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Full Length Research Paper

Impact of shade and cocoa plant densities on soil organic carbon sequestration rates in a cocoa growing soil of Ghana

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Cropping systems have influence on the conservation of soil organic matter. Soil samples were taken from a long term experiment that was designed to study the impact of shade and cocoa plant densities on cocoa yields. The impact of the treatments on soil organic carbon sequestration rates and the gains or losses of soil organic carbon under the treatments with reference to adjacent undisturbed bush were assessed. The experiment was sited at the Bunso substation of the Cocoa Research Institute of Ghana on Rhodi-lixic ferralsol with annual precipitation of about 1500 mm. The shade was provided by forest trees of 18 trees ha^{-1} and no shade, while the cocoa densities were 1111, 1428 and 1667 trees ha^{-1}. Shade effects on organic carbon pools within the top soil (0-30 cm) under cocoa were not significant (p=0.05). Cocoa plant densities per unit area influenced the soil organic carbon pools. The soil organic carbon pools were significantly lower (p=0.05) in the closely planted farms than in the widely spaced farms. There were no soil organic carbon sequestration in the highest cocoa plant density of 1667 trees ha^{-1} but 250 and 190 kg soil organic carbon ha^{-1} yr^{-1} in the top soil (0-15 cm) were sequestered in the soils under cocoa with density of 1111 trees ha^{-1} for shaded and unshaded farms respectively. Irrespective of the shade conditions, the net gains of carbon in the soils were higher in farms with lower cocoa plant density. The results suggest that cocoa planted at low plant density under shade stores more carbon per unit area of soil than an equivalent area of cocoa planted at high density without shade. It is concluded that cocoa farming could be an effective means to mitigate carbon dioxide emissions in cocoa growing countries.

Key words: Soil organic carbon, sequestration rates, cocoa plant density, shade.

INTRODUCTION

Cocoa is an under storey tree and can be planted under thinned forest canopy, naturally regenerating forest or the canopy of artificially planted trees (Greenberg, 1998; N' Goran, 1998). Murray (1975) has summarized most of the impact of shade effects on cocoa as reduction in diurnal variations in both soil and air temperatures, reduction in wind movement and improved nutrient recycling. In spite of these environmental benefits of shaded cocoa, the area of cocoa grown without shade in the major cocoa producing countries of West Africa has expanded largely at the expense of the primary forests which hold large stocks of carbon and play a major role in global carbon cycle (Dixon et al., 1994; Philips et al., 1998).

In recent years there has been growing concerns about the considerable increase in the concentration of carbon dioxide in the atmosphere (Paustian et al., 2000; Albrecht and Kandji, 2003), which consequently make the earth warmer following the rise in atmospheric temperature. The effect of these changes on the climate has resulted in the development of mitigation initiatives (UNFCC, 1992; MEA, 2005).

In Ghana, the Cocoa Research Institute of Ghana (CRIG) recommends to farmers to maintain 16 -18 well spaced mature forest trees per hectare on a cocoa farm with the cocoa trees spaced at 3.0 m apart (Manu and Tetteh, 1987). However, a survey to assess the adoption of CRIG recommendations on cocoa cultivation indicated that majority of cocoa farms had been established at much closer spacing (Donkor et al., 1991) and under full

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Table 1. Land use and management effects on SOC pools (t/ha).

Land use/cocoa density	Depth (cm)		
	0-15	15-30	30-45
Land use			
Shade	24.7	18.9	17.1
No shade	24.5	17.6	15.2
LSD (0.05)	ns	ns	1.5
Cocoa (trees ha^{-1})			
1667	21.8	15.8	14.4
1428	25.0	19.5	16.1
1111	27.1	19.6	17.9
LSD (0.05)	2.5	3.1	1.4

sun (Ruf et al., 2006).

Agro-forestry ecosystems store higher carbon than other cropping systems. (Albrecht and Kandji, 2003; Montagnini and Nair, 2004). The cocoa industry is an important component of the agricultural sector of West African countries. The conversion of agricultural lands to cocoa agroforest could be a management strategy for storing large quantities of carbon to maximize benefits from the lands. The objectives of this study were to assess the impact of shade and cocoa plant densities on soil organic carbon sequestration rates and to estimate historic gains or losses of soil organic carbon under the different land use and management systems with reference to adjacent undisturbed bush.

MATERIALS AND METHODS

Studies were undertaken on a 19 year old experimental plot established to evaluate the effect of shade/variety/spacing on the growth and yield of cocoa at the CRIG substation Bunso (060 13' N, 000 22' W). The design of the experiment has been described by Osei-Bonsu et al. (2000). The soils are Rhodi-lixic Ferralsols (WRB, 1998) with an annual precipitation of about 1500 mm which is optimal for cocoa cultivation. Shade was supplied by 16 to 18 mature forest trees per hectare and half of the plot was under no shade. The cocoa trees were spaced at 3.0 x 2.0, 3.0 x 2.5 and 3.0 x 3.0 m giving cocoa densities of 1667 trees ha^{-1}, 1428 trees ha^{-1} and 1111 trees ha^{-1} respectively. Each sub-plot size was 18 x 18 m. In each sub-plot, two spots were sited and the soils sampled at 15 cm intervals to 45 cm depth. The soils from each depth were bulked and sub sampled to represent each treatment. There were four replicates of the soils sampled. The soils were air- dried and sieved through a 2 mm mesh. The organic carbon concentrations in the soils were determined by the method of Tinsley (1950). Bulk densities were also determined for every soil core as described by the method of Blake (1965). The soil organic carbon (SOC) per hectare per layer (0 -15, 15-30, 30-45 cm) was determined according to the following formula: [%C] x [bulk density] x [depth of layer] with bulk density measured in g cm^{-3} and depth of layer in cm. The differential soil organic carbon sequestration rates were calculated for the land use and the cocoa densities using the adjacent undisturbed bush as a reference treatment and the difference was divided by the years of the experimental duration (Lal et al., 1998). The data recorded was analyzed statistically (ANOVA) and treatment means were compared by the least significant difference method.

RESULTS AND DISCUSSION

The effects of land use and cocoa densities on soil organic carbon (SOC) contents are presented in Table 1. Shade effects were not significant within the 0-30 cm depth but the differences were significant (p=0.05) in the 30 - 45 cm depth. The significant difference in the SOC contents in the 30 - 45 cm depth suggests that roots of both the cocoa and shade trees contributed to the stored SOC pools at that depth. Toxopeus (1986) reported that the root system of the mature cocoa tree consists of a tap-root 120-200 cm long with an extensive system of lateral feeder roots which extend to 40-50 cm. At each soil depth, the carbon content tended to be higher in the shaded farm than in the un-shaded farm. In both shaded and un-shaded farms, the carbon contents decreased with increasing soil depth. Irrespective of the shade conditions of the farm, cocoa plant densities significantly (p=0.05) influenced the carbon contents of the soil. The lowest plant density of 1111 and 1428 trees ha^{-1} recorded significantly (p=0.05) higher soil organic than the highest plant density of 1667 trees ha^{-1} at all soil depths. The soil organic carbon also decreased with increasing soil depth for all plant densities (Table 1).

The interaction between shade and cocoa plant densities were however not significant. The lack of significant differences in shade effects on soil organic carbon in the top soil (0 - 30 cm) suggests that the shade trees contribution to the total litter fall and subsequent addition of carbon to the soils was very minimal. Ofori-Frimpong et al. (2007) observed that shade trees litter fall contributed about 3% of the total litter fall under shaded cocoa farms. The significantly higher soil organic carbon in low density plantings (1111 trees ha^{-1}) compared to high density plantings (1667 trees ha^{-1}) suggest that crop management has influence on carbon storage in soils under cocoa. Minimizing organic carbon mineralization by

Table 2. Land use and management effects on SOC Sequestration rate (kg ha-1 yr-1).

Land use/cocoa density	Depth (cm)		
	0-15	**0-30**	**0-45**
Shade			
Cocoa density (trees ha^{-1})			
1667	-40	-105	-100
1428	+95	+60	+15
1111	+250	+170	+145
No shade			
Cocoa density (trees ha^{-1})			
1667	-55	-120	-100
1428	+135	+65	+30
1111	+190	+70	+40

Table 3. Land use and management effects on percent historic gains (+) and loss (-) of SOC.

Land use/cocoa density	Depth (cm)		
	0-15	**15-30**	**30-45**
Land use			
Shade	+8.1	+2.1	+15.5
No shade	+7.9	-8.8	+2.9
Cocoa (trees ha-1)			
1667	-3.9	-18.1	-2.7
1428	+10.1	-1.0	+8.7
1111	+19.4	+1.6	+20.6

means of managing crops and soil to reduce conditions that break down or oxidize organic matter may be a strategy to increase carbon storage in soil. It may therefore be speculated that perhaps the micro climate within the closely planted cocoa (1667 trees ha^{-1}) enhanced the decomposition of plant material and hence increased organic carbon mineralization in the soil. Under shade and close spacing of cocoa trees, Ampofo and Mensah (1973) observed higher temperatures during the night. This could also enhance the activities of micro-organisms in the soil to release SOC to soluble forms which could be taken by the roots of high density cocoa and shade trees. Table 2 presents the rates of soil organic carbon sequestration in the treatments.

Under each shade regime the highest amount of carbon sequestered was recorded in the low density planting of 1111 trees ha^{-1} at all soil depths. The highest amounts of carbon sequestrated in the 0 -15 cm depth were 250 and 190 kg SOC ha^{-1} yr^{-1} in the lower plant population (1111 trees ha^{-1}) for the shaded and un-shaded farms respectively. The values were equivalent to 900 and 700 kg CO_2 ha^{-1} yr^{-1} respectively. The historic gains or losses of the soil organic carbon pool under the treatments are presented in Table 3. Shaded cocoa gained carbon and was higher in the deeper layer (30 - 45 cm) than in the surface soils. There was a net loss of soil carbon in the 15 - 30 cm soil depth in the un-shaded farm. Similarly, in the closely planted farms (1667 trees ha^{-1}) a net loss of soil organic carbon occurred but there were gains of soil organic carbon in the widely spaced farms (1111 trees ha^{-1}) at all soil depths. These trends in carbon sequestration rates and historic depletion of soil organic carbon in closely planted cocoa may be attributed to the lower concentration of the soil organic carbon under the closely planted farms.

Conclusions

Cocoa planted at low plant density and under shade stores more carbon per unit area of soil than an equivalent area of cocoa planted at high density without shade. Conversion of natural forest to agricultural land with cocoa planted at high density (1667 trees ha-1) resulted in the historic depletion of soil organic carbon but there were gains of soil organic carbon with cocoa at lower plant density (1111 trees ha-1). Soil organic carbon concentrations under shaded and un-shaded cocoa farms were not significantly different but it is suggested that cocoa should be planted under some shade trees preferably 16 to 18 trees ha^{-1} and at the CRIG recommended planting density of 1111 trees ha^{-1} to increase carbon accumulation in soils as a way of reducing carbon dioxide emissions into the atmosphere.

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