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A low input cocoa agroforestry can be a profitable climate change mitigation land use system.

Oppong J.[1], Blaser W.[2] Yeboah E.[3] Six J.[4]

[1]James Oppong, CSIR-Soil Research Institute, Ghana, kwakuoppong677@yahoo.com (*)
[2]Wilma Blaser, Two, brief contact details in one line] wilma.blaser@usys.ethz.ch
[3]Edward Yeboah CSIR-Soil Research Institute, Ghana, eyeboah5@hotmail.com
[4]Johan Six, Dep. of Environmental Systems Science, ETH, Zürich, Switzerland, jsix@ethz.ch

Abstract

A field study conducted in Ghana investigated the variation in soil organic carbon, micro-climate and cocoa bean yield in shaded and non-shaded low input cocoa farms. The aim was to verify if shade trees could both mitigate climate change and also maintain high cocoa yield. Soils of mature cocoa plantations, irrespective of the number of shade trees, contained organic carbon levels ranging from 20 to 25g/kg soil, lower than the 40g/kg soil for virgin forest but higher than 5 to 10 g/kg soil for two- year- fallow lands, used for food crops cultivation. Shade trees reduced maximum daily temperature by 2^{0}C and minimum daily relative humidity by 3%. Reduction in photosynthetic active radiation (PAR), which peaks at 2080 μmol/m²s for bright sunny days, depended very much on the tree heights. Trees had no influence on moisture induced stress on cocoa which occurs when volumetric soil moisture falls below 0.20 m³/m³. Bean yield, generally, is negatively linear correlated with tree density. Average cocoa bean yield of 0.65Mg/ha for tall shade tree population of 33 per ha, is higher than the national average of 0.4Mg/ha. Shade trees in cocoa if well managed mitigate climate change and also give profitability cocoa bean yields.

Keywords: cocoa, agroforestry, soil carbon, weather, yield

Introduction.

Ghana's cocoa *(Theobroma cacao*) industry supports her economic development through employment, family income and direct foreign capital provision. The problem with the cocoa industry is that highest average cocoa dry beans yield per hectare of 0.40 Mg, is the lowest compared to that of other major cocoa producers like Cote d'Ivoire and Indonesia which are 0.6 Mg and 1Mg respectively (ICCO, 2011). This is due to the fact that more than half of the country's cocoa farmers are in low input or low class of producers (Opoku-Ameyaw et al.2010). What is peculiar to this type of cocoa farming is that the farmers nurture their young cocoa with shade trees from the forest and/or planted fruit trees within the plantation creating a cocoa agroforestry. Naturally, the cocoa tree has some physiological adaptations that allow it to grow and produce under shade. However, the level of shade commercial cocoa production requires for good bean yield is not known. Studies done, however, have indicated that cocoa agroforestry has the potential to improve soil fertility and also ameliorate the causes of declining yields (Rice and

Greenberg (2000), Clough et al. (2009) and Tscharntke et al. (2011). What these advocates of cocoa agroforestry, fail to provide is measured data to support the levels to which the presence, number and type of trees, which vary so much in the low input farms, influence the major determinants of cocoa yield; soil fertility and micro-climate. The other economic benefits of these shade trees are also well documented. In contrast other works have reported that sole cocoa, cropped under full sunlight, with adequate minerals and water gives optimum yield. And have gone further to prove that yields of cocoa doubled by removing permanent shading intercepting 30-50% incident radiation with fertilizer application (Lechenaud and Mossu, 1985). The combined effect of climate and vegetation on pedological processes and hence soil properties are well known. In the low input farms, cocoa agroforestry and monoculture are commonly practiced on the same cocoa plantation under the same management. The opposing views require that established low input cocoa plantations gives conducive environment to test the null hypothesis that cocoa is a tree crop that grows equally well under shade provided by other trees or under full sunlight need not create significant variation in micro-climate, soil properties and cocoa yields.

Methodology

The objectives of this study were to measure,

i. carbon content of soil under cocoa plantation, to determine the system's ability to sequester carbon, (as indication of soil fertility and climate change mitigation) compared to other common land use systems that pertain in the area.

ii. Weather (micro-climatic) data to assess how they vary under shaded and non-shaded cocoa.

iii. Cocoa bean yield under shaded and non-shaded cocoa to determine how the presence or absence of trees influences it.

The study was conducted in Ghana during the period April 2015 to June 2017. The study area is enclosed between latitudes, 6.66 and 6.69^{o} N and longitudes 1.82 to 1.95^{o} W within Ashanti region. The age of the cocoa plantations ranged between 15 to 25 years. The area falls within the semi-deciduous forest zone of Ghana and has a bimodal rainfall pattern with peaks in June and September/October. The area has an undulating topography with altitudes ranging from 185 to

240 m above mean sea level. Cocoa plantations' cover slightly over 50 per cent of the landscape and it is the dominant land use system of the study area.

Individual tree species were selection based on height, and economic fruit production. Four replicates each of twenty six tree species, healthy, matured and isolated, were studied for their influence in soil properties. Top soil samples (0-20 cm) were taken with an auger, dried sieve with 2mm mesh and 0.2g was dry combusted for carbon content.

For weather and soil moisture, four replicates each of nine tree species were selected and sensors with dater loggers were mounted under the trees.

Forty plots of size 900m2 with different number with different tree populations of 0, 11, 22, 33, 56, 67, 78,122, 144 and 189 per hectare plots, i.e. four replicates of ten tree population treatments, were demarcated to study how the presence and number of trees per unit area also affect soil carbon, micro-climate and yield. To minimize bias and variation in sampled soils, the plots were divided into 36 grids of 25m2 size from which auger samples were taken from each and composited. The soil samples were dried, sieved with 2mm mesh and a sub sample of 0.2g for each treatment was dry combusted to determine carbon content. Sensors with data loggers to measure weather (photosynthetic active radiation (PAR), temperature, relative humidity) and soil moisture content were mounted within these plots.

Similar sized plots, soil sampling and laboratory analytical methods were used to determine soil carbon for two- year- fallow lands for the cultivation of food crops and virgin forest.

Data on dry bean weight taken for different year of the study.

Statistical analysis

Data from individual trees and demarcated plots were statistically analyzed using the R-statists. The R console's ANOVA packages and linear regression tools were used to compare means of parameters and the degree of agreements between measured parameters by quantifying the amount of variability that can be explained by R^2 respectively.

Results

The total soil C were significantly higher under individual trees than open areas where alone cocoa grows. For demarcated plots (shade gradient plots), there are no significant differences in soil carbon within the range of the number of shade trees studied. However, their organic carbon levels which range from 20 to 25g/kg soil, though lower than the 40g/kg soil for virgin forest , is higher than the 5 to 10 g/kg soil which were obtained for two- year- fallow lands used for food crop cultivation.

The impact of shade trees on micro-climate in cocoa is quite significant. Shade trees reduced maximum daily temperature by 20C and minimum daily relative humidity by 3%. Photosynthetic active radiation (PAR), peaks at 2080 $\mu mol/m^2s$ for bright sunny months, and hardly reaches 1800 $\mu mol/m^2s$ for the overcasts months of July and August it is necessary to prune dense cocoa canopies under shade to increase light penetration during the overcast months to minimize depressed cocoa yield associated with suppressed flower production observed by Asomaning et al. under low light intensities. Rainfall is, no doubt, the most important climatic factor influencing the survival, growth and yield of cocoa but there is high variability in annual rainfall making soil moisture storage more reliable soil information to predict performance of cocoa. From this study, oil moisture conditions that favours optimum growth of cocoa in the study area ranges between 0.25 t0o 0.35 m^3/m^3 whilst moisture stress, indicated by increased leaf senescence of matured cocoa sets in when soil moisture content falls below 0.20 m^3/m^3. The presence of tress in cocoa plantations, however, does not have any marked effect on the level of soil moisture. For most soils it takes about fourteen days to obtain a 0.1 m^3/m^3. reduction in volumetric soil moisture when no rain occurs in the driest month of January. There is, generally, a negative linear correlation between tree density (shade) and cocoa bean yield as shown in fig1. Tall trees allow more shade to enter the cocoa canopy and on the average cocoa bean yield of 0.65Mg/ha was recorded for plots with tall shade tree population of 33 per ha which is higher than the national average of 0.4Mg/ha.

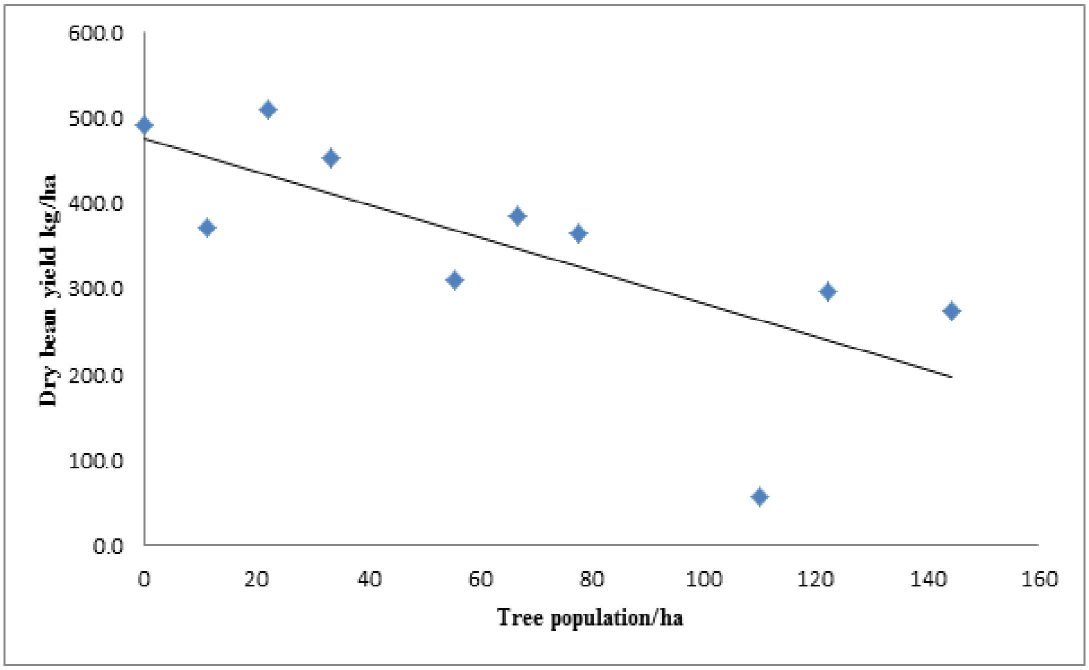

Fig1: Relationship between dry cocoa bean yield and tree population

Discussion

The dynamics of soil carbon in shaded and non-shaded cocoa seems a bit complicated but this study shows that cocoa plantations store more carbon relative to other land use systems in cocoa growing areas of Ghana. Cropping more land to cocoa instead of fallowing them for short period for food production stabilizes the carbon sequested previously by primary forest that are destroyed for cultivation of various crops.

Conclusions

Our results show that trees are able to change soil carbon mainly at the tree level and might hence be beneficial to increase overall soil fertility and help mitigate climate change. However, the lack of variation in soil carbon as tree density increases in the shade gradient plots means effects observed at the individual tree level do not scale up to plot levels. This could be because of high within plot variation. A further study is needed to see when the effect of the high variability in former forest soils has minimum impact on the soils under study.

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