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Net primary productivity, carbon sequestration and carbon stocks in areca-cocoa mixed crop system

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Abstract

Carbon sequestration by terrestrial biomass is one of the mitigation strategies reducing GHGs in the atmosphere. The areca-cocoa mixed crop not only ensures a sustainable crop production, but also serves as a good system for biomass production and carbon accumulation. Arecanut is grown either as mono-plantation or intercropped with other plantations like cocoa, banana, *etc*, whereas, cocoa is grown only as an intercrop of either coconut or arecanut. Areca-cocoa system had a standing biomass of 23.15, 54.09, 87.10 and 121.93 t ha^{-1} in 5th, 8th, 15th and 20th years of growth, respectively. Annual increments in biomass or net primary productivity ranged from 1.38-2.66 t ha^{-1} in cocoa and 3.34-7.11 t ha^{-1} in areca. Parallel to these, CO_2 sequestration ranged from 2.02-3.89 and 5.14-10.94 in cocoa and areca respectively. The standing biomass increased over time indicating accumulation of biomass in stem and also due to increase in yield by arecanut and cocoa plants an age up to 20th year of planting. The study has thus revealed that the biomass and primary productivity is considerable with areca-cocoa mixed crop and comparable to any agro-forestry systems involving cocoa. Arecanut cocoa based cropping systems produce abundant biomass to qualify for carbon sequestration. In this paper, the net primary productivity in an arecanut-cocoa system in terms of biomass production, calculation by biomass models and carbon sequestration are discussed.

Keywords: Areca-cocoa crop system, biomass production, carbon sequestration, soil organic carbon

Introduction

Capturing atmospheric carbon (C) and storing it in the terrestrial biosphere is one of the options, which have been proposed as a mitigation option for greenhouse gas (GHG) emission reduction. Forests, cultivated lands and grass lands are sources of carbon sequestration apart from soil. In UNFCC clean development mechanism, agro-forestry (Albrecht and Kandji, 2003; Montagnini and Nair, 2004), forestation and reforestation (Shrestha *et al*., 2005) are designated for carbon trade. Thus, agroforestry as a land-use system is receiving wider recognition not only in terms of agricultural sustainability but also in the perspective of climate change. Efforts are on to include some other perennial systems like plantation crops in to this mechanism. Once these systems are approved for carbon trade, there will be large demand for plantation crop systems in terms of information on carbon sequestration potential and sustainable crop productivity. The areca-cocoa mixed crop not only gives a sustainable crop production, but also serves for biomass production and carbon accumulation. Agro-forestry systems of cocoa with shade trees have been reported to be good examples of biomass production in Costa Rica (Beer *et al*., 1990).

Arecanut is grown either as mono-plantation or intercropped with other cocoa, banana, *etc*. Whereas, cocoa is grown only as an intercrop of either coconut or arecanut. The area under arecanut is about 0.381 million hectares with a production of 0.483 million MT arecanuts, which provides shade for under-storied cocoa, forming considerable amount of land use system that provides sustenance

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to over six million people. Demand for cocoa is ever increasing both in India and at global level, making this crop more remunerative. Presently, cocoa is grown in an area of 46,320 hectares with about 12,950 MT production. On the other hand arecanut is being consumed locally and national level. However, the income levels of farmers are highly fluctuating owing to market uncertainties. These suggest the importance of stable income from arecanut-cocoa plantation systems. Exploiting carbon sequestration potential of this cropping system is important not only for augmented income but also in the perspective of global warming and climate change.

With this in view, a study on carbon sequestration was made in areca and cocoa mixed cropping system to evaluate the net primary productivity and carbon sequestration potential. Use of models to calculate biomass, the net primary productivity in terms of biomass production and carbon sequestration in the system are discussed. This paper discuss the carbon sequestration potential in areca-cocoa tropical agro-forestry systems and the role they can play in reducing CO_2 concentration in the atmosphere.

Materials and methods

Data were collected from areca–cocoa mixed crop experiments laid out in the Research Farm, CRCRI Regional Station, Vittal (75° E longitude, 12° N latitude, 90 m altitude) during 1991. Soil is lateritic in nature with 5.4 pH. Cocoa plants were spaced at 2.7 x 5.4 m within areca plantation spaced at 2.7 x 2.7 m. Plants were given fertilizers *viz*., NPK @ 100:40:140 and irrigated regularly (20 L/day) during dry season from December to June. All other management practices were followed as per recommended management package.

Development of regression model for biomass estimation in areca

A set of 20 areca palms of different age was destructively sampled for collecting data to be used in development of regression equation for estimating biomass of standing arecanut plantations. The regression model developed for areca is as below:

Total dry weight = $6.0719 - 3.9038\,H + 0.9222\,H^2$

Where, H is the height of palm (m) up to the base of the crown.

Using this regression model, it is possible to estimate dry biomass of areca by giving palm height (below crown) as an input. The R^2 for this model is 0.93 indicating high efficiency for estimating biomass.

In case of cocoa, model developed earlier for biomass estimation was used (Balasimha and Nair, 1989).

The regression model for cocoa is as follows:

Total dry weight = $-8.41 + 0.47\,CA + 0.28\,SG + 2.69\,SH$

where, CA – canopy area (m^2), SG – stem girth (cm) and SH – stem height (m) up to base of crown.

Biomass estimations in cocoa-areca systems

Measurements on growth parameters *viz*., stem height, girth, canopy spread, canopy height on cocoa, and stem height and girth of areca plants in 300 m^2 area were taken for estimating the biomass using regression equations. Data were taken from 21 cocoa and 36 areca plants for calculating the biomass during each year. Results were up-scaled to hectare basis with 1350 areca palms and 675 cocoa trees. All parts of plant like pruned biomass, ripe nuts and pods were accounted for total biomass estimations. Data on pod and bean yield (in case of cocoa) and nut yield (in case of arecanut) were collected from the experimental plot. All data collected as mentioned above were summed to get total above ground biomass production. Harvest index was calculated as ratio of bean dry weight (in case of cocoa) and dehusked nut dry weight (in case of arecanut) to annual total dry matter increment.

Carbon in different plant parts like stem, leaf, twig, pod, husk, nut and bean was estimated by combustion method (Kalra and Maynard, 1991) modified for plant samples. Accurately weighed oven dried plant samples were combusted in a muffle furnace at 500 ^{o}C for 6 hrs. Combusted portion formed the carbon percentage of tissue. Results indicated that the percentage of carbon in different tissue was about 40-44 per cent. Annual increments in biomass and carbon content were also computed.

From these basic data the carbon sequestered was calculated. Carbon content in standing biomass formed carbon stock. From the experimental plot soil samples were collected at 30, 60 and 90 cm depth from the basins of arecanut and cocoa plants. Soil organic carbon was estimated following the modified method of Walkley and Black (1934) as described in (Kalra and Maynard, 1991).

Results

Development and testing of regression model for non-destructive estimation of arecanut biomass

Data on girth of stem at collar, plant height (up to base of canopy) and number of leaves in crown were used as independent variables to develop a regression model for non-destructive estimation of areca biomass. However, it was found that single parameter like stem height up to the base of canopy gave a highly significant goodness of fit for biomass estimation (Fig.1). The model was further validated for biomass estimation and found that the estimated and measured biomass was highly correlated with an R^2 of 0.93. The validated model was used for further estimation of arecanut biomass. Results indicate that this model can be used for non-destructive estimation of arecanut biomass with significant reliability. Estimates were done on hectare basis.

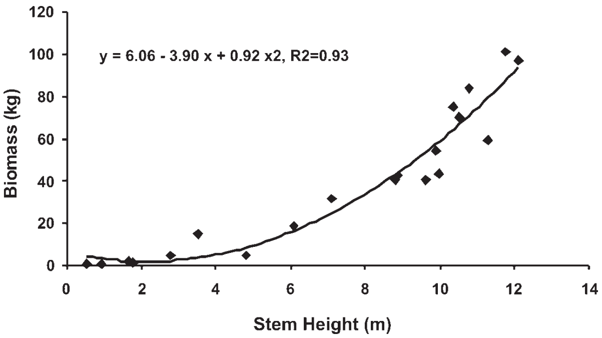

Fig. 1. Regression for estimating areca biomass

Standing biomass, carbon stocks, net primary productivity and carbon sequestration

The results indicated that arecanut standing biomass increased from about 2.92 t ha^{-1} in third year of field planting to about 94.5 t ha^{-1} by the time plantation attained 20 years age after field planting (Fig. 2). This accounts to an annualized increment in biomass of about 5.38 t ha^{-1}. However, this can vary significantly depending on the nut yield which ranged from 0.8 to 1.8 kg plant^{-1} during 20 year period with dry weight varying from 1.1 to 2.4 t ha^{-1}. Arecanut yield stabilizes after eight years of field planting (Balasimha, 2001).

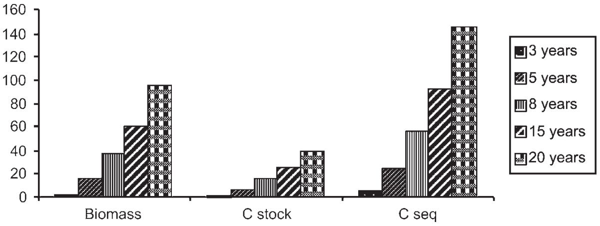

Fig. 2. Biomass, carbon sequestration and carbon stock in arecanut

The areca and cocoa plant samples were estimated for total carbon contents. The carbon content in areca and cocoa plant parts ranged from 39-42 per cent. The concentration of carbon in tissue is multiplied with biomass to get the carbon stocks in arecanut plants. Such standing carbon stocks varied from 1.23 t ha^{-1} in the third year after field planting to 39.69 t ha^{-1} by 20th year after field planting. This makes an annualized increment of carbon stock to about 2.26 t ha^{-1}. Similarly, model developed for cocoa (Balasimha and Nair, 1989) was used to estimate the biomass production by cocoa plants. Estimated cocoa standing biomass accumulated from about 3.02 t ha^{-1} in the third year of field planting to about 27.43 t ha^{-1} by the time plantation attained 20 years age after field planting (Fig. 3). This accounts to an annualized increment in biomass of about 1.43 t ha^{-1}. As in case of arecanut, this can vary significantly depending on the pod yield which ranged from 0.5 to 1.237 kg plant^{-1} during 20 year period with a dry weight varying from 0.3 to 0.8 t ha^{-1}.

The concentration of carbon in tissue is multiplied with biomass to get the carbon stocks in cocoa plants. Such standing carbon stocks varied

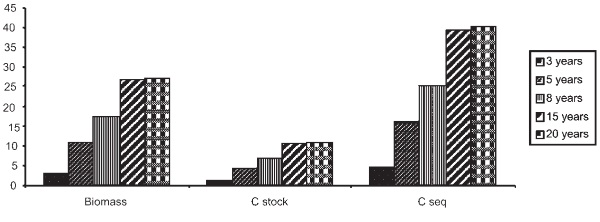

Fig. 3. Biomass, carbon sequestration and carbon stock in arecanut

from 1.2 t ha^{-1} in the third year after field planting to 10.97 t ha^{-1} by 20th year after field planting. This makes an annualized increment of carbon stock to about 0.57 t ha^{-1}. In arecanut-cocoa plantations, the total biomass production is obtained by summing up the biomass of arecanut and cocoa plants in proportion of their population in one hectare. Thus, total standing biomass of areca-cocoa plantations was 23.15, 54.09, 87.10 and 121.93 t ha^{-1} in 5th, 8th, 15th and 20th year of growth, respectively (Fig. 4). Contribution of arecanut plants towards biomass accumulation was greater as compared to that of cocoa.

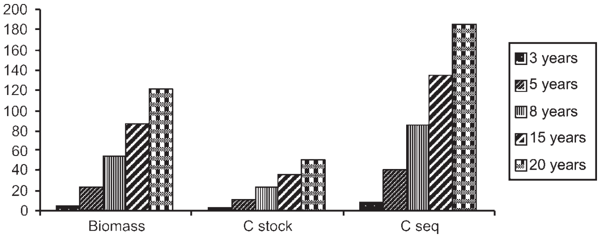

Fig. 4. Total biomass, carbon sequestration and carbon stock in cocoa

The CO_2 sequestration during the years of growth is presented in Fig. 2-4. The sequestration of cocoa increased from 4.44 in 3rd year to 40.27 t ha^{-1} in 20th year. Similarly, in areca it ranged from 4.51 to 145.26 t ha^{-1} during 3rd to 20th year. The total CO_2 sequestration was thus increased from 8.95 in 3rd year to 185.53 t ha^{-1} in 20th year in cocoa + arecanut system.

Estimates of annual biomass increment ranged from 1.38-2.66 t ha^{-1} in cocoa and 3.34-7.11 t ha^{-1} in areca. The total biomass ranged from 4.72 to 9.77 t ha^{-1}. This represents the net primary productivity in the mixed crop system over the 20 year period (Table 1, 2). The CO_2 sequestration in whole system ranged from 7.16 to 13.99 with an average of 10.54 t ha^{-1} annually (Table 2). The yield and harvest index during these years were also presented (Table 3). These variables showed higher values during later years as compared to early years of growth indicating greater partitioning of biomass towards economic yield in later years.

Table 2. Total annual net primary productivity, carbon stock increments and CO_2 sequestration in areca-cocoa system

Parameter	Annual increment (t ha^{-1}) Total			
	3-5 yrs	6-8 yrs	9-15 yrs	15-20 yrs
Biomass	6.87	9.77	4.72	6.96
Carbon stock	2.84	3.81	1.95	2.92
Net CO_2 sequestration	10.48	13.99	7.16	10.62

Table 3. Yield and harvest index in areca and cocoa system

Parameter	Areca age*		Cocoa age*	
	6-8 yrs	9-20 yrs	6-8 yrs	9-20 yrs
Mean yield (t ha^{-1})	1.96	2.05	0.61	0.78
Harvest index	0.28	0.45	0.30	0.57

*from field planting

Soil carbon contents in areca and cocoa basins were estimated (Fig. 5). The total soil organic carbon in the entire area was also computed (Fig. 6). The organic carbon content was higher in areca basin. In both the crops values were higher in upper layer (0-30 cm) of soil profile. These values gradually declined with the depth of soil in basins of both arecanut and cocoa plants. The total carbon on hectare basis was almost 1. 0 lakh kg ha^{-1}.

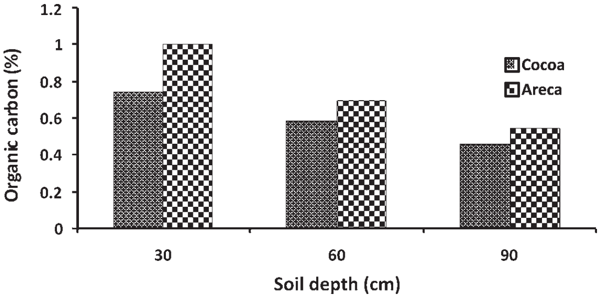

Fig. 5. Organic carbon in soils in areca - cocoa system

Table 1. Annual net primary productivity, carbon stock increments and CO_2 sequestration in areca-cocoa system

Parameter	Annual increment (t ha^{-1}) in areca				Annual increment (t ha^{-1}) in cocoa			
	3-5 years	6-8 years	9-15 years	15-20 years	3-5 years	6-8 years	9-15 years	15-20 years
Biomass	4.21	7.11	3.34	6.84	2.66	2.06	1.38	0.12
Carbon stock	1.78	2.98	1.4	2.87	1.06	0.83	0.55	0.05
Net CO_2 sequestration*	6.53	10.94	5.14	10.46	3.89	3.05	2.02	0.16

*1 CO_2 $t.ha^{-1}$ = C ($t.ha^{-1}$) x 3.67

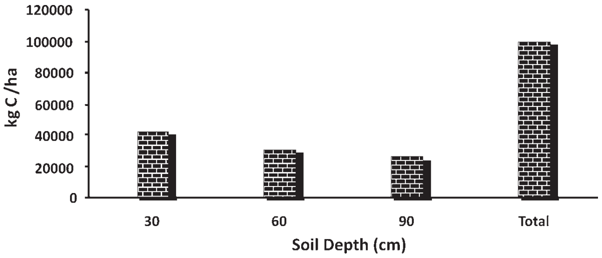

Fig. 6. Total soil organic carbon in areca - cocoa system

Discussion and conclusions

Mitigation of green house gas emission is one of the important aspects related to quest against climate change. Carbon sequestration by terrestrial biomass is one of the mitigation options used for reduction of GHGs. Agro-forestry systems provide opportunity for carbon sequestration under clean development mechanism. Arecanut and cocoa based cropping systems produce abundant biomass to qualify for this. The standing biomass increased over time indicating accumulation of biomass in stem and also due to increase in yield by arecanut and cocoa plant with age up to 20th year of planting. However, the increments were not linear over different periods. The comparatively low values during 9th -15th years may be due to reduced biomass accumulation during that period. Arecanut produces stable yield from eight years after planting (Balasimha, 2001). In case of cocoa yield stabilization takes place around five years of field planting (Balasimha, 2001). Around 30-50 per cent of photosynthetically active radiation is transmitted trough arecanut canopy (Balasimha, 1989; Balasimha and Subramonian, 1984). Cocoa, with its compact and high leaf area, is able to intercept 90 per cent of the remaining PAR. Cocoa production under shade trees has been reported to be 1 t ha^{-1} $year^{-1}$ in Costa Rica (Beer *et al*., 1990). However, biomass production under arecanut and cocoa agro-forestry system under tropical conditions prevailing in India is higher. The micro-climate especially shade, soil moisture and temperature in arecanut gardens were found to be ideal for cocoa growth and productivity (Bhat and Bavappa, 1972). More over these systems are reported to be highly compatible arecanut and cocoa population ratio at 1:2.

Carbon estimations, done on the basis of biomass and carbon percentage in tissue indicate net carbon sequestration by arecanut-cocoa system. The CO_2 sequestration increased considerably during the growth of these plants. Positive carbon sequestration estimations in various land use systems in Southern Cameroon including several shaded cocoa based agroforestry systems were reported (Kotto-Same *et al*., 1997). However, these include the uncertainties related to future shifts in global climate, land-use and land cover, the poor performance of trees and crops on substandard soils and dry environments, pests and diseases. In addition, more efforts are needed to improve methods for estimating carbon stocks and trace gas balances such as nitrous oxide (N_2O) and methane (CH_4) to determine net benefits of agro-forestry on the atmosphere.

High soil organic carbon levels indicate higher sequestration of carbon by soil as well in the system. Temporal changes in soil organic carbon of cocoa-*Gliricidia* agro-forests in Indonesia has indicated that it remains fairly stable in different stratum (Smiley and Kroschel, 2008). Therefore, it can be assumed that areca - cocoa system accumulates high amount of carbon in the soil.

The study has thus revealed that the biomass and primary productivity is considerable with areca-cocoa mixed crop and comparable to any agro-forestry systems involving cocoa (Alpizar *et al*., 1986; Beer *et al*., 1990). However, in view of the fact that only afforestation and reforestration systems can be used for CDMs (Shrestha *et al*., 2005), the areca–cocoa system cannot be considered for carbon trade under clean development mechanism as of now. However, these methods on above ground biomass and carbon estimations provide useful basic information on these aspects and can be used as models in future, if there is any change in the policies before or after 2012 when IPCC is to renegotiate the procedures.

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