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Biomass productivity, carbon stocks and carbon sequestration of cocoa in relation to planting density and canopy regimes

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Forests, cultivated lands and grass lands are sources of carbon sequestration apart from agroforestry (Albrecht and Kandji, 2003; Montagnini and Nair, 2004). 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 into this mechanism. Once these systems are approved for carbon trade, one can expect large demand for plantation crop systems in terms of information on carbon sequestration potential and sustainable productivity. The areca-cocoa mixed crop not only gives a sustainable production, but also serves as a good system for biomass production and carbon accumulation. Agroforestry systems of cocoa with shade trees have been reported to be good examples of biomass production in Costa Rica (Beer *et al*., 1990), Ghana (Ofori-Frimpong *et al*., 2009) and Indonesia (Wibawa *et al*., 2009; Smiley and Kroschel, 2008). Areca - cocoa plantations are reported to produce considerable quantity of carbon sequestration (Balasimha and Naresh Kumar, 2009).

Cocoa (*Theobroma cacao* L.) is grown as a mixed crop in arecanut plantations. The income levels of farmers are highly fluctuating owing to market dynamics. These suggest the importance of stable income from arecanut-cocoa plantation systems. Exploiting carbon sequestration potential of this system is important not only for augmented income but also for mitigating green house gas emissions in the perspective of climate change. In an earlier report effect of spacing and pruning regimes on photosynthesis and yield in cocoa has been reported (Balasimha, 2009). In this paper, biomass estimations, carbon stocks and carbon sequestration in relation to planting density and canopy regimes of cocoa are discussed.

The experiment was laid out with cocoa as a mixed crop with arecanut in 1994 at the Regional Station, Vittal. The arecanut was planted at 2.7 x 2.7 m spacing which works out to 1350 trees/ha. There were two spacing (S1 - 2.7 x 2.7 m; S2 - 2.7 x 5.4 m) and three canopy size (P1 - small, 10 m^3, P2 - medium, 10-15 m^3 and P3 - large, 16-20 m^3) treatments for cocoa. The plants were fertilized with 100:40:140 g of NPK per plant annually and irrigated regularly during summer months. The arecanut palms were four years old at the time of planting cocoa. For cocoa the plant density in these spacing works out to 1350 and 675 per ha in S1 and S2 treatments, respectively. The plot size was 6 trees. The canopies of cocoa were pruned annually during August by removing required quantity of branches and foliage to maintain the pruning regimes.

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) upto base of crown.

Carbon in different plant part samples like tissues of stem, leaf, twigs, pods, husk, nuts and beans 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 to 44. Annual increments in biomass and carbon content were also computed. From these basic data, the carbon sequestered was calculated.

The biomass, carbon stock and carbon sequestration varied in relation to age and treatments. The biomass increased from fourth year to 10th year which showed variations from 4.15 to 33.35 t/ha among the planting density and pruning regimes (Fig.1). The concentration of carbon in tissue is multiplied with biomass to get the carbon stocks in cocoa plants. The increase during the years showed that highest values were recorded in S1P3 treatments (Fig.2). Such standing carbon stocks varied from 1.66 t/ ha in the 4th year after field planting to 13.34 t/ ha by 10th year depending on spacing and pruning treatments. The CO_2 sequestration in different treatments ranged from 6.12 to 48.96 t/ ha (Fig. 3).

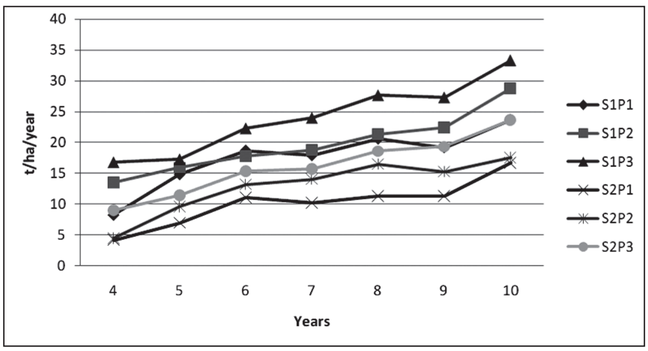

Fig. 1. Biomass productivity in cocoa

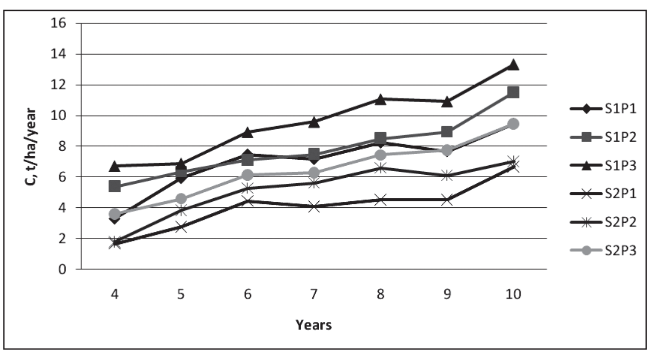

Fig.2. Carbon stock in cocoa

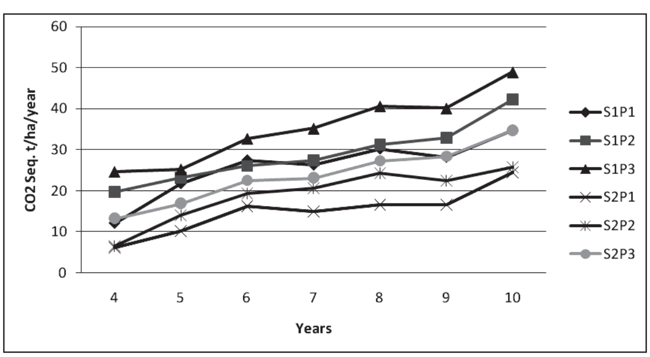

Fig.3. Carbon sequestration in cocoa

Estimates of annual biomass increments ranged from ranged from 2.09 to 2.76 t/ ha/year in cocoa with highest in S1P3. The carbon content ranged from 0.84 to 1.10, while carbon sequestration of cocoa ranged from 3.06 to 4.05 t/ha/year (Table 1).

Table 1. Annual biomass productivity, carbon stock increments and CO2 sequestration in cocoa (t/ha/year)

Spacing	Biomass	C stock	CO_2 Seq
S1P1	2.57	1.03	3.77*
S1P2	2.56	1.02	3.76
S1P3	2.76	1.10	4.05
S2P1	2.09	0.84	3.06
S2P2	2.18	0.87	3.20
S2P3	2.45	0.60	3.59

*1 CO_2 t/ha = C (t/ha) x 3.67

Carbon sequestration by terrestrial biomass is one of the mitigation options used for reduction of GHGs. Agroforestry systems provide opportunity for carbon sequestration under clean development mechanism. The standing biomass increased over time indicating accumulation of biomass in cocoa plant with age up to 10th year of planting. Cocoa, with its compact and high leaf area, is able to intercept 90 % of the PAR. Cocoa production under shade trees has been reported to be 1 t /ha/year in Costa Rica (Beer *et al*.,1990). Cocoa agroforestry system in Ghana was found to be effective in accumulating carbon (Ofori-Frimpong *et al*., 2009). In Indonesia also cocoa agroforestry system showed increased accumulation of carbon over the years (Wibawa *et al*., 2009). The biomass production under arecanut and cocoa system in tropical conditions prevailing in India is high.

Carbon estimations, done on the basis of biomass and carbon percentage tissue indicate net carbon sequestration by cocoa system. The CO_2 sequestration increased considerably during the growth. 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.

The study has thus revealed that the biomass and primary productivity is considerable with areca-cocoa mixed crop and comparable to any agroforestry systems involving cocoa (Alpizar *et al*., 1986; Balasimha and Naresh Kumar, 2009; Beer *et al*., 1990). Therefore, the cocoa mixed cropping with arecanut could be an effective means of mitigating carbon emissions thus contributing to reduce global warming.

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