Hindawi
Applied and Environmental Soil Science
Volume 2018, Article ID 1057242, 12 pages
https://doi.org/10.1155/2018/1057242

Research Article

Assessment of Greenhouse Gas Emissions from Different Land-Use Systems: A Case Study of CO_2 in the Southern Zone of Ghana

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Received 24 September 2017; Accepted 8 February 2018; Published 5 April 2018

Academic Editor: Teodoro M. Miano

The emission of greenhouse gases (GHGs) results in global warming and climate change. The extent to which developing countries contribute to GHG emissions is not well known. This study reports findings on the effects of different land-use systems on GHG emissions (CO_2 in this case) from two locations in the southern zone of Ghana, West Africa. Site one (located at Kpong) contained a heavy clay soil while site two (located at Legon) contained a light-textured sandy soil. Land-use systems include cattle kraals, natural forests, cultivated maize fields, and rice paddy fields at site one, and natural forest, woodlots, and cultivated soya bean fields at site two. CO_2 emissions were measured using the gas entrapment method (PVC chambers). Trapping solutions were changed every 12–48 h and measurement lasted 9 to 15 days depending on the site. We found that, for the same land-use, CO_2 emissions were higher on the clay soil (Kpong) than the sandy soil (Legon). In the clay soil environment, the highest average CO_2 emission was observed from the cattle kraal ($256.7\,mg\cdot m^{-2}\cdot h^{-1}$), followed by the forest ($146.0\,mg\cdot m^{-2}\cdot h^{-1}$) and rice paddy ($140.6\,mg\cdot m^{-2}\cdot h^{-1}$) field. The lowest average emission was observed for maize cropped land ($112.0\,mg\cdot m^{-2}\cdot h^{-1}$). In the sandy soil environment, the highest average CO_2 emission was observed from soya cropped land ($52.5\,mg\cdot m^{-2}\cdot h^{-1}$), followed by the forest ($47.4\,mg\cdot m^{-2}\cdot h^{-1}$) and woodlot ($33.7\,mg\cdot m^{-2}\cdot h^{-1}$). Several factors influenced CO_2 emissions from the different land-use systems. These include the inherent properties of the soils such as texture, temperature, and moisture content, which influenced CO_2 production through their effect on soil microbial activity and root respiration. Practices that reduce CO_2 emissions are likely to promote carbon sequestration, which will consequently maintain or increase crop productivity and thereby improve global or regional food security.

1. Introduction

Land-use and land-cover change is among the most important human alterations of the Earth's land surface [1]. Conversion or overutilization of land by processes such as cultivation, excessive removal of vegetation, burning, tree plantation, and other forms of degradation and restoration can add or remove greenhouse gases (GHGs) from the atmosphere and thereby impact on the global carbon cycle [2]. GHGs are substances believed to make the atmosphere function like the glass in a greenhouse. They trap the sun's shortwave energy and re-emit it as heat-producing longwave radiation, causing an increase in atmospheric temperature [3]. GHG emissions and their interaction with radiation are believed to be the major cause of global climate change, which has become a major threat to development and food security, especially in the tropics [4, 5]. The anthropogenic gases that are primarily responsible for causing the greenhouse effect include CO_2, methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). In 2010, CO_2, N_2O, and CH_4 accounted for 66.5%, 17.2%, and 15.4% of greenhouse gases, respectively, worldwide [6].

The level of CO_2 in the atmosphere is estimated to have been ~280 ppmv on average during the preindustrial period before rising from ~315 ppmv in 1957 to ~356 ppmv in 1993 when more accurate monitoring began [7]. The current rate of increase of ~1.5 ppmv/yr is due to the combustion of fossil fuels, cement production, and land-use conversion [3]. Agriculture accounts for approximately 10–12% of total global anthropogenic emissions of GHGs, which amounts to 60% and 50% of global N_2O and CH_4 emissions, respectively [8]. In tropical countries, a great amount of the CO_2 emissions steams from vegetation removal, burning and decomposition, and soil carbon loss due to cultivation and soil degradation [9]. The CH_4 and N_2O emissions emanate from marshy fields such as those found in lowland rice production systems, but also from animal production sites. Recent results of a meta-analysis of N fertilizer effects on GHG emissions showed that the N fertilizer-induced N_2O emission factor during the rice growing season was 0.21% for continuously flooded rice systems and 0.40% for fields with drained periods [10]. Much of the historical emissions of GHGs may be attributed to fossil fuel burning [11]. Land-use change accounts for recent increases in emissions from fertilizer application, lowland rice fields due to fertilizer applied in water, and domestic animals such as cattle [12].

By far, agriculture and forest waste constitute the largest sources of GHG emissions from tropical countries such as Ghana [13]. Agriculture and climate change are inextricably linked. Nelson [14] observed that "Agriculture is part of the climate change problem, contributing about 13.5% of annual GHG emissions (with forestry contributing an additional 19% compared with 13.1% from transportation)." Agriculture is, however, also part of the solution, offering promising opportunities for mitigation through carbon sequestration, improved soil and land-use management, and biomass production [14]. The release of CO_2 from soil is the largest source of carbon emissions to the atmosphere [15]. Soil CO_2 emissions and production are the result of complex interactions between climate and soil biological, chemical, and physical properties [16, 17].

Soil surface CO_2 production is a major component of the biosphere's carbon cycle because it may constitute about three quarters of total ecosystem respiration [18]. In recent years, soil CO_2 production has been the subject of intense studies because of its potential role in amplifying global warming [19]. The rate of soil CO_2 production is dependent on land-use and land management systems [20]. In Ghana, common land-use systems include forestry, upland agriculture, paddy rice, and animal husbandry [21]. Understanding the controls on soil CO_2 emissions is critical because relatively small changes in soil CO_2 fluxes from these land-use systems may dramatically alter atmospheric concentrations of CO_2. The critical factors reported to influence soil CO_2 production rates include atmospheric temperature and moisture, soil organic matter and nutrient content, root respiration, microbial processes, soil aeration, porosity and water, net primary productivity, and vegetation type [15, 22].

For many years, most tropical countries such as Ghana have considered themselves as being net carbon sinks or, at worst, carbon neutral. This anecdotal assertion is based on the low level of industrialization in these countries. But given the extensive land-use change occurring in many tropical countries including deforestation and land degradation through poor management and periodic bush fires, it is conceivable that their GHG emissions are increasing [23]. There are relatively few studies estimating GHG emissions in sub-Saharan West Africa, especially within the agricultural sector, and likewise, comparative studies across major land-use types are scarce. Consequently, the majority of practices and techniques for adaptation to climate change that are now being advocated [24, 25] are largely based on knowledge generated in other parts of the world. The GHG inventory initiative of Ghana's Environmental Protection Agency (EPA) uses the Intergovernmental Panel on Climate Change (IPCC) guidelines to estimate GHG emissions from several sectors such as agriculture, forestry waste, animal manures, methane emissions from cattle, and lowland paddy rice fields [26]. Findings from these estimates as well as those from the Carbon Dioxide Information Analysis Centre (CDIAC) (http://www.cdiac.org) indicate that per capita carbon emissions in Ghana are on the increase. As stated by Milne et al. [27], a general weakness in these estimations is the heavy reliance on lower tier IPCC methodologies. Estimates by Ghana's EPA also show a gradual increase in GHG emissions with projected further increases based only on "best guesses" or by the use of emission factors (EFs) published by the IPCC [26]. Actual measurements to validate these estimates or EFs are lacking. Thus, there is an urgent need for more assessments of ecosystem responses to land management (and mismanagement) in order to improve decision-making regarding climate change adaptation and mitigation. This study sought to address some of these identified knowledge gaps. It aims to measure the CO_2 emissions resulting from some of the major land-use systems operating within the coastal savanna agroecological zone of Ghana.

2. Materials and Methods

2.1. Study Area Description. The CO_2 emissions experiment was carried out between July and November in 2012 at two locations with different land-use systems in the Coastal Savanna agroecological zone of Ghana. The first site, the Soil and Irrigation Research Centre (SIREC) at Kpong, University of Ghana, is located within the lower Volta basin (Figure 1). The 1,036 ha SIREC site is located at latitude 6° 09′ N and longitude 00°04′ E, with an altitude of 22 m asl (Table 1). The second site, the Legon research farm, University of Ghana (main campus, Accra), is located at latitude 5°66′ N and longitude 00°19′ E, with an altitude of 88 m asl. The general

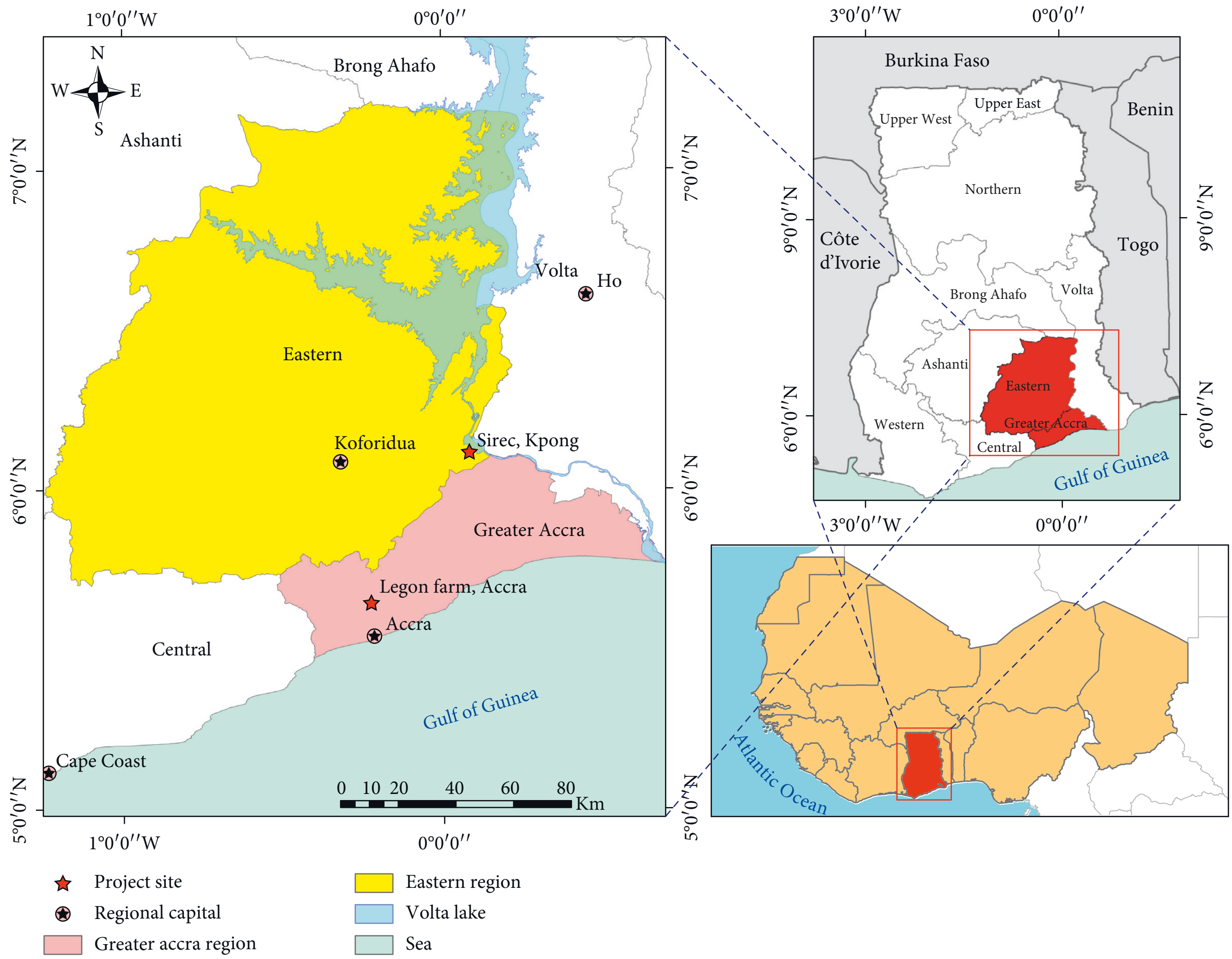

FIGURE 1: Map of Ghana showing study areas: SIREC-Kpong and University of Ghana main campus, Legon-Accra.

TABLE 1: Main characteristics of the experimental sites.

Characteristics	Sites	
	Kpong, SIREC	Legon, University of Ghana
Coordinate	6°09′ N 00°04′ E	5°66′ N 00°19′ E
Altitude (m)	22	88
Rainfall (mm)	800–1326	900–1010
Temperatures (°C), min (mean) max	22.1 (27.2) 33.3	21.5 (27) 30.9
Relative humidity, %	70–100	70–100
Soil type	Typic calciustert (tropical black clay, Akuse series)	Ferric Acrisol (sandy loam) mineral with argillic horizon, Toje series)
Vegetation	Grassland	Scanty savannah
Slope (topography)	Gentle (1–5%)	Gentle (1–2%)

topography of the SIREC-Kpong site is gently sloping with slopes ranging from 1 to 5%. The Legon-Accra site has a gentle, undulating relief with slopes ranging from 1 to 2%.

The Kpong site has an annual rainfall of 800–1326 mm, which is bimodal and characterised by a major rainy season (March–July), a short period of drought in August, a minor rainy season (September–November), and another period of drought (December–February) (Table 1). About 60% of the total rainfall occurs in the major rainy season and 30% in the minor rainy season. The rainfall distribution at the Legon site is similarly bimodal, with a mean annual rainfall range of 900–1010 mm. Prolonged heavy rain is occasionally experienced in the major rainy season from March/April to June whilst the minor rainy season begins from September/October to December. Temperatures at both study sites are warm. The mean maximum and minimum temperatures at the Kpong

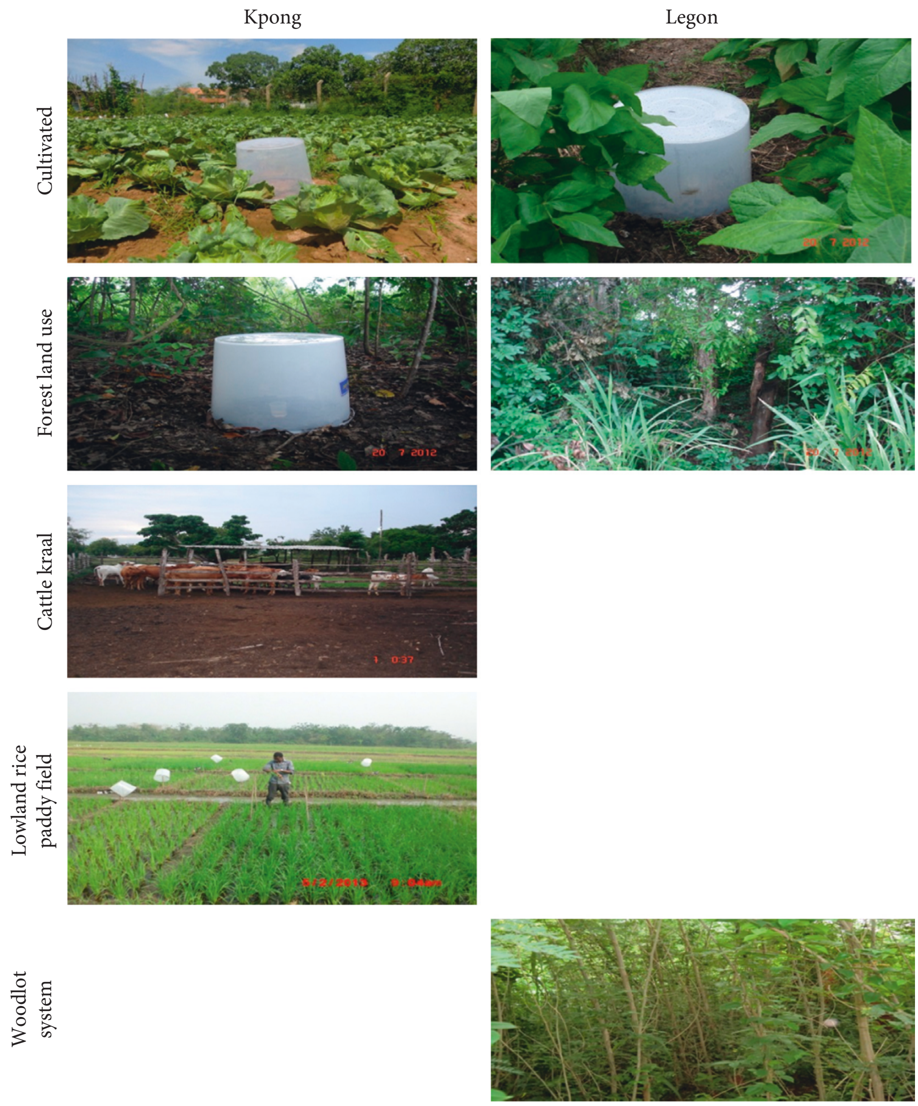

Figure 2: Layout of identified land-use systems used for the study.

site are 33.3°C and 22.1°C, respectively, and 30.9 and 21.5°C, respectively, at the Legon site. The relative humidity for the night time to the early hours of the day for both sites ranges from 70 to 100%. The afternoon relative humidity ranges from 20% to 65% throughout the year.

The vegetation at the Kpong site is limited to grasses and slow-growing, deep-rooting tree species. This is due to the soil's high clay content, and its shrink-swell characteristics and structure, combined with the climate effect (Table 1). The main features of the natural vegetation in these soils are tolerance to drought, as well as development of deep roots to overcome root damage as a consequence of the annual cracking of the soil. The Legon site is covered with lush grass, thicket patches, and shrub vegetation community with little litter falls. Only a small amount of organic matter can therefore accumulate and the humus top soils are poorly developed. The soil at the Kpong site is an alluvial material derived from the weathering of garnetiferous hornblende gneiss (Table 1). It is classified as Typic calciustert [28]. Locally, it is the tropical black clay called Akuse series [28] which is categorized as a vertisol [29]. These are generally deep black soils that contain more than 30% clay which is often dominated by smectite mineralogy [30]. Generally, the clay content is very high in vertisols, and the dominant clay minerals are 2 : 1 type minerals (smectite and montmorillonites). At the Legon site, the soil is derived from a ferruginized weathered country rock, the Togo quartzite schists. It is classified as a ferric acrisol (sandy loam), which is a mineral soil with a characteristic argillic horizon [31]. Locally, it is classified as a Toje series [32].

2.2. Experimental Layout for Sampling of Carbon Dioxide Fluxes. Data were collected following a stratified random sampling approach. The sites sampled were stratified into land-use types and within each land-use type or strata, sampling for carbon dioxide was randomly done at three replicate locations. At the Legon site, the studied land-use systems were woodlot (*Leucaena leucocephala*), cultivated maize (*Zea mays*) field, and a natural forest stand. At the

Kpong site, four land-use systems, namely, cultivated soya bean (*Glycine max*) field, natural forest, cattle kraal (an enclosure for cattle and other domestic animals), and lowland (paddy) rice field were considered (Figure 2).

At the Kpong site, the soya bean was at the flowering stage. The soil did not receive any form of amendment (e.g., mineral fertilizer or manure). The land management system practiced includes ploughing with a tractor a week prior to sowing. The soya bean crops were under rainfed conditions throughout the growing season. The natural forest is at least 50 years old with the dominant tree species comprising *Cassia fistula* L., *Ehretia anacua* I. M. Johnst., and *Azadirachta indica* A. Juss. The forest floor was covered by a thick mat of leaf litter and twigs. The paddy field was under constant irrigation with about 5 cm head of flood water. At the time of sampling, the rice plants were at their emergence stage.

Management of the paddy includes fertilization with urea two and six weeks after planting. The kraal was a semi-intensive cattle raising system with a stocking density of one cow per 3.0 m^2. They were fed mainly on grasses (*Brachiaria mutica* Stapf, *Ischaemum* spp., *Axonopus compressus* P.Beauv., *Paspalum* spp., *Panicum maximum* Jacq., *Melinis minutiflora* P.Beauv., *Pennisetum* spp., *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf., *Digitaria* decumbens Stent, and *Eragrotis* spp), legumes (*Calopogonium mucunoides* Desv., *Centrosema pubescens* Benth., *Pueraria phaseoloides* Benth., *Stylosanthes gracilis* Kunth (GCI), *Mimosa pudica* L., and *Stizolobium aterrimum* Piper & Tracy), and fodder (*Gliricidia sepium* (Jacq.) Kunth, *Atriplex* spp, *Kochia sedifolia* F. Muell., and *Ficus* spp.). Soils within the kraal are covered with cattle dung mixed with their urine.

At the Legon site, the cultivated maize field was harvested prior to the sampling campaign. The field has been continuously under maize cultivation for more than five decades. Weeding is done by hand, and dead weeds and stovers from previous maize crops are left on the soil surface. The 20-year-old *Leucaena leucocephala* woodlot was adjacent to the cultivated maize field. Originally, this site was cultivated before its conversion to a woodlot for the production of fuelwood. The soil surface was covered with a thin layer of leaf litter. The natural forest was over 60 years old and consisted of plant species such as *Zanthoxylum zanthoxyloides*, *Azadirachta indica* A. Juss., *Dichrostachys glomerata* Chiov., *Antiaris toxicaria* Lesch., *Uvaria siamensis* (Scheff.), *Panicum maximum* Jacq., *Byrsocarpus coccineus* Schumach. & Thonn., *Canthium orthacanthum* Robyns, and *Cissus petiolata* Hook.f. (personal observation). The soil surface was covered by a thick mat of leaf litter and twigs.

2.3. Measuring Soil CO_2 Production. The gas entrapment method described by Hutchinson and Mosier [33] and Sullivan et al. [34] was used. Transparent polyvinylchloride "PVC" chambers were inserted 2 cm into the mineral soil at the three random locations. A 10 ml solution of 3M NaOH was dispensed into a vial and placed under the plastic chamber to trap CO_2 evolving from the soil. Additional vials containing 10 ml of 3M NaOH placed in the transparent PVC with their lids on to exclude CO_2 evolved from the soil served as controls to account for the CO_2 trapped from the atmosphere. Measurement duration ranged from 9 to 15 days depending on the site. For each land-use system at the Kpong site, the trapping solutions were changed following these arrangements: (I) twice daily from the 19th to the 24th of July 2012 (12 h interval at 5:30 am and 5:30 pm for 6 days); (II) once daily from the 24th to the 27th of July 2012 (24 h interval at 5:30 pm for 4 days); and (III) once every two days from the 27th July to the 2nd of August (48 h interval at 5:30 pm for 7 days). For each land-use system at the Legon site, the trapping solutions were changed once daily (24 h) from the 28th of October to the 5th of November 2012 (9 days). The trapping chambers were placed at the same location after each measurement duration. After exposure of the alkali, the vials were removed, immediately covered with lids (air-tight seal), and taken to the laboratory for analysis. The evolved CO_2 was determined by back titration using a phenolphthalein indicator.

2.4. Soil Characteristics Sampling and Analyses. The main soil characteristics with potential to influence CO_2 emissions were also measured. Prior to the beginning of the study, soil samples were taken by augering to a depth of 0–0.15 m at three random positions in each of the land-use systems at both study sites. Air-dried samples were bulked (for each land-use), crushed, and then sieved through a 2 mm sieve for characterization. The soil samples were analyzed for texture, pH, C, and N using the modified Bouyoucos hydrometer method [35], an electrode pH meter, the Walker and Black method, and the Kjeldahl method, respectively.

Soil temperature and soil moisture content were measured at the same time duration as gas sampling during the whole experimental period at the Legon site (only). Soil temperature was measured at a depth of 5 cm using a digital probe (pH/mV/C meter, RS232). Moisture content was determined by sampling with a core sampler and oven drying at 105°C for 24 hours. Daily ambient air temperature and precipitation data (that can also influence soil temperature and moisture) were obtained from the weather data station at SIREC, Kpong.

2.5. Statistical Analysis. The soil and environmental variables data were assessed using the dispersion and analysis of variance methods to relate differences to land-use systems [36]. Analysis of variance was performed on soil CO_2 production rates on each sampling date separately, to assess differences between land-use systems and times during the day. Regression analysis was also used to determine the relationship between CO_2 production rates and environmental parameters (temperature and moisture) as expressed for each land-use system. To predict CO_2 production based on soil temperature, we used an exponential equation as suggested by Davidson et al. [37] and Raich & Potter [38]. For soil water, we used a quadratic relationship between production and water content [37]. Statistical differences were considered significant at $p \leq 0.05$. In addition, the statistical package Statistix version 9.0 was used to test differences in means using the Tukey range test procedure at a significance level of $p \leq 0.05$. Analysis of

Table 2: Initial soil chemical and physical properties of land-use systems at SIREC-Kpong (A) and Legon, University of Ghana (B).

Land-use systems	pH (1 : 1) soil : H_2O	SOC (%)	OM (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
A.							
Cultivated	6.95 (0.2)	0.96 (0.08)	1.65 (0.13)	29.40 (3.40)	13.80 (1.0)	56.80 (1.3)	Clayey
Forest	7.10 (0.1)	2.23 (0.18)	3.84 (0.30)	24.05 (1.10)	16.95 (0.5)	55.00 (1.5)	Clayey
Kraal	7.95 (0.35)	4.32 (0.42)	7.43 (0.70)	27.50 (1.50)	15.90 (1.0)	56.60 (0.8)	Clayey
Lowland	7.10 (0.2)	0.59 (0.04)	1.01 (0.07)	19.80 (1.60)	22.20 (1.6)	58.00 (1.1)	Clayey
B.							
Cultivated	4.95 (0.2)	0.70 (0.08)	1.20 (0.14)	61.98 (1.40)	10.52 (1.2)	27.50 (1.2)	Sandy clay loam
Forest	5.5 (0.3)	2.42 (0.18)	4.16 (0.30)	60.95 (1.27)	12.80 (1.7)	26.25 (0.8)	Sandy clay loam
Woodlot	5.10 (0.2)	1.55 (0.11)	2.67 (0.19)	60.42 (0.92)	14.58 (1.1)	25.00 (1.0)	Sandy clay loam

Soils were sampled at 0–0.15 m depth; SOC = soil organic carbon; OM = organic matter; standard deviation in parenthesis.

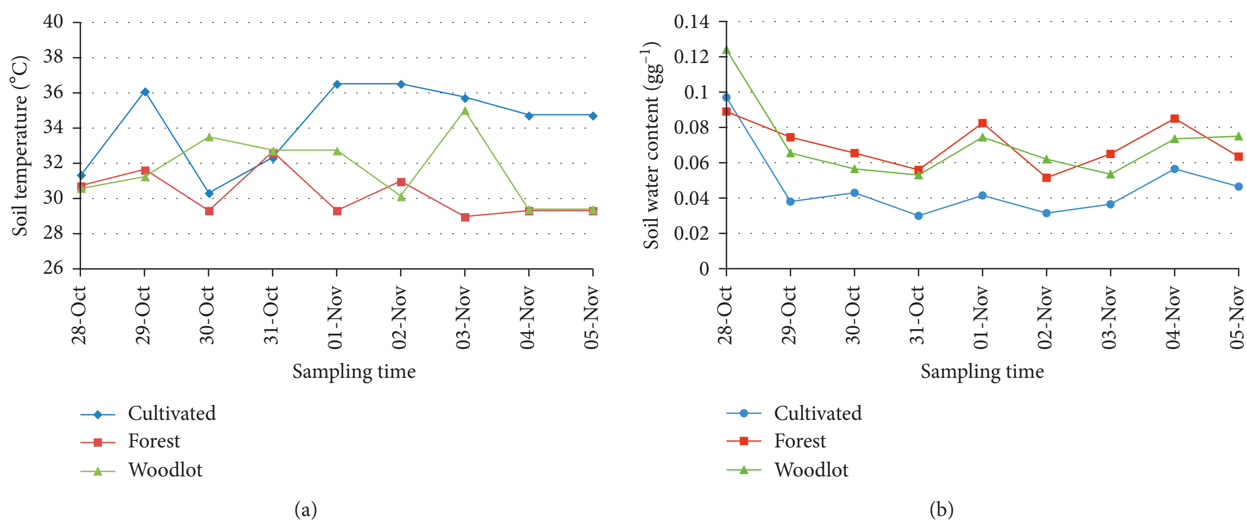

Figure 3: Variation of soil temperature (a) and soil moisture content (b) from different land-use systems at Legon farm.

variance was performed with Genstat statistical software (Genstat version 9.2).

3. Results

3.1. Soil and Environmental Variables. Table 2 summarizes information on the physical and chemical characteristics of the land-use systems at the Kpong and Legon sites, respectively, prior to commencement of the experiment. The high clay content of the soils at the Kpong site confirms their vertic characteristic, whereas soils at the Legon site are predominantly sandy. The average pH of the Kpong site's vertisol soil is 7.0, described as neutral except for soils from the cattle kraal in which the pH was approximately 8.0 (alkaline). The Legon site's alfisol soil is strongly acid. The organic carbon (OC) content differed with each land-use system. The OC content of this site's kraal and forest soils is high. At the Legon site, the OC of the cultivated field is low. The OC content of the forest floor is high (2.42%), whereas in the woodlot the OC is medium (1.55%).

The total rainfall during the year of study (2012) at the Legon site was 594.7 mm (minor season), with only one small rainfall event (i.e., 5.1 mm) occurring during the measurement time frame. The average annual temperature in Kpong is 26.6°C. The total rainfall at the Kpong site was 714 mm in the season where measurements were made. During the measurement time frame, five rainfall events were recorded (i.e., 14.4, 46.6, 52.0, 3.6, and 0.5 mm), amounting to a total of 117.1 mm. Soil temperature varied between 28.95 and 36.6°C during the study period at the Legon site (Figure 3(a)).

Temperatures were particularly high for the cultivated land-use system, whereas low soil temperatures were recorded in the forest land-use. Under the cultivated land-use, soil temperatures peaked during the second and fifth sampling time and then decreased gradually to 34.7°C. For the woodlot system, soil temperature increased gradually from 30.57°C to 32.7°C during the first and third sampling times. A sudden decrease in temperature then occurred on the sixth sampling time after which it up-surged to 35°C and again decreased sharply to 29.37°C. Low soil temperatures were found in the forest land-use, with a temperature average of 32.6°C. A maximum temperature of 33.9°C was measured during the fourth sampling time. The temperature then dipped to 28.95°C during the last sampling time.

The moisture content of the Legon site's forest soils was relatively higher compared with the moisture contents of

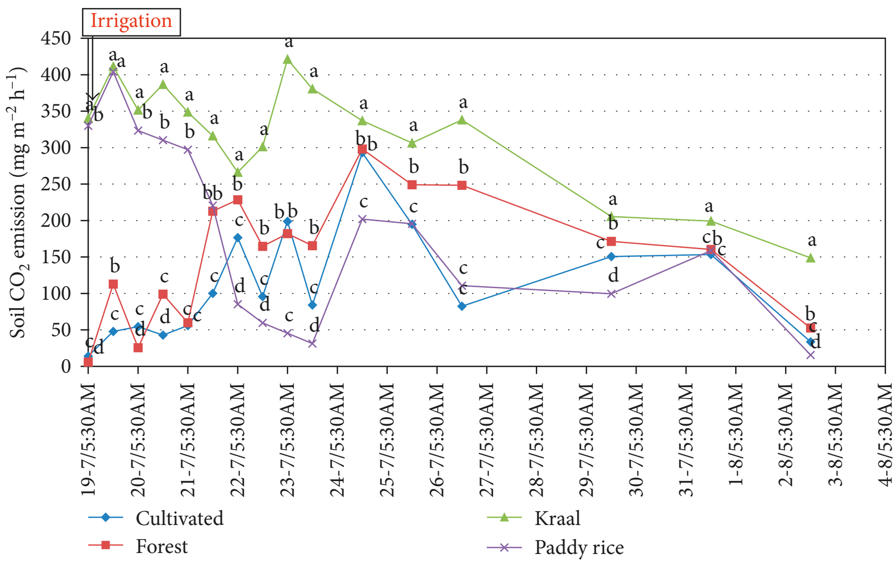

Figure 4: Temporal CO_2 emission from different land-use at Kpong site.

the cultivated and woodlot system soils (Figure 3(b)). The cultivated land-use recorded a low moisture content. The woodlot and cultivated field initially recorded high moisture contents of 0.124 and 0.097 gg^{-1}, respectively, compared to 0.089 gg^{-1} from the forest soil. Moisture content decreased sharply to 0.065 and 0.038 gg^{-1} for the woodlot and cultivated field, respectively, during the second sampling time. In most cases, woodlot soils stored much more moisture than cultivated soils. The moisture content of forest soils decreased gradually with time but was higher compared to the other land-use systems.

3.2. CO_2 Fluxes

3.2.1. CO_2 Emission from a Clay Soil Environment (Kpong). Soil CO_2 emissions differed significantly with different land-use systems and for most measurement times. The highest CO_2 emission was observed from the cattle kraal, followed by the paddy rice and the forest ecosystem. Higher CO_2 fluxes occurred during the daytime (5:30 am–5:30 pm) compared to emissions observed at night time (5:30 pm–5:30 am). During the first sampling time, the highest CO_2 emission of 340.5 mg·m^{-2}·h^{-1} was emitted from the kraal during the night time. During the day, the CO_2 production increased to 411.4 mg·m^{-2}·h^{-1} (Figure 4).

The CO_2 emission pattern was maintained for sometime but decreased gradually to 226.3 mg·m^{-2}·h^{-1} during the fourth sampling time and up-surged to 421.3 mg·m^{-2}·h^{-1} during the fifth sampling time during the day. Initially, the CO_2 emission from the paddy field showed non-significant differences from the kraal. A CO_2 production of 330.0 mg·m^{-2}·h^{-1} was measured during the night time and increased to 404.3 mg·m^{-2}·h^{-1} during the day. The emission decreased gradually to 85.3 mg·m^{-2}·h^{-1} after which a sharp decrease resulted in a production of 31.3 mg·m^{-2}·h^{-1}.

The forest and cultivated land-use systems initially revealed lower CO_2 emissions compared to the kraal and paddy field but increased with time. The lowest CO_2 emission of 5.8 mg·m^{-2}·h^{-1} was from the forest land-use at the beginning of the measurement. This peaked to 112.8 mg·m^{-2}·h^{-1} during the daytime and dipped to 25.6 mg·m^{-2}·h^{-1} during the night time. Again, CO_2 emission ascended to 228.6 mg·m^{-2}·h^{-1} in the next sampling time and gradually decreased to 165.6 mg·m^{-2}·h^{-1}. The cultivated field initially emitted 14.0 mg·m^{-2}·h^{-1} CO_2, but this gradually increased to 176.6 mg·m^{-2}·h^{-1}, after which it decreased to 95.8 mg·m^{-2}·h^{-1}. The CO_2 production then up-surged to 198.8 mg·m^{-2}·h^{-1} and finally decreased to 84.2 mg·m^{-2}·h^{-1}.

Soil CO_2 emissions measured over a 24-hour interval were consistent with those based on a 12 h interval. For this period of measurement, cattle kraal CO_2 production was followed by emissions from the forest, whereas the paddy field and cultivated land-uses emitted relatively lower CO_2. Overall, during the whole measurement time, the highest average CO_2 emission was observed from the cattle kraal (256.7 mg·m^{-2}·h^{-1}), followed by the forest (146.0 mg·m^{-2}·h^{-1}) and paddy rice (140.6 mg·m^{-2}·h^{-1}) land-uses. The lowest average emission was observed for the cultivated land (112.0 mg·m^{-2}·h^{-1}).

3.2.2. CO_2 Emission from a Sandy Soil Environment (Legon). Soil CO_2 emissions from the three land-use systems at the Legon site are shown in Figure 5.

Generally, low emissions were observed in the mornings, before peaking in the midafternoon and thereafter decreasing into the late afternoon (Figure 5(a)). In most cases, high CO_2 production was observed from the cultivated field followed by emissions from the woodlot. Lower emissions were particularly recorded from the forest ecosystem (Figure 5(b)).

Soil CO_2 production from all of the land-use systems at first sampling showed nonsignificant differences in emissions. The average CO_2 production was 31.3 mg· m^{-2}·h^{-1}. CO_2 emissions ascended gradually at the second sampling time for

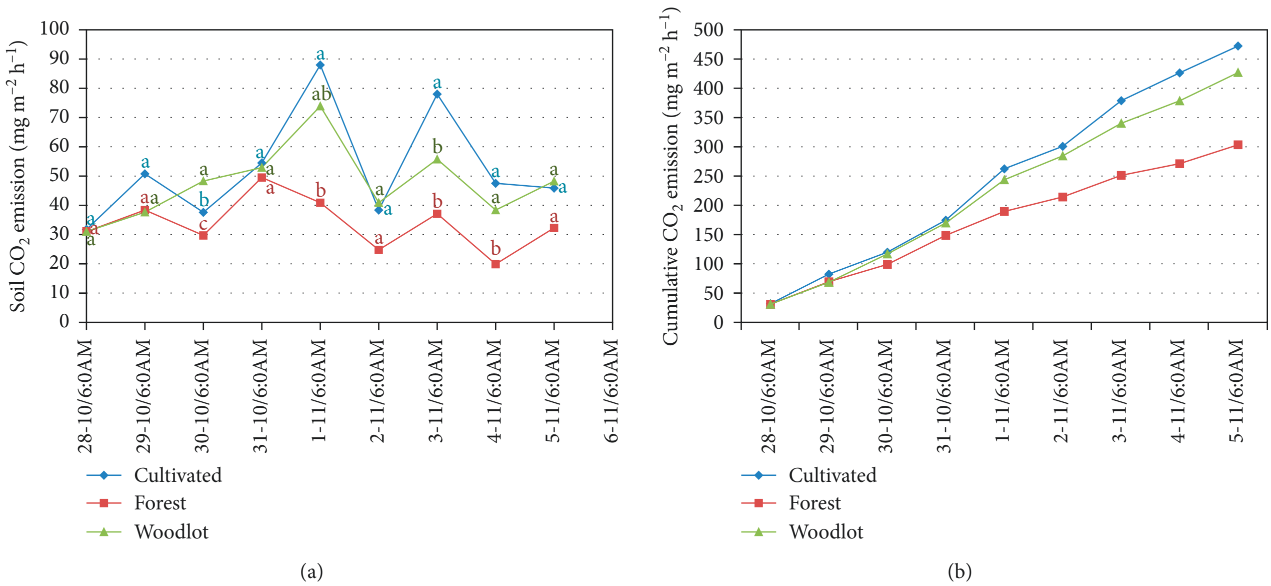

FIGURE 5: Temporal (a) and cumulative (b) CO_2 emission from different land-use at Legon farm site.

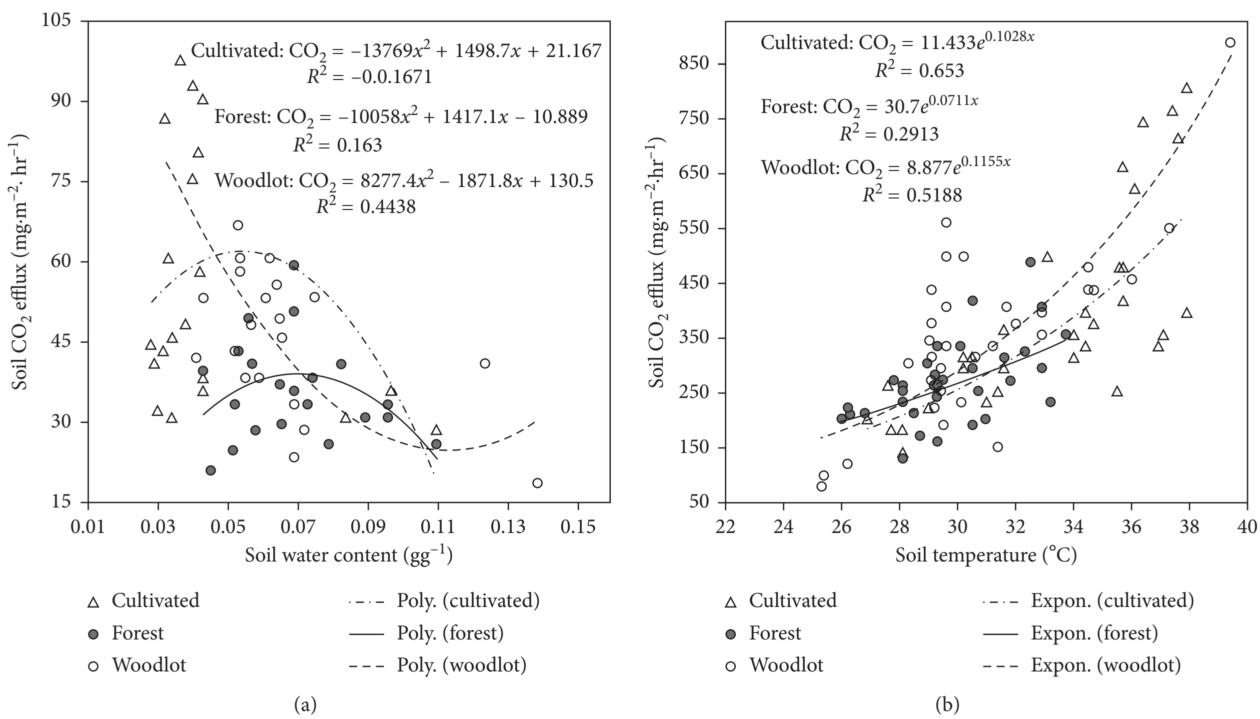

FIGURE 6 : Relationship between soil water content and soil CO_2 production in different land-use systems on Ferric Acrisol at Legon farm, Coastal Savanna agroecological zone of Ghana.

both the forest and woodlot land-use systems. However, a steep increase in emissions was observed from the cultivated field. A sudden drop in emissions to 37.6 mg·m^{-2}·h^{-1} was followed by a sharp increase to 88.0 mg·m^{-2}·h^{-1} which was the highest CO_2 production recorded for this land-use. Soil CO_2 emissions then dipped to 38.4 mg·m^{-2}·h^{-1} and then upsurged again to 78.0 mg·m^{-2}·h^{-1} where it finally declined to 45.9 mg·m^{-2}·h^{-1} at the last sampling time.

The CO_2 emissions from the woodlot showed a similar pattern as that of the cultivated field, but the dynamics were gradual rather than steep. From 31.0 mg·m^{-2}·h^{-1} CO_2 during the first sampling time, the CO_2 emissions increased gradually to 73.9 before decreasing sharply to 40.9 mg·m^{-2}·h^{-1}. Thereafter, a gradual decrease and increase in emissions was maintained until a CO_2 production of 48.3 mg·m^{-2}·h^{-1} was recorded at the last sampling time.

The forest land-use recorded quite low CO_2 emissions compared with the cultivated and woodlot land-use systems. An initial production of $31.0\,mg{\cdot}m^{-2}{\cdot}h^{-1}$ increased to $49.5\,mg{\cdot}m^{-2}{\cdot}h^{-1}$ during the fourth sampling time. The lowest CO_2 emission of $19.9\,mg{\cdot}m^{-2}{\cdot}h^{-1}$ was observed on the sixth sampling time. Overall, during the whole measurement time, the highest cumulative CO_2 emission was observed from the cultivated land ($250.02\,mg{\cdot}m^{-2}{\cdot}h^{-1}$), followed by the woodlot ($228.95\,mg{\cdot}m^{-2}{\cdot}h^{-1}$) and forest ($175.31\,mg{\cdot}m^{-2}{\cdot}h^{-1}$) land-use systems (Figure 5(b)).

3.2.3. Soil CO_2 Production, Temperature, and Moisture Measurements on Sandy Soil Environment. A regression analysis reveals significant correlations between the respiration rate and soil temperature and moisture ($p < 0.001$). The predictive power of the model, given by R^2, was low in some cases. The regression of soil temperature on soil CO_2 production showed a positive correlation, with CO_2 evolution increasing as soil temperature increased (Figure 6). Soil temperature explained 65% of the total CO_2 production on cultivated land, 52% on woodland, and 29% on forest stand. Relationship between soil CO_2 production and volumetric soil moisture was higher in woodlot as compared with cultivated land and natural forest.

4. Discussion

4.1. Impacts of Land-Use Systems on CO_2 Emissions. Land-use and management practices may influence carbon inputs and hence CO_2 emissions [39]. Indeed, the CO_2 emissions from different land-use systems at our study's Kpong site differed significantly. Higher CO_2 emissions were particularly observed from the cattle kraal and may be due to mineralization of this land-use's high organic matter content compared with the other land-use systems. Applications of organic manure to soil can increase CO_2 emissions [40]. Indeed, after fresh organic matter input to soils, many specialized microorganisms grow quickly and to accelerate the soil organic matter leading to the priming effects [41]. McGill et al. [42] proposed that soluble organic C in the soil is an immediate source of C for soil microorganisms, which in turn emit CO_2. Hence, large quantities of organic manure that are added to agricultural soils every year for supplying nutrients to crops may contribute significantly to CO_2 emission. The measured organic matter content of the various land-use systems decreased in the order of kraal, forest, cropped land, and paddy rice. However, the initial high CO_2 emissions observed from the paddy rice field during the 12-hour sampling time could be due to adequate moisture content which increased microbial activity and hence enhanced the decomposition of organic matter. Thereafter, the emissions decreased steadily, and low CO_2 emissions were observed during the 24- and 48-hour measurement interval. The onset of decreasing CO_2 production from the paddy rice field coincided with a period of flooding (irrigation) of the field. During this submerged period of paddy rice cultivation, CO_2 evolution in the soil is severely restricted due to the flooding condition [43].

The soils of the studied forest land-uses contained a high amount of organic matter due to the accumulation of litter fall over time. During decomposition, microbial tissues and depolymerization products are produced which undergo chemical stabilization through complexation with mineral cations or physical stabilization by clays [44]. Since vertisols contain heavy or high amounts of clay, the stabilized materials decompose about 100 times slower than the original litter [44]. The forest soil CO_2 emission at the Kpong site was therefore low compared to emissions from the kraal. However, the emissions were significantly higher than emissions from the cultivated soils.

Cultivation of the soil increases the mineralization of the soil organic matter and hence the emission of CO_2 [45]. The decomposition of soil organic matter is increased by the physical disturbance caused by soil cultivation, which breaks down macroaggregates and exposes the carbon protected in their interiors to microbial processes [46]. In this study, the low CO_2 emissions from the cultivated soil at the Kpong site could be partly due to its low organic matter content. Even though cultivation is expected to expose the organic matter to microbial decomposition, the heavy clay nature of this site's soil might have protected it. This may have significantly reduced the cultivated field's CO_2 emissions compared with the other land-use systems except for the paddy rice where flooding conditions impeded CO_2 emissions. At the Legon site, the cultivated field contained the lowest organic matter content, but it had high CO_2 emissions compared to the woodlot and forest land-uses. This may be due to the low clay content (i.e., sandy nature) of this site's alfisol soil which exposes the organic matter to microbial decomposition.

Soil temperature and moisture content are abiotic factors which influence processes that affect the dynamics of soil carbon. Soil microflora contributes 99% of the CO_2 arising as a result of decomposition of organic matter [47], while root respiration contributes 50% of the total soil respiration [48]. Soil temperature affects microbial respiration, whereas soil moisture affects microbial respiration and soil respiration, and hence CO_2 evolution [49, 50]. Maximum CO_2 evolution was noted on the 1st and 3rd of November (at 88 and $78\,mg{\cdot}m^{-2}{\cdot}h^{-1}$, resp.). This may be attributed to the increasing role of root activity and organic matter decomposition in line with an increase in soil temperature which peaked at 36.5 and 35.7°C on the 1st and 3rd of November, respectively.

At the Legon site, even though the forest floor had a higher organic matter content than that of the woodlot, low CO_2 emissions may be due to the low soil temperature slowing decomposition of its organic matter. Indeed, soil temperature can have a marked effect on CO_2 evolution from the soil [51]. Considerable variations in soil CO_2 emissions during different periods (i.e., day and night) were observed. Soil CO_2 emissions from the various land-use systems during daytime were higher than the night time production. This may be attributed to the higher soil temperatures during the daytime measurements.

4.2. Temperature and Moisture Effects on CO_2 Emissions. Soil water content and soil temperatures are known to be important drivers of soil CO_2 production, and they may change as a result of forest thinning [52, 53]. Similar to Tang et al. [54], we used both soil water content and soil water content squared in our model. In many research studies, soil temperature was noted to be a strong and positive predictor of soil respiration, accounting for 43–75% of the variation in soil CO_2 production rates [55]. On the other hand, increasing soil moisture would increase CO_2 evolution up to an optimum level, above which it would reduce CO_2 evolution [51]. The interaction of soil temperature and soil moisture assumes great significance in view of global warming and likely disturbance in precipitation patterns. However, Kowalenko et al. [56] observed that temperature was the most dominant factor in determining CO_2 evolution from the soil.

The regression of soil temperature on soil CO_2 production (Legon site) showed a positive correlation, with CO_2 evolution increasing as soil temperature increased. Soil temperature explained up to 65% (on cultivated land) of the total CO_2 production in the regression model. This strong relationship between soil temperature and CO_2 production is expected since soil respiration rates reflect heterotrophic and autotrophic activities that are highly temperature dependent [56]. This was reflected by the soil CO_2 emissions of the forest (with a low soil temperature) being low compared to the emissions from the kraal and cultivated land-use systems, of which the latter had a particularly high soil temperature. The temperature sensitivity coefficient (i.e., Q_{10} values) is a convenient index for comparing the temperature sensitivity of soil CO_2 production. It is commonly used to express the relationship between soil biological activity and temperature [58]. The Q_{10} values from 25 to 35°C for CO_2 emissions in this study suggests that CO_2 emission was controlled primarily by soil biological activity. It is estimated that a 1°C increase in temperature could lead to a loss of 10% of soil organic carbon in regions of the world with an annual mean temperature of 25°C [59]. While in regions having a mean temperature of 30°C, a 1°C increase in temperature would lead to a 3% loss of soil organic carbon.

5. Conclusion and Way Forward

Measurement of CO_2 emissions from soils of different land-use systems allows the understanding and accurate evaluation of soil management practices to reduce GHG emissions. In our study, soil CO_2 emissions were significantly influenced by different land-use systems. Soil organic matter decomposition and mineralization were the main drivers of CO_2 emissions. The soil itself could serve as a source or sink of $CO_{2,}$ depending on the management or land-use system imposed on it. Land-use systems which often disturb and expose the soil's organic matter to decomposition and mineralization are liable to emit more GHGs.

In our study, cattle kraals emitted large and increasing amounts of $CO_{2.}$ This suggests that such kraals could become an increasing threat to global warming due to the large tracts of land occupied by livestock in developing countries. To reduce CO_2 emissions from cattle kraals, livestock management systems such as improved pasture with low stocking rates must be practiced. Our studied woodlot and forest land-uses recorded relatively low CO_2 emissions. This was despite the high organic matter content of their soils and could be attributed to the low level of soil disturbance in these land-uses. This finding implies that maintaining forest reserves and promoting agroforestry systems that include woodlots is highly desirable for mitigating GHG emissions. We also found that CO_2 emissions from the lowland rice paddy field peaked when oxic conditions were maintained. Periodic flooding of the field (anoxic condition) often reduced CO_2 evolution; however, research studies show that this condition can promote CH_4 production. Due to the lack of access to a gas chromatograph (GC), other GHGs such as CH_4 and N_2O could not be studied. While it is important to reduce CO_2 emissions through maintaining some head of water on the soil surface (i.e., flooding), periodic drainage is also important to reduce CH_4 emissions.

Overall, several factors influenced CO_2 emissions from the different land-use systems in our study. These include inherent properties of the soils such as texture, temperature, and moisture content which influenced CO_2 production through their effect on soil microbial activity and root respiration. Soil temperature explained more than 50% of the variation in soil CO_2 production. A temperature coefficient sensitivity Q_{10} of 4.1 depicts that the soil CO_2 emission was controlled primarily by soil microbial activity.

Hence, development and implementation of practices that increase tree cover to directly reduce emissions through carbon capture and sequestration should be of priority in the study area. This will help to mitigate global GHG emissions but importantly will also help to maintain or increase crop productivity and thereby improve global or regional food security.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The authors thank the University of Ghana for providing land for our research and laboratory for sharing chamber caps and canisters. The authors also thank Dr. John Meadows for proofreading and editing this paper.

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