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Cocoa farmers' perceptions of soil organic carbon effects on fertility, management and climate change in the Ashanti region of Ghana

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Farmers can play an important role in climate change mitigation through sustainable soil management practices. Semi-structured interviews were conducted in the Atwima Nwabiagya municipality of Ashanti region, Ghana, to explore farmers' knowledge and perceptions of their soils, soil fertility, applied management practices, and climate change on soil organic carbon. The interviews included topics related to farmers' access to training and its impact in adopting and changes in management strategies. Summary for interviews was prepared based on notes and recordings and analyzed with the Qualitative Content Analysis (QCAmap) software using emergent codes. Results show that farmers had a lot of knowledge on soil organic matter (SOM) and how it affects climate and the relationship between SOM and soil fertility. They also acknowledged that their management practices affect quantities of SOM in topsoil and subsoil and soil fertility. The adoption of current and new management practices including, the use of organic and inorganic fertilizers, manure, mulching, and shade management, is a reflection of their newly acquired knowledge and understanding of fertility sustaining processes. The study highlights the relationship between farmers' training and changes in their adopted practices and how management practices affect SOC influencing climate change and soil fertility.

Key words: soil organic carbon, cocoa farmers, perception, soil management, soil fertility and climate change.

INTRODUCTION

Soil organic carbon (SOC) is essential for its contributions to the mitigation and adaptation to climate change and soil fertility critical for food production (Lal, 2004). SOC is the main component of soil organic matter (SOM) and an indicator of soil health (FAO, 2017). Carbon fluxes in the soil are essential in determining

whether the soil will act as a sink for or a source of Green House Gases (GHGs) in the atmosphere contributing to global warming and climate change in general (IPCC, 2013; Batjes, 2014).

Carbon dioxide (CO₂) and methane (CH₄) are the leading human influence emitted GHGs, having carbon

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dioxide as the most abundant carbon-based gas in the atmosphere (FAO, 2017).

According to Le Quéré et al. (2016), it reached 397 ppm in 2014 and IPCC (2014) attributes this increase to fossil fuels' combustion and land-use change, mainly deforestation.

Soil respiration is the second-largest terrestrial carbon flux. The oxidation of organic residues or soil organic matter (SOM) by soil fauna releases CO₂ from the soil into the atmosphere. Contrastingly, soils have storage potential on carbon through soil carbon sequestration (Jobbágy and Jackson, 2000; Bajgai et al., 2013; Batjes, 2014; Vashum et al., 2016). Atmospheric carbon is stored through plants or organic residues and transferred to the soil as soil organic carbon (SOC), known as the labile pool (Batjes, 2014; Chandler, 2016).

Soils with high SOM content provides nutrients to plant and improves water availability (Ayalew and Dejene, 2012). Moreover, SOC is essential for soil structural stability as it promotes the aggregate formation and improves porosity ensuring good aeration and water infiltration to support plant growth. SOM is the primary provider of organic nutrients to the soil; hence, an undisturbed forest soil can be cultivated for a period of time without adding inorganic nutrients to it (Quansah et al., 2001). According to Quansah et al. (2001), farmers from the southern part of Ghana also view SOM and soil fertility as interrelated.

Cocoa (*Theobroma cacao*) contributes about 25% to Ghana's GDP and employs about 60% of the total farmers in the country, providing over 700,000 jobs to farmers in the southern belt (Kolavalli and Vigneri, 2011). It grows well within the moist and semi-deciduous forest zones having double maxima rainfall regime (Omoshola, 2015), explaining why about 1.45 million hectares of forest land have been displaced for its cultivation (Mohammed et al., 2016). Cocoa farming is dominated by smallholder farmers who cultivate small farms of about 0.5 to 5 ha (Dawoe et al., 2014; Omoshola, 2015). It is grown under non-shaded (full sun) or shaded (agroforestry) systems having cocoa trees mixed with upper canopy trees (e.g., *Terminelia superba*, *Newbouldia laevis*) and food crops (plantain, cocoyam, and cassava), respectively (Afrifa and Acquaye, 2010). Cocoa trees are spaced at 2.4 × 2.4 m to 3.6 × 3.6 m, and the heights of matured cocoa trees range between 4 and 8 m (Dawoe et al., 2014). The potential of cocoa agroforestry systems to either sequester carbon dioxide from the atmosphere or emit sequestered carbon from the soil back into the atmosphere in response to farmers' management practices is well established (Afrifa and Acquaye, 2010; Wade et al., 2010; Dawoe et al., 2014). What is still not well understood is cocoa farmers' perception about how their management practices impact on soil organic matter in their farms. This study (i) explores farmers' perception on soil organic matter and soil organic carbon, (ii) assesses the perception of

farmers on management practices adopted on cocoa farms that affect soil organic carbon content, and (iii) assesses farmers' perception of climate change, the effect of climate change on SOM/SOC and the effects of SOM/SOC on mitigating the impacts of climate change.

MATERIALS AND METHODS

Study region

The Atwima Nwabiagya municipality is one of the forty-three administrative districts in the Ashanti region found in the southern part of Ghana, which lies approximately between latitude 6° 32'N and 6°75'N and between longitude 1°36' and 2°00'West (Figure 1). It is situated in the western part of the region and covers an estimated area of 184 km². According to the 2010 population and housing census, the population was 149,025 with an annual growth rate of 2.6%. The municipality is marked by a double maximum with annual rainfall between 170 and 185 cm. The major rainfall season is from mid-March to July, and the minor season is between September and mid-November. Temperature is fairly uniform, ranging between 27 (August) and 31°C (March) (Atwima Nwabiagya Municipality, 2018). The vegetation is predominantly a semi-deciduous forest type but has mostly been influenced by human activities. The dominant soils are developed from weathered Phyllites, Schist, Greywack, and Gneisses (Adu, 1992; Atwima Nwabiagya Municipality, 2018).

Agriculture

Agriculture in the current study area involves the cultivation of food crops (plantain, cocoyam, cassava, maize, rice, and local and exotic vegetables), cash crops other than cocoa (oil-palm and citrus), cocoa, livestock rearing, and forestry. It has a farmer population of about 29,700. Amanchia, Kobeng, and Seidi are some of the major cocoa-producing areas in the municipality. Citrus is cultivated across the whole area and on a large scale, but oil palm is not widely produced. Food crop production is the backbone of the municipality's agriculture setup. The livestock sector comprises the rearing of ruminants, poultry, piggery, and grasscutter (Atwima Nwabiagya Municipality, 2018).

Cocoa cultivation involves land preparation where small parts of primary/secondary forest are cleared and burned to make room for cocoa planting (Akowuah, 2010; Dawoe et al., 2014). Cocoa seedlings are planted and intercropped with food crops such as cocoyam, cassava, maize, and plantain to serve as shade for the young seedlings (Atwima Nwabiagya Municipality, 2018). Where the agroforestry system is adopted, stands of cocoa are mixed with a variable proportion of trees. Fruiting occurs typically 3 to 5 years after planting. Weed control through manual labour is essential for profitable growth. Fungal (black pod disease) attacks of pods can decrease growth hence crop yield (Wade et al., 2010; Kolavalli and Vigneri, 2011; Ashitey, 2012). Most farmers do not apply fertilizers, and yields decrease after about 20 years, but production is possible for up to 50 years (Isaac et al., 2009).

Methods for data gathering and analysis

Semi-structured interviews (Patton, 2002) were conducted with 33 cocoa farmers from three communities, namely, Seidi, Kobeng, and Amanchia, in July and August 2018. Interview questions are shown in the Appendix. Farmers were selected through a purposeful sampling using a key informant and the agricultural extension

Table 1. Tree species mentioned as being used on farms as shade and their botanical or scientific names.

Local name	Botanical name
Emire	<i>Terminalia ivorensis</i>
Odum	<i>Chlorophora excelsa</i>
Mango	<i>Mangifera indica</i>
Sesemasa	<i>Newbouldia laevis</i>
Nyame dua	<i>Alstonia boonei</i>
Mahogany	<i>Khaya ivorensis</i>
Wawa	<i>Triplochiton scleroxylon</i>
Oduma	<i>Musanga cecropioides</i>
Framo	<i>Terminalia superba</i>
Akuokuo nosuo	<i>Spathodia campanulata</i>
Nwama	<i>Ricinodendron heudelotii</i>
Nyankyrene	<i>Ficus exasperata</i>
Papia	-
Atowa	-
Adugene	-

to farmers, a maximum of nine trees is ideal for a 0.8 ha (2 acres) cocoa farm. Farmers perceive these trees to provide shade, which protects the soil from excessive sunshine and conserves soil moisture, thereby minimizing evaporation. Trees improve organic matter through shedding and subsequent decomposition of their leaves and root exudates. Table 2 shows management practices that are perceived by farmers to increase and decrease soil fertility. Farmers perceived practices such as shading, mixed cropping, mulching, and fertilizer application as practices that increase fertility while burning of weeds, excessive use of agrochemicals, and non-pruning of cocoa and shade trees as practices that decrease fertility. Farmers apply practices such as weeding, mulching, pruning, mixed cropping, fertilizer application, manure, and compost application on farms to increase SOM/SOC.

Changes in management practices; fertilizer, manure, and compost application have been made since the start of the plantation, whereas at first, none of these mentioned was applied. *“Ever since I learned about the importance of SIDALCO’s liquid fertilizer on my soils, I have applied it for the past 7 years, and I have seen tremendous changes in my yield”* (Cocoa farmer K1_7). Also, farmers now practice regular weeding and pruning, mulching to increase organic matter in soils.

Farmers said they do not burn their plots; instead, weed residues and litter are used for mulching, which improves soil moisture and micro and macrofauna functioning, leading to carbon increase in the soil. Cocoa pod husks are also applied as mulch material. Farmers said they avoid management practices that decrease their soil fertility.

Farmers were aware that their management practices affect the quantities of soil organic matter. While a few

said their practices affect only the top layer of organic matter on their farms, the majority said both the topsoil and subsoil are affected.

Most of them said within the period ranging from the past four (4) months (prior to the interviews) dating far back as 25 years ago; they had made changes in their farm management practices. The majority of those who had done major changes said this was within the last 10 years. Changes included (i) weeding and using of residue as mulch, (ii) application of inorganic and organic fertilizers, (iii) reduction in the use of weedicides and herbicides, (iv) use of pesticides, and (v) organic amendment (local compost and manure).

The key challenge mentioned by farmers was a monetary constraint that hinders the continuity and implementation of old and new management practices that increase soil fertility, increasing crop yield.

Access to training

Most farmers attest to or claim to have observed improvement in the OM content or fertility status of their fields, and they were therefore optimistic that if this trend continued, there would be an increase in cocoa beans yield in the next 10 to 20 years. This understanding of associating increased cocoa beans yield with increased soil organic matter and fertility over time is likely to have been informed by their involvement in training and capacity building activities organized by MoFA and some NGOs.

Out of the 33 interviews, 20 farmers had gone through training related to agriculture, farming, and soil management. Training undertaken by farmers is likely to have significantly influenced their adoption of new and

Table 2. Farmers' responses to management practices that increase or decrease soil fertility.

Increase fertility	Decrease fertility
Mulching	Burning of weeds on the farm
Weeding/no-burning	Excessive use of chemicals (weedicides and pesticides)
Fertilizer application	Tillage
Shade to protect soil and crops	No-pruning
Turning up of soil surfaces	
No-till	
Litterfall	
Mixed cropping	

improved farm management practices. The training was organized for farmer groups and facilitated by field extension officers from the Ministry of Food and Agriculture (MoFA) and the Howard G. Buffet Foundation Centre for No-till Agriculture (NGO). *“Through this foundation, I have learned about the importance of mulching on soil fertility. I now have a job with them which enables me to transfer this knowledge to other farmers in the community”* (Cocoa farmer S2_2). Training methods included seminars, field demonstrations, and farmer field schools under special cocoa farming-related programs. According to some farmers, the Howard G. Buffet Foundation Centre for No-till Agriculture had a school located in the Amanchia community for the training of farmers on acceptable agricultural management practices about climate change effects on crop growth, organic matter, and soil fertility in general. Farmers also learned from their fellow farmers and shared their good management practices when they visited each other's farms. *“I have not had any formal training on any management practice, but I learn a lot from my colleague farmers when I visit their farms”* (Cocoa farmer K1_1).

Farmers' perception about soil and soil organic carbon

None of the farmers knew of the presence of organic carbon in the soil and, indeed, had not even heard about the term, but the organic matter was not new to them. Table 3 shows farmers' perception of factors that influence crop yield, indicators of good soil, organic matter, and effects of organic matter on climate, vegetation, and biological activities on organic matter and how organic matter influences soil properties.

All farmers knew what organic matter was and called it in the Twi language 'Asaase mu Srade3' which literally means 'Fat in the Earth.' All the farmers mentioned at least 3 to 4 of the soil organic matter indicators shown in Table 3. A majority said the organic matter could be found both in topsoil and subsoil at depths of 30 to 120 cm. *“I believe that organic matter can also be found*

in deeper layers, if not how does the cocoa grow considering its root depth” (Cocoa farmer K2_5). The majority said that excessive rainfall and sunshine affect soil organic matter negatively with quantity. Farmers mentioned that litterfall (from cocoa and shade trees) and cocoa pod husks contribute to increasing organic matter and fertilizing the soil and acting as shade to protect the soil. They explained that microorganisms and larger animals like earthworms, termites, ants, caterpillars, millipedes, rodents, etc., aid in soil aeration, water infiltration, and movement of organic matter into the subsoil. One farmer also mentioned the importance of dead tissues of microorganisms that add to the organic matter in the soil. According to farmers, soil organic matter improves soil moisture, soil structure, colour, and soil nutrient.

Perceived changes in soil organic matter and fertility status of farms since cultivation

A few farmers mentioned that there had been changes in either organic matter content or fertility levels of their farms. They assumed possible changes in SOM and soil fertility because of an increase in their crop yield. They also associated poor growth and low yield with declining soil fertility. One farmer said he thinks the organic matter is low on the part of his farm saying, *“part of my land looks very dry therefore cocoa trees in that part of the land is not healthy at all, so I think the soil is tired and has low organic matter”* (Cocoa farmer A3_4). A good majority were not sure if there were any changes. Most were, however, optimistic that within the next 10-20 years, organic matter content and fertility status of soils on their farms would increase due to litterfall and improved management practices, leading to increased cocoa beans yields. A few, however, said that their farms would lose 'strength' or 'die' because of their age and money constraint. One farmer said, *“Looking at how old I am now, I might not be alive and if there is no one to take proper care of it as I do, then the farm would not be in good shape or might even die”* (Cocoa farmer A3_3). A few were not sure of what will happen in the future; they

Table 3. Summary of farmers' response to soil.

Soil related characteristics	Factors and indicators mentioned by farmers
Factors that influence crop yield	Management practices
	Organic matter
	Soil type
	Climate
Importance of soil	Soil organisms
	Plant growth
Indicators of good soil	Habitat for microorganisms
	Colour
	Texture
	Vegetation
	Presence of microorganism
Indicators of organic matter	Age
	Organic matter
	Presence of microorganism
	Smell
	Vegetation
	Colour
	Thickness
Climate effects on organic matter	Moisture content
	Texture
Vegetation effect on organic matter	Rainfall (wet season)
	Sunshine (dry season)
Biological activity on organic matter	Litter fall
	Husk of cocoa pods
	Breaking down of leaves or litter
The impact of organic matter on soil properties	Soil mixing and turning
	Burrowing
	Water movement through soil
	Improve soil structure
	Improve soil colour
	Improve soil texture
	Improve soil moisture

said it would depend on the availability of help they get in terms of money to hire labour to work on the farm and buy fertilizers to improve soil nutrient leading to higher crop yield. *"Weeding is the most difficult thing for me, but I also do not have the means to hire labourers to weed throughout the year"* (Cocoa farmer K1_2).

Farmers' perception of climate change, the effect of climate change on SOM/SOC, and the effects of SOM/SOC on mitigating the impacts of climate change

According to farmers, climate change is known to them

as "Ewiem Nsesaye" in the Twi language, which literally means "Changes in the atmosphere." To them, climate change is mainly about sunshine and rainfall; therefore, soil and cocoa yield is affected by extremes of these climatic factors. They also said excessive sunshine and prolonged dry weather affect soil organisms that aid in SOM formation. On the other hand, some said that heavy rains remove the topsoil that contains most of SOM and also kills some soil organisms and cocoa trees when soils are waterlogged for long periods. They also observed that the effects of organic matter breakdown on climate include worsening drought due to increased evaporation, rains with thunderstorms, and rising temperatures. Farmers reported that litterfall from cocoa trees influences

organic matter formation. Most of them also mentioned cocoa pod husks as a source of organic matter formation. Even though farmers knew the sources of SOM and how they form on their cocoa farms and the effects of rainfall and sunshine (climate) on SOM, they had no idea how SOM influenced climate change.

With regards to soil fertility properties, farmers were of the opinion that the presence of and addition of SOM to soil and its subsequent breakdown influence soil water holding capacity creates a conducive habitat for soil biota (earthworm), and improves soil structure and infiltration of water into the soil thereby minimizing soil erosion.

DISCUSSION

Activities and farm management practices related to SOC/SOM

Soil fertility management strategies and their relation to soil organic carbon

Like farmers in most tropical countries, farmers in the Atwima Nwabiagya district are smallholders farming small tracts of land for subsistence purposes. A cash crop like cocoa is cultivated usually also on a small scale; it is seen as a source of income and household security (Isaac et al., 2009). With the high cost of inorganic fertilizers and their inability to pay for them, farmers have developed indigenous approaches involving nutrient cycling to sustain fertility. Management practices in the current study area have consequently developed over time and have been influenced by the training and other capacity-building programs farmers have had. The readily available source of SOM and SOC to farmers are crop residues which include leaves (litterfall), cocoa pod husks and fine roots turnover (Dawoe et al., 2012; Sollins et al., 1996). Adejuwon and Ekanade (1988), in their study, also reported the use of cocoa pod husks as a residue to increase organic matter in the soil. These residues are used as mulch on the soil surface, enhancing water availability to crops due to lesser evaporation from the soil and better infiltration (López-Vicente et al., 2020). This practice also controls the growth of unwanted weeds and regulates soil temperature (USDA, 2007). The farmers also use the application of manure amendments (organic fertilizers) to increase soil organic matter, as also reported by Paul et al. (2017) on the adoption of compost by farmers in tropical Caribbean Islands. Poultry litter, goat, sheep, and cattle manure are some of the common manures applied by farmers in Ghana, and this is considered to be best in regulating soil acidity (Ayalew and Dejene, 2012). Most times, manure is added to green waste and processed food waste to form compost, which is applied to the soil to increase organic matter and soil organic carbon.

Most of the farmers used inorganic fertilizers (when available) as well to increase soil nutrients. Adjei-Nsiah et al. (2004) made similar observations about migrant and

native farmers in the Wenchi district of the Brong-Ahafo region in Ghana. Majority in the current study apply inorganic fertilizers almost every year because it is cheaper and more readily available than organic fertilizer and increase crop yield as reported by Ayalew and Dejene (2012). Farmers apply any type of inorganic fertilizers when they have access to them, for example, free or subsidized fertilizers from the government (Omoshola, 2015). Inorganic (mineral) fertilizers boost soil nutrients for crop growth, which can improve organic carbon through litterfall, crop residue, and root exudates (Lal, 2010). Even though inorganic fertilizers boost soil nutrients in the short term, continuous use negatively affects environmental elements such soil biota and ground and surface waters through leaching and erosion, respectively in the long term (Mcisaac, 2003; Henneron et al., 2014; Khan et al., 2018). Another important practice is regular pruning in farms, which prevents organic carbon sharing between cocoa trees and unwanted wood and plant climbers (Isaac et al., 2009; Dawoe et al., 2014).

Land cultivation in Ghana is usually manually done using cutlass and hoe for weeding and planting (Akowuah, 2010; Omoshola, 2015). Weeds were cleared and burned to make land accessible for cultivation in the past. In recent years, however, the land is cleared, and weed residues are spread on the field to serve as mulch and organic matter input as they decomposed and mix with the soil (Dawoe et al., 2012). According to Adeyolanu et al. (2013), soil organic carbon decreased after the land was slashed and burned in a study conducted in Nigeria. Farmers perceived trees to be very important in adding up to organic matter. Trees of about 6 to 8 in number are found on farms of about 0.8 ha, and these serve as shade against intense sunshine, regulation of soil moisture, and production of litter (Hartemink, 2005; Afrifa and Acquaye, 2010; Blaser et al., 2017; Wartenberg et al., 2018). Soil moisture also creates a conducive atmosphere for micro and macrofauna to help in the decomposition of litter into humus and improving organic carbon in the soil (Jobbágy and Jackson, 2000; Lal, 2004).

Changes in farm management practices and their effect on SOM/SOC

Since the 1960s, traditional cocoa farms in Ghana though generally characterized with high shade trees density, were subject to irregular weeding, rare disease, and pest control, irregular harvesting, and very little shade management (Craswell and Lefroy, 2001). Omoshola (2015) observed that these management practices normally resulted in low soil fertility hence low yield with an average yield of 32- 46.8 kg per 0.4 ha on some farms in the Ashanti region.

Most farmers said they modified these traditional farm management practices and adopted more ecologically

friendly and sustainable methods. According to them, slash and burn, which was an easy and inexpensive way of clearing land for cultivation, is hardly practised anymore. It leads to soil degradation, fertility loss, increased erosion, and leaching of SOM/SOC. Adeyolanu et al. (2013) made a similar observation about farmers in Nigeria. Another implemented change is the use of herbicides to kill weeds and unwanted plants. This practice was introduced to substitute the slash and burn practice, but currently, farmers said they use it on the minimum rate because it can negatively affect soil biota, which eventually affects SOM/SOC formation. Pruning of side branches and climbers from cocoa trees, weeding, and leaving the residues to decompose on farms (proka) is currently being implemented (Isaac et al., 2009; Dawoe et al., 2012). Though farmers claim they are challenged with this practice because it was labour-intensive and expensive to sustain, they nevertheless believe the practice has helped maintain SOM/SOC and nutrient levels compared to the old practice. They believe competition between cocoa trees and unwanted plants and climbers and epiphytes is also reduced. Application of organic and inorganic fertilizer has become very important for restoring soil productivity (SOM/SOC and nutrient levels). Therefore, farmers now apply fertilizer on their farms, whereas in the past, they did not apply fertilizers (Olutokunbo and Ibikunle, 2011; Ayalew and Dejene, 2012; Hijbeek et al., 2017). This practice also depends on the farmer's socio-economic environment (Baah and Anchirinah, 2010; Janvry et al., 2016). Manure application and local composting are used by a few farmers on their farms in small quantities, especially poultry waste, food waste, and sawdust, to increase SOM/SOC and fertility in general, but that was not the case in the past. All these practices increase SOM/SOC in soils, which aids in a continuous carbon cycle between the soil and the atmosphere.

Access to training and their impacts on management practices

Results showed that current management practices adopted by farmers were as a result of their traditional knowledge and skills as well as that acquired through their involvement in training and other capacity-building activities provided by extension officers, NGOs, and also by fellow farmers. Other studies (Ketterings, 2014; IPA, 2015; Janvry et al., 2016) have also emphasized the importance of farmer training in the adoption of innovative agricultural practices. The scarcity of farmlands has led to agricultural (cocoa) intensification (Gockowski and Sonwa, 2011), putting pressure on the soil as a resource and increased the need for conservation practices and sustainable use of the soil (UN, 1992). This has influenced farmers within the current study area in the adaptation of management practices through the training

given by extension officers, NGOs, and their fellow farmers (Olutokunbo and Ibikunle, 2011). A study conducted by IPA (2015) in Ghana also confirmed that the knowledge of farmers was improved, and farmers were more likely to adopt best practices as a result of receiving extension services and training from community extension agents. The study of Baah and Anchirinah (2010) showed that training activities were mainly centred on soil management emphasizing soil organic matter and soil fertility, which affected SOC. The adoption of these strategies is greatly influenced by the economic status of farmers (Craswell and Lefroy, 2001; Janvry et al., 2016). In the interviews, farmers mentioned lack of money as the main constraint in the implementation of these strategies since their incomes did not allow them to hire labourers and buy fertilizers which are key components in their farming.

Perception of soil and soil organic carbon

To farmers, the soil is the most important terrestrial system since their livelihood depends on it. In their estimation, good soil, therefore, is one that can support plant growth and increased crop yield, which translates into increased household income and better living standards. The current study showed that soil type (texture), organic matter, soil organisms, management practices, and climate are the main drivers of SOC and cocoa yield in the Atwima Nwabiagya district. Bationo et al. (2007) made similar observations concerning agroecosystems in West Africa. Our study showed that soil organic matter (asaase mu sraadee) is the most important soil ingredient. According to them, without it, there is no soil fertility. This corroborates the findings of Dawoe et al. (2012) in the same district. According to Quansah et al. (2001), farmers from the southern part of Ghana also view SOM and soil fertility as interrelated. Many studies have linked soil colour (black) to the presence of soil organic matter as perceived by local farmers (Quansah et al., 2001; Desbiez et al., 2004; Dawoe et al., 2012; Yageta et al., 2019). Farmers in the study area have also made similar observations. The decomposition of leaves, weeds, and crop residues gives soil its dark colour (Lal, 2004, 2015). Organic matter and iron oxides add most to soil colour (Owusu-Bennoah et al., 2000; Rowe, 2005); hence, farmers' perception that black or dark soil represents the presence of organic matter in the soil in this study. Quansah et al. (2001) observed that 91% of farmers in Ghana's humid forest sector assessed SOM status by colour. Dark soil colour enhances the rate of soil warming (temperature) in the wet season and cooling in the dry season and improves soil moisture availability (Jackson, 2014).

Farmers explained the importance of the cocoa tree in forming organic matter through the decomposition of litterfall and cocoa pod husks. This is confirmed by other

studies (Isaac et al., 2005; Isaac et al., 2009). Decomposed and partially decomposed litter generally aids in humus (SOC) formation in tropical forest ecosystems (Malhi and Grace, 2000; Sanchez et al., 2003). SOM/SOC is the primary provider of organic nutrients to the soil. It also acts as a binding agent that makes it easy for nutrients from organic and inorganic fertilizers to be adsorbed onto soil surfaces (Lorenz and Lal, 2005; Chabbi et al., 2009; Lal, 2015). The importance of macro-fauna (earthworm, termites, millipedes, and beetles) and microorganisms in organic matter/SOC formation shown in other studies (Dawoe et al., 2014; Henneron et al., 2014; Chen et al., 2015; Kuria et al. (2018) was also investigated and confirmed in the current study. Through their activities such as mixing, breaking, and burrowing, leaves, weed, and crop residues are broken down into pieces and mixed with soil. Also, through burrowing, there is litter sequestration into nests, termitaria, and biogenic pits that affects SOM/SOC in sub-soils (Chabbi et al., 2009). Their activities aid in aeration and water movement in the soil improving soil fertility (Chabbi et al., 2009). Most farmers reported that organic matter is not only found in the topsoil but also deeper layers of soil and related the existence of soil organic matter in subsoils to the root depth of cocoa trees, which is in relation to the natural science findings on the depth distribution of SOM and SOC (Jobbágy and Jackson, 2000; Sommer et al., 2000; Lorenz and Lal, 2005; Chabbi et al., 2009). These studies identified root exudates and DOC as sources of organic matter and organic carbon in subsoils.

Perception about the effects of SOM/SOC on mitigating climate change effects

According to farmers, they were not aware of the effect of SOM/SOC on climate change. Still, they have observed that in recent years, ambient temperatures have risen (Buxton et al., 2018), which has led to global warming negatively affecting their crop yield. Some of the effects of organic matter breakdown on climate, according to FAO (2017), including worsening drought, rains with thunderstorms, and rising temperatures. Direct sunshine on soil aids in rapid mineralization and subsequent breakdown of carbon compounds back into the atmosphere, serving as a source of CO₂. Yaro (2013), in his work on a small scale and commercial farmers' perceptions of and adaptation to climate variability in Ghana, made similar observations about how farmers are aware of the changes in temperatures, rainfall, and sunshine and how it has been affecting their livelihoods. Buxton et al. (2018) indicated that 33% of farmers interviewed observed longer dry period than before making it difficult to predict rainfall pattern. These findings are in line with this current study showing the experience farmers have in observing climate change over time.

In the current study, farmers have continued to experience the negative effects of climate change. Therefore in pursuit of mitigation, they perceive some of their management practices as some adaptation strategies. Mulching (using cocoa leaves, plantain and cassava leaves, etc.) is one of the strategies for adaptation. While increasing organic matter, it also reduces evaporation, thereby retaining water for plant use during hot temperatures. Also, they perceive that mulching reduces erosion. With soils covered with litter, soils are not easily washed away even with heavy and intense rainfall, thereby protecting SOM/SOC. They believed that in the dry season when there is no rainfall, soil biota can survive because of mulching due to the coolness it gives to the soil (USDA_NRCS, 2014). Most farmers that practised shaded cocoa systems were of the view that shading is mainly to protect cocoa seedlings from excessive sunshine, and this also true for mature cocoa trees. Isaac et al. (2009) and Dawoe et al. (2012) emphasize that trees planted among cocoa protect their leaves and fruits from the hot sun, preventing them from drying and dying.

Conclusion

Farmers' knowledge and perceptions about modern farming systems regarding their soil management practices and their effect on soil fertility have developed over time. Their knowledge of soil organic carbon and its impact on climate change and soil properties was non-existent. Still, they knew a lot about organic matter and soil fertility, and this was based on their experiences and information acquired from their forefathers, fellow farmers, and formal training. Most importantly, their current management practices have been influenced by knowledge gained through their involvement in the training given to them through extension officers from the MoFA and NGOs.

Farmers perceived that there was a relationship between organic matter and soil fertility. Even though they did not have a scientific understanding about this, they knew that soils would not be fertile without organic matter but would be less productive. This expressed knowledge conforms with Dawoe et al. (2012), who confirm farmers' knowledge on nutrient provision through the decomposition of organic plant litter and cycling processes and nutrient loss. This research also shows that farmers perceive their management practices to affect organic matter and soil fertility. The adoption of good and improved practices is dependent on the economic status of farmers. While cash availability is the main challenge farmers face, cash is invariably required to adopt these enhanced practices. Therefore, it was not surprising that farmers believe the sustainability of their farms is dependent on the provision of subsidies and aids. The important role of training provision on

management practices in the study area suggests the need for improved extension services to enable more farmers to be informed about soil management required to mitigate the effects of climate change and increase soil fertility. Against the background that farmers have an essential role to play in the mitigation of climate change for a sustainable future, every opportunity must be seized to educate farmers about the relationship between SOC and SOM and its role in climate change.

CONFLICT OF INTERESTS

The authors declare there are no conflicts of interest.

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APPENDIX

INTERVIEW QUESTIONS FOR FARMERS IN THE ATWIMA NWABIAGYA DISTRICT

INTRODUCTION - ACTIVITIES OF THE FARMERS

1. How would you describe what you do in general?
2. How long have you worked on this farm?
3. What kind of activities do you do?
4. What are some of the benefits you get from cocoa farming?
5. Do you get any subsidies from the government or NGOs which improve your farming activities? Please elaborate if you do.

SOCIAL CAPITAL (RELATION) –ACCESS TO TRAINING

6. Are you a member of any farmer groups?
7. If yes, what are some of the benefits you derive from this farmer group?
8. Do you usually participate in training related to farming, agriculture, soil management?

PERCEPTION OF FARMER ABOUT SOIL

9. In your opinion, what do you think the most important factors that affect crop yield?
10. What is the importance of soil?
11. What makes good soil?
12. Do you know what organic matter is?
13. And what are some of the indicators that show the presence of organic matter on your farm?
14. Do you have any idea if the organic matter can be found in the deeper layers of soil?
15. Do you have any knowledge of soil being able to store atmospheric carbon dioxide? If yes, can you speak a little on that?
16. Do you have any idea of how climate affects organic matter/organic carbon?
17. Does the vegetation (cocoa tree) affect the presence of organic matter/ organic carbon? If yes, how?
18. Can you tell me the importance of macrofauna on organic matter
19. Do you think soils with high organic matter/ organic carbon have good water holding capacities?

MANAGEMENT PRACTICES

20. In your view, what are some of the management practices that can increase or decrease soil fertility (SOM/SOC)?
21. How do your management practices affect soil fertility (SOM/SOC) on your farm?
22. Do your management practices on the farm affect the quantities of soil organic matter/ soil organic carbon in deeper layers?
23. What are some of the good management practices you would want to implement on your farm, but you cannot? Why? (e.g., because it is expensive)

PERCEIVED CHANGES (in the past and the future)

24. Since you have been working on this farm, do you perceive any changes in the landscape, organic matter content, and soil fertility in general?
25. How do you think the farm will look like in 10-20 years? How do you perceive changes in 10 years?
26. Can you suggest some other farmers visit?