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THE CONTRIBUTION OF MANGO AGROECOSYSTEMS TO CARBON SEQUESTRATION IN NORTHERN GHANA

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Abstract

The amount of carbon sequestered by trees and soils is a tool for determining the sustainability and environmental impact of carbon on ecosystems. This study was conducted to determine the amount of carbon sequestered by a mango (Mangifera indica L.) plantation as well as soil productivity in terms of soil nutrients and other physical properties under mango plantations in Gbullung in the Tolon District of Northern Region. Systematic sampling was used to collect data on tree height and diameter from six (6) sample plots, each of size 50 m x 50 m constituting 15000 m^2 out of the total plantation area of 21432 m^2. Soil samples were collected diagonally at four (4) spots across the plantation. Four (4) control samples were collected on adjacent land use which was 15 m away from the plantation as a control. Soil samples were collected from soil depth of 0-30 cm at 5 m intervals in the mango plantation and in the control and analyzed for pH, percentage Organic Carbon (O.C), percentage Nitrogen (N), available Phosphorus (P) and Potassium (K). The study revealed a mean height and diameter of 3.6 m and 5.7 cm respectively for the studied plantation. The estimated above ground carbon stock density was 3.591 t ha^{-1} while the soil organic carbon was 29.484t ha^{-1}. The study revealed mean pH values of 5.6 and 5.2 for soils under the plantation and soils under the control plots respectively. These means did not differ significantly from each other. The mean level of nitrogen in the soil under the plantation was comparable to the levels of nitrogen (0.05) in the control plots. However, the mean levels of phosphorous, potassium and organic carbon recorded in the control plots were 5.3 mg/kg, 195 mg/kg and 0.66% respectively. These values were not significantly higher than those under the mango plantation. The study concluded that mango agroecosystems sequester substantial amounts of carbon in addition to providing economic gains, although they make little contributions to improving soil nutrients.

Keywords: *Mangifera indica L.*, Carbon sequestration, Soil nutrients, Plantation, Biomass

Introduction

Carbon sequestration is the process by which carbon dioxide (CO_2) from the atmosphere is absorbed by trees, plants and crops through photosynthesis and stored as carbon in biomass such as tree trunks, branches, foliage, roots and soils (EPA, 2010). A variety of human activities lead to the emission of CO_2 which are referred to sources of CO_2 and the removal of CO_2 refers to sinks of CO_2. However, forests and soils have a large influence on atmospheric levels of CO_2 as the forest vegetation serves as a major component of the global carbon cycle and it is estimated that the forest vegetation stores at least 350pg of carbon (Dixton *et al.*, 1994). It is also estimated that as much as 90% of the world's terrestrial carbon is stored in the forest (Houghton, 1996). Although the forest can store high levels of CO_2, the estimated carbon storage by the forest is subject to either an increase or decrease due to factors such as conversion of forest lands to other land uses, harvesting of timber, mining etc. resulting in changes in carbon fluxes to the atmosphere.

These human activities are also considered as factors that lead to loss of vegetation cover resulting in deforestation and forest degradation. Forest degradation and deforestation are said to result in 20 per cent of global green house gas emissions with carbon dioxide taking the greater part. In view of this, tropical deforestation has also been reported to be responsible for about 20 percent of the world's annual carbon dioxide emission (IPCC, 2000). Forest soils are also major sinks of CO_2 because of their higher organic matter content. Soils found under forest vegetation are said to be richer in plant nutrients as a result of high rate of decomposition of biomass and high rate of supply of organic materials in the soil. Globally, soils are estimated to contain approximately 1,500 gigatons of organic carbon, more than the amount in vegetation and the atmosphere (Batjes, 1996 and Smith, 2008). Soil can act as a sink or source for carbon in the atmosphere depending on the changes happening to the soil organic matter. Carbon stored in biomass of trees serves as nutrient recycler and rejuvenating element of nutrients in the soil. Soil organic matter can increase or decrease depending on numerous factors such as vegetation type, climate, nutrient availability disturbance and land use management practices. With the increasing rate of demand on the forest for fuel (fire wood and charcoal production), indiscriminating cutting of trees for timber, mining and equally increasing demand for lands for farming, road construction and other related activities, there is no doubt that the carbon stock balance is affected in most parts of the country and the world as a whole.

Carbon sequestration rates vary by tree species, soil type, regional climate, and topography and management practice (EPA, 2010). Pine plantations of 90 years in the Southeast of USA can accumulate 2.5Mg ha^{-1} of carbon per year (Birdsey, 1996). Changes in forest management (e.g., lengthening the harvest-regeneration cycle) generally result in less carbon sequestration on a per acre basis. Changes in cropping practices, such as from conventional to conservation tillage, have been reported to sequester about 0.1 – 0.3 metric tons of carbon per acre per year (Lal *et al.*, 1999; West and Post, 2002).

Bush burning has been a topic under discussion nationwide (Alhassan *et al.*, 1999) and is found to be one of the effective mechanisms which destroy the natural vegetation that serve as the reservoir for carbon removal and storage (sequestration). As the vegetation is destroyed by bush fires, it decreases the reservoir for carbon storage and this leads to a decrease in the amount of carbon dioxide the vegetation may sequester. There is an increasing need to improve upon the accuracy of estimated carbon storage in forest biomass so that its role in the global carbon cycle can be characterized and understood. The advent of the United Nation Framework Convention on Climate Change (UNFCCC) and its Kyoto protocol has added impetus to the need for such information.

In view of this, countries around the world are developing strategies and measures to mitigate this global problem. Plantations are seen as the alternative way to help solve effects resulting from the depletion of the forest through the degradation and deforestation of forest in order to replace the lost forest and increase the reservoir base for carbon sequestration. This research is to investigate the ability of an organic mango plantation to sequester carbon and add nutrients to the soil. This is intended to highlight the environmental values of mango plantations beside their socio-economic benefits. The specific objectives of the study were to; (1) estimate the amount of above ground carbon sequestered by the plantation (2) estimate the amount of soil organic carbon and (3) to compare the amount of soil nutrients in the mango plantation with that of the surrounding soils.

Materials and Methods

Study Area

The study was conducted at Gbullung, a community in the Tolon District of Northern Region, Ghana which is situated between latitude 08N – 09 29 29N and longitude 00 41W – 001 03 45W.Gbullung is located within the Guinea Savanna zone of West Africa with latitude 9^0 29 N and longitude 0^0 45 W at an altitude of 183 m above sea level (SARI, 2004). The area has a unimodal rainfall pattern with an annual rainfall of 1034.4 mm distributed uniformly from April to late November with temperature ranges of 22^0 C during the rainy season and a maximum of 34^0 C during the dry season (SARI, 2004). The study was carried out on a plantation established in 2005 by Integrated Tamale Fruit Company (ITFC) with a total area of 2.14 ha. The trees were planted at a spacing of 7 m x 6 m between and within rows of trees. Land preparation was done with a hoe and cutlass the following cultural practices administered at various stages; watering, weeding, pruning and mulching.

Experimental Design

Systematic sampling was used to collect data on tree height and diameter from six (6) sample plots (A, B, C, D, E and F) of size 50 m x 50 m out of the total plantation area of 21432 m^2. The diameter at breast height (dbh) and height of individual trees in all the sample plots were measured using diameter tape and graduated stick. Each tree was tagged with a label of its plot name and tree number to prevent double counting. Each tree was recorded individually, together with its identification label (E.g. PaT1 plot A tree 1). For multiple stems, each individual stem was measured separately and the average diameter taken.

Soil samples were collected diagonally at four (4) spots across the plantation. Four (4) control soil samples were collected on adjacent land use which was 15 m away from the plantation. Soil samples were collected from depths of 0-30 cm at 5 m intervals in the mango plantation and in the control plots and analyzed for pH, % Organic Carbon (O.C), % Nitrogen (N) available Phosphorus (P) and Potassium (K) using standard laboratory procedure.

Data Analysis

The Allometric model was used to calculate above-ground tree biomass (AGTB) using the formula

$$AGTB = 0.0509 \times \rho \times (dbh)^2 \times H \quad \text{.....(1)} \quad \text{(Chave et al., 2005)}$$

Where dbh is the diameter at breast height (cm), H is the total tree height (m) and ρ is wood specific gravity (g/cm^3).

$$BSD = \frac{TotalAGTB}{Area} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots (2)$$

Where BSD is the biomass stock density whiles the total AGTB is obtained by multiplying the total number of trees by the AGTB.

The biomass stock density was multiplied by the IPCC (2006) default carbon fraction of 0.47 to convert to carbon stock density.

The soil bulk density is a measure of the weight of the soil per unit volume expressed as g/cm^3 (usually given on an oven- dry (105˚C) basis. Variation in bulk density is attributable to relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. A core sampler was driven into the soil with the aid of a mallet. Soil at both ends of the tube was trimmed and the end flushed with a straight – edged knife. The volume of the core sampler was determined by measuring height and radius of the core sampler.

Calculation; $\rho_d = \frac{(W_2 - W_1)}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$

Where ρ_d = Dry Bulk Density, W2 = Weight of core cylinder + oven – dried soil, W1 = Weight of empty core cylinder, V = Volume of core cylinder ($\pi r^2 h$), π = 3.142, r = radius of the core cylinder and h = height of the core cylinder.

The carbon stock density of soil organic carbon was calculated using;

$SOC = \rho \times d \times \%C$ ……………………………………………..(4) (Pearson *et al.*, 2007)

Where, SOC = soil organic carbon stock per unit area [t ha^{-1}], *p* = soil bulk density [g cm^{-3}],

d = the total depth at which the sample was taken [cm] and % C = carbon concentration [%].

The data on soils under plantations and the surrounding soils were subjected to t-test using GENSTAT statistical software at 5% significance level.

Results and Discussions

Estimation of Above Ground Carbon

The mango trees that were measured had dbh between 4.6– 6.8 cm. The mean dbh was 5.70 cm. The highest dbh was in sampling plot B while the least dbh was recorded in sampling plot A while the least in the 3 – 3.9 cm range (Fig. 1).

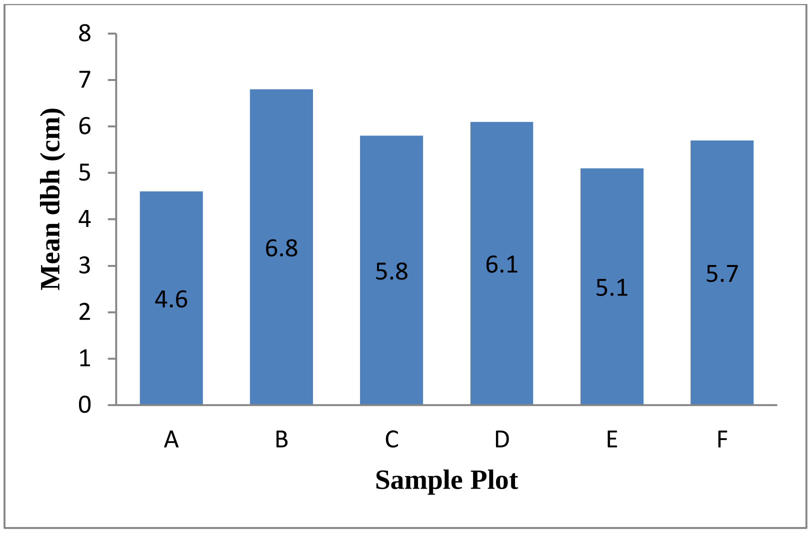

Fig. 5: Mean dbh of mango trees in the various sampling plots

The mean height of trees measured in the sampling plots was 3.6 m for the total number of trees measured. The highest height of 3.9m was recorded on plot E while the least height of 3.1m was recorded in plot A (Fig. 2).

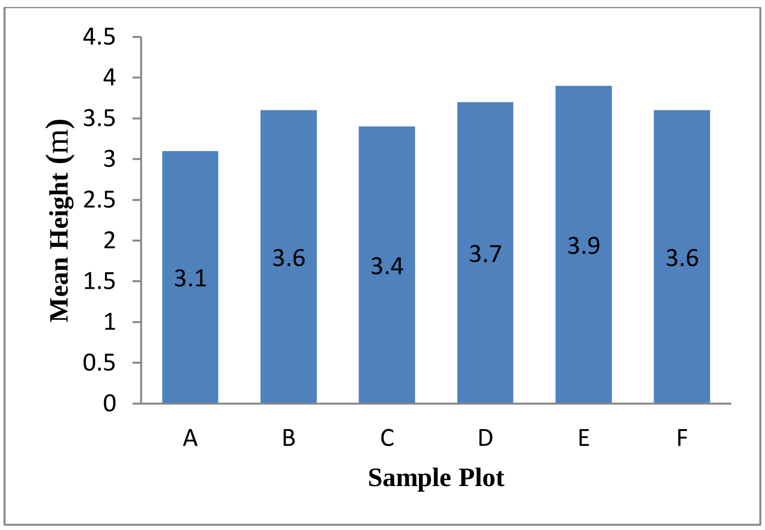

Fig. 2: Mean Height of Trees in the sampling plots

The estimated carbon stock density for the entire plantation was 3.591 t ha^{-1}.The minimal variation in diameter and height of trees in the plantation was due to the fact that the trees were even aged. The diameter and height of the trees had an influence on the above-ground tree biomass obtained from the plantation (16372.5 kg). Perez and Kanninen (2003) revealed that the total above-ground biomass is influenced by the diameter and age class of a plantation. Ibrahim (2011) recorded higher values of AGTB in a study to compare a Teak plantation (2001.31 kg) and a forest reserve (8382.86 kg).This was due to the fact that trees with bigger dbh were recorded in the forest reserve compared with the Teak plantation. Therefore as the diameter of trees increases with age, the above-ground biomass also increases respectively resulting in increases of total above-ground biomass.

The above ground tree biomass is one of the carbon pools in forest carbon estimation. The amount of carbon in living trees increases with time, but carbon is lost during the course of a rotation cycle owing to natural mortality and as a result of thinning and pruning as well as harvesting. The use of the allometric model was to minimize the destructions caused by the use of the other methods which affect the environment apart from the cost being prohibitive. A study conducted by Ibrahim (2011) in a teak plantation using the same method, the above ground carbon stock density of 23.52 t ha^{-1} was recorded, which is more than the above ground carbon obtained from this study in a mango plantation (3.591 t ha^{-1}). This difference may result from differences in the ages of the plantation and their diameter and height differences. In estimating the carbon stock of vegetation, the choice of allometric equation can strongly influence the calculation of the tree biomass (William *et al.*, 2007), but in some cases, site-specific allometric equation for above ground-ground were developed. In view of this, comparing a study conducted by Ryan *et al.*, (2010) where trees ranged in dbh from 5 cm to 73 cm produced a stem biomass of 21.2 tC/ha in Mozambique. This shows that site-specific allometric equation has a link to that particular area.

A study conducted by Baalong (2011), using the allometric equation AGTB = 0.112 x $(pD^2H)^{0.916}$ gave above-ground carbon of 22.94 t/ha and 11.53 t/ha in a forest devoid of anthropogenic disturbance and one subjected to anthropogenic disturbance respectively. These values compared with the results of the above ground carbon obtained from this study (3.591 t ha^{-1}) indicates that biomass stock density of a forest type depend on the allometric model used and stand characteristics (area, dbh and height), which influences the amount of carbon stored.

Although forests in general have much higher carbon sequestration rates than found for a mango plantation in this study, plantations can reduce the adverse effect of deforestation on carbon storage. The estimation of above-ground carbon sequestration potential are based on the assumption that 45% to 50% of branches and 30% of foliage dry weight constitute carbon (Shepherd and Montagnini, 2001; Schroth *et al.*, 2002). The above-ground biomass of an ecosystem serve as basic indicator for productivity (Pearson *et al.*, 2007) whiles the organic carbon in vegetation represents half its dry biomass. The amount and variability of the above-ground biomass and thus of the carbon that an arboreal ecosystem may store, respond to the diversity and relative abundance of the species (Hector *et al*., 1999; Bunker *et al.*, 2005). Despite numerous theoretical and experimental works carried out to date, the relationship between species diversity and ecosystem productivity continues to be one of the most controversial subjects in Ecology (Garnier *et al.*, 1997; Guo and Berry, 1998; Mittelbach *et al.*, 2001). However, in the case of plant communities, this relationship has been studied mostly for grassland and temperate forest.

Estimation of the Amount of Soil Organic Carbon

The soil bulk density of samples collected from the plantation was1.56 g cm^{-3}.Soils are the largest carbon reservoir in the terrestrial carbon cycle and contain about three times more carbon than in the world's vegetation. The soil bulk density from the various plots showed very little variation, which gave a mean value of 1.56 g cm^{-3} which is close to the bulk densities of 1.36 by Ellis and Mellor (1995) as being an ideal for crop production. The value is also lower than the 1.8 g cm^{-3} given by Brown (1981) for sandy soils. This was used in calculating the soil organic carbon. Comparing the mean bulk density obtained from the study to a study conducted by Akrasi (2011) revealed a mean bulk density of 1.46 g cm^{-3} of the control plot than the mean values (1.29 g cm^{-3}) and (1.35 g cm^{-3}) of a five year and three year farmlands of compost application which indicates compost application as having an influence on soil bulk density. Ibrahim (2011) also revealed mean bulk densities of (1.53 g cm^{-3}), (1.37 g cm^{-3}), (1.17 g cm^{-3}) and (1.5 g $cm^{-3)}$ in burnt farmland, unburnt farmlands, forest reserve and a teak plantation respectively, which were comparable to the bulk density recorded in this study.

The result from the study showed that, the amount of carbon in the plantation soils (29.484 t ha^{-1}) was higher than the above-ground carbon of (3.591 t ha^{-1}) sequestered by the plantation. Comparing this to similar work by Ibrahim (2011), the amount of soil carbon recorded from the plantation and forest reserve (5480 t ha^{-1}) and (8185.5 t ha^{-1}) respectively were higher than the above-ground carbon of (23.52 t ha^{-1}) and (98.03 t ha^{-1}). The Soil Science Society of America (2001) recognized that carbon is sequestered in soils in two ways: directly by soil sequestration occurring as inorganic chemical reactions that convert carbon dioxide into soil inorganic carbon compounds and indirectly by plant carbon sequestration occurring as plant photosynthesize atmospheric carbon dioxide into plant biomass. Some of this plant biomass is indirectly sequestered as SOC during the decomposition process. The amount of carbon sequestered at a site reflects the long-term balance between carbon uptake and release mechanisms. Because these flux rates are large, changes in land cover and/or land-use practices that affect pools and fluxes of SOC have large implications for the carbon cycle and earth's climate system.

Afforestation, as a way converting non-forested lands to forests, is a tool for sequestering anthropogenic carbon dioxide into plant biomass. However, in addition to altering biomass, afforestation can have substantial effects on soil organic carbon (SOC) pools, some of which have much longer turnover times than plant biomass but the effect of afforestation on SOC may depend on mean annual precipitation. Berthrong *et al.* (2012), reveals that afforestation increased up to 1012 kg C or decreased as much as 1294 kg C. The findings from this study also revealed that drier sites gained more SOC and total nitrogen as plantations aged, while losses reversed as plantations aged in wet sites, suggesting that plantation age in addition to precipitation is a critical driver of changes in soil organic matter with afforestation (Berthrong *et al.*,2012). This indicates that establishing plantations in the savannah can sequester more soil organic carbon. Comparing the results of soil carbon (29.484 t ha^{-1}) from this study to a study conducted by Anikwe (2010) which revealed higher carbon stocks (7906-9510 g C m^{-2}) found at natural forest sites while plantation forest, artificial grassland ecosystems and continuously cropped and conventionally tilled soils had about 70% lower carbon stock (1978-2822 g C m^{-2}). Comparably Raji and Ogunwole, (2006) revealed that afforestation without recommended soil management practices, using neem and eucalyptus could sequester up to (305 g C m^{-2} yr^{-1}) in the semi-arid savanna while planted *Brachiaria decumbens* in the Sub-humid savanna sequestered about (825 g C m^{-2} yr^{-1}) in 35 years of planting. This shows that vegetation cover enhances the carbon storage capacity of soil. It is also asserted that in savanna woodlands, soil carbon stocks typically exceed woody carbon stocks, and when the woodland is cleared, loss of soil carbon can be a significant flux (Walker &Desanker, 2004).

Comparing the amount of soil nutrients in the mango plantation to that of the surrounding soils

The comparison of the mean values of the chemical and physicalproperties of the soils under the plantation and its control plots (surrounding landuse).

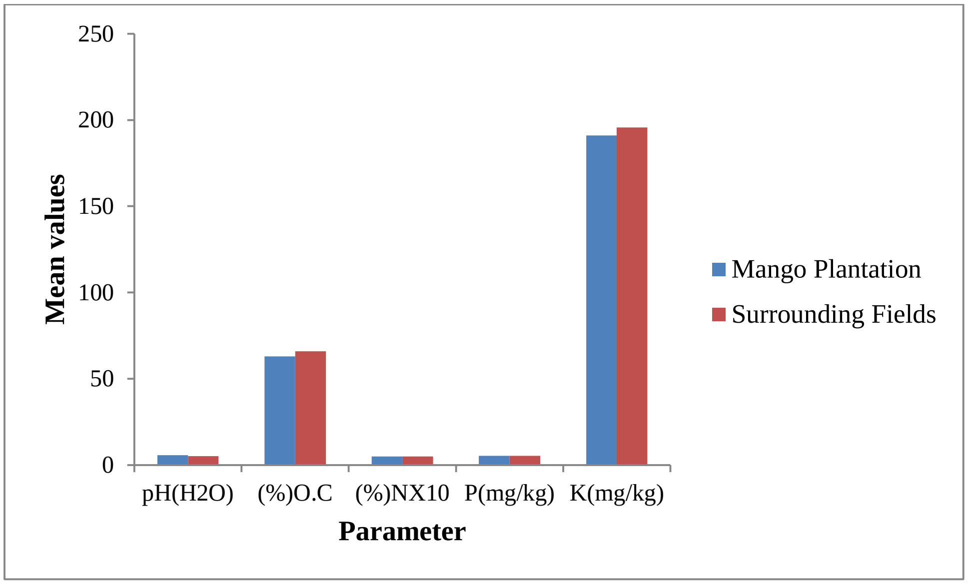

Fig. 3: Comparison of the mean values of pH and soil nutrients of plantation and its control plots.

The mean pH values (Fig. 3) of the soils under the plantation were slightly higher than the mean pH of the soils under the control plot, however the difference was not significant (Table 1). The mean level of nitrogen in the soil under the plantation was the same as the levels of nitrogen in its control plot therefore recording no significant difference. However, the mean levels of phosphorous, potassium and organic carbon in the soils under plantation were slightly lower than the levels in the control plots. This may be due to the fact that, the control plots had been bunt before samples were collected causing the release of these elements into the soil but there was no significant difference ($p>0.05$) between the recorded values. Studies have shown that farm fires which heat the soil to 200° C are actually beneficial because it increase nutrient availability to plants whereas temperatures in excess of 400° C are detrimental because they completely destroy the soil organic matter and reduce the cation exchange capacity of the soil (IFFN, 1996, Gonzáles-Perez *et al.*, 2004 and Knicker, 2005). Comparing the analysis of soil nutrients to a study conducted by Imoro *et al.* (2012) the levels of nitrogen and organic carbon added by the mango plantation (0.05) and (0.63) were less than levels added by the teak plantation (0.35) and (2.4) and *Albizia* plantation (2.3) and (1.9) respectively. However, the levels of phosphorous added by the mango plantation (5.29) were higher than the levels of phosphorous added by the *Albizia* plantation (4.8) but less than levels added by the added by the teak plantation (5.7) respectively. This might be due to the difference in the ages of these plantations. A study conducted by Jaiyeoba (1995) showed that soil conditions were slightly better under *Mangifera* than under *Eucalyptus* plantations but the differences were mostly non-significant.

Table 1. t-test of comparison of soil properties of plantation soils with control means

Parameter	Sample size	Mean	t-statistic	p-value

%OC	8	0.648	-0.46	0.656 NS
K	8	193.300	-0.48	0.646 NS
N	8	0.054	1.28	0.241 NS
P	8	5.312	-0.14	0.895 NS
pH	8	5.460	1.81	0.113 NS

Conclusion and Recommendation

The above ground carbon sequestered by the mango plantation was 3.591 t $ha^{-1}$and it is expected to increase with increasing height and diameter at breast height. Moreover, the soil carbon sequestered by the plantation was 29.484 t $ha^{-1}$and is also expected to increase with time as high litter fall and decomposition of the leaves may contribute to high organic carbon. Since there was no significance difference in nutrients added by the mango plantation compared to the adjacent land use the plantation still serves to protect the soils against the agents of erosion namely wind and rainfall. The study recommends that more communities should be encouraged and assisted by the government and NGOs to adopt the use of mango in establishing plantations and in agro-forestry programmes as they have both economic as well as environmental values.

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