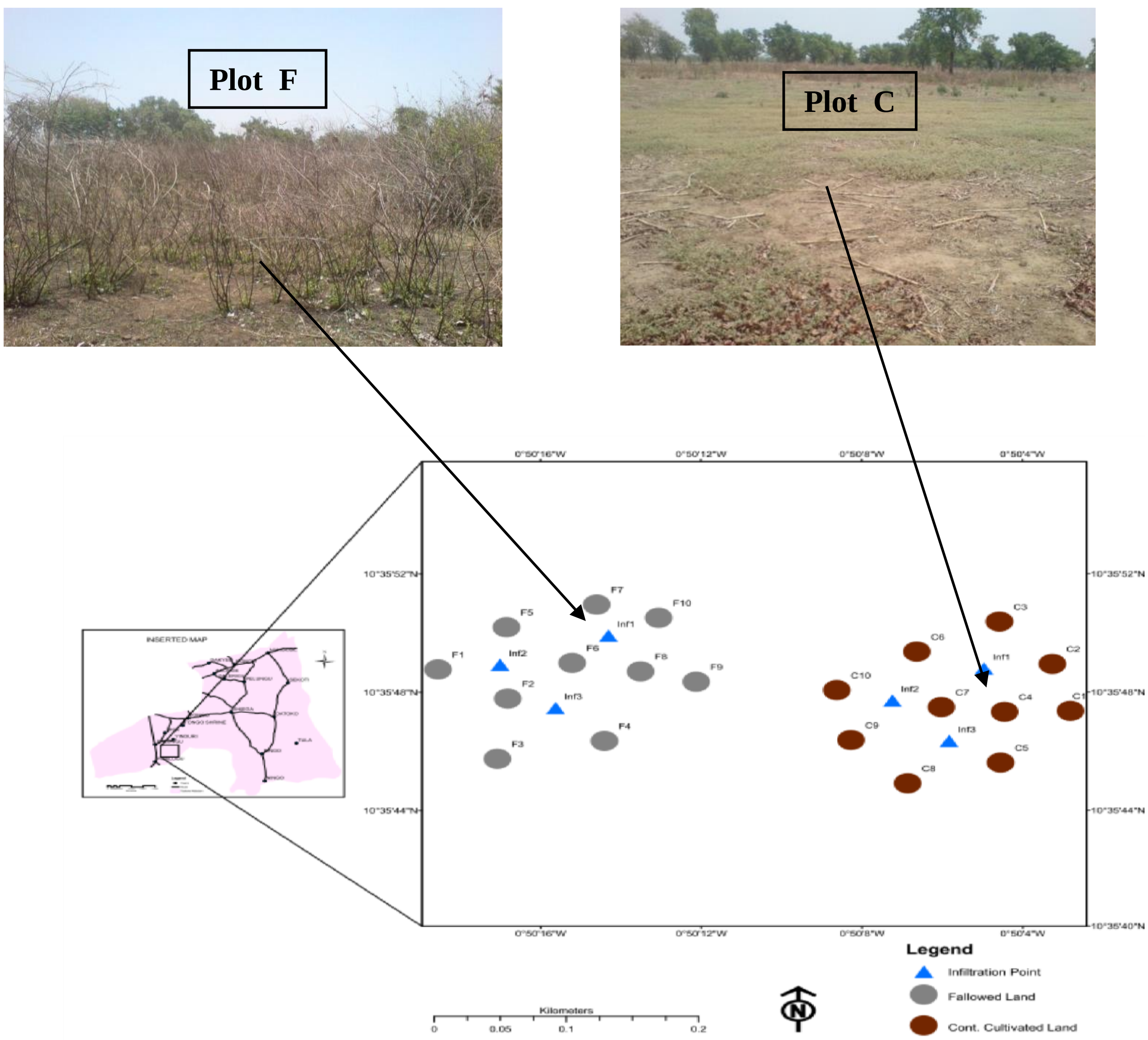

Figure 2. Fallowed land (Plot F) and continuously cultivated land (Plot C) along the White Volta River at Pwalugu at the end of the Dry Season in April.

The state of these parameters assessed clearly shows that the soil structure under continuous cultivated land is compacted and, as such, degraded, owing to the extent of continuous cultivation of the land.

The effect is detrimental to soil physical properties and will likely exacerbate processes leading to gradual and rapid soil deterioration. This will likely hamper root development and nutrient uptake in crops, such as tomato, which are grown intensively in the area.

The variations of soil physical properties between the land-use types indicate the risk to sustainable crop production in the area. Therefore, strategies that will ensure sustainable solution and better addresses integrated soil management have to be sought and employed.

For instance, increased use of organic matter in the area is recommended. This will affect positively the soil bulk density as well as the state of the other physical soil properties observed. The application of organic matter will also result in reducing soil compaction, improving infiltration rates and, consequently, increasing crop yield. Furthermore, management practices such as agro-forestry, composting, land rotation, and significant fallow periods to ensure substantial amount of biomass transfer should be adopted. Also, further research into the soil chemical properties should be conducted in the area to provide more in-depth information on the soil properties.

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