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Research Article

EVALUATION OF THE CARBON SEQUESTRATION POTENTIAL OF INTERCROPPING SYSTEMS UNDER COCONUT IN SRI LANKA

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ABSTRACT

Perennial plantations play a significant role in mitigating climate change since trees can hold much more carbon per unit area than other types of vegetation. Hence, this study was carried out to investigate the potential of two coconut based intercropping systems, cocoa (*Theobroma cacao* L.) and gliricidia (*Gliricidia sepium* L.) on stocking carbon in their biomass and in soil. The experiment was conducted in a coconut (*Cocos nucifera* L.) plantation of variety Sri Lanka Tall at Makandura (IL_{1a}) intercropped with cocoa (variety Forastero) and gliricidia from August to November 2015. Three systems; Cocoa intercropped with coconut (T_1), *Gliricidia* intercropped with coconut (T_2) and Coconut monoculture (T_3) were compared with three replicates per each treatment. Above ground carbon stock of coconut (stem, leaves & nuts), gliricidia and cocoa were estimated using standard models while soil carbon stock was estimated using standard laboratory protocols. There were no significant ($p>0.05$) differences among carbon stock of stem, nuts and leaves of coconut palms across three treatments. Similarly, no significant ($p>0.05$) differences were found in total above ground carbon stock of coconut palms across three treatments. Conversely, gliricidia used as an intercrop in T_2 had significantly higher total above ground carbon stock of 117.92 MgC/ha when compared to cocoa 47.65 MgC/ha used in T_1. Further the estimated soil carbon content were 20.59, 20.87 and 19.53 MgC/ha respectively for T1, T2 and T3 and no significant ($p>0.05$) differences among treatments. Considering the total ecosystem carbon stock, the highest carbon stock was found in T_2; coconut intercropped with gliricidia, of 138.79 MgC/ha followed by T_1; Coconut intercropped with cocoa, (68.24 MgC/ha) and the lowest by T_3; coconut monocrop, 60.01MgC/ha. The results have revealed the potential of coconut based intercropping systems as carbon sinks with long turnover time in the aspects of mitigation of climate change.

Keywords: *Carbon Sequestration, Climate Change, Coconut, Cocoa, Gliricidia, Soil Carbon Content*

INTRODUCTION

Climate change is directly linked to the build-up of greenhouse gasses in the atmosphere enhancing the natural greenhouse effect (Ranasinghe and Thimothias, 2012). Large number of factors have been identified as responsible for climate change including biotic factors such as anthropogenic activities (land use change, deforestation, burning of biomass) and abiotic factors also (Stocker, 2013). Global warming is a clear indicator of climate change and strongly contributed by greenhouse gases such as carbon dioxide (CO_2), water vapour, Methane (CH_4), Nitrous oxide (N_2O), Fluorocarbons (FCs) in the earth's atmosphere. Such gases are absorbing the heat of the solar radiation, radiated back from the earth's surface changing the energy balance in the atmosphere.

Concentration of the CO_2 in the atmosphere has been increasing rapidly due to large number of anthropogenic involvements including intensive agricultural practices, but combustion of fossil fuels is the largest contributor to emission of Carbon dioxide. Therefore, mitigation measures are essential in order to face this problem and carbon sink expansion has been identified as one of the major measure to mitigate the adverse impact due to increasing CO_2 in atmosphere.

Forest ecosystems and tree plantations could play a significant role in mitigating climate change since trees can hold greater carbon per unit area than other type of vegetation. Under the present context of Sri

Lanka, expansion of forest area is not practicable hence focusing on increase of plantation sector potential is the best alternative.

Coconut is a perennial palm with a lifespan of around 50-60 years and it is important that its carbon sequestration potential or capturing carbon dioxide from atmosphere and its ability of long term storage of carbon especially in the stem. Carbon sequestration potential of the palm can be different due to several factors such as age of coconut plantation, variety, soil type and nutrient management, agronomic practice etc.

However, the carbon sequestration potential of coconut plantations can be greatly enhanced due to higher availability of space and solar radiation to the understory. Therefore, intercropping or agroforestry in coconut lands plays a major role not only in food and economical security but also in sequestration of carbon. However, carbon sequestration potential of coconut based intercropping systems in Sri Lanka has not been broadly studied, except the estimation for coconut monoculture plantations under different growth conditions (Ranasinghe and Thimothias, 2012).

Monoculture coconut lands can be converted in to perennial mixed cropping or agroforestry systems after 20 years of establishment and the large number of selections are available based on the agro ecological region and the preference of the farmer. Among those crops cocoa and gliricidia may have higher impact on carbon sequestration, soil and terrestrial ecology, and also widely used.

Cocoa based agroforestry systems are credited for stocking significant amount of carbon and have a higher potential to mitigate climate change. Due to longer life span and provision of nutrient rich litter and soil organic materials, cocoa is having a higher impact on the agro forestry system than most of the other intercrops. Also, Gliricidia is a multipurpose tree species with rapid growth rate and nitrogen fixing ability, which has diverse habitats around the country with huge ecological and economical potential.

Therefore, this study has designed to evaluate the soil and terrestrial carbon sequestration potential of coconut and coconut based intercropping systems in intermediate zone of Sri Lanka.

Objectives of the study are to determine the total ecosystem carbon stock of two different coconut based intercropping systems comparatively with monoculture and to evaluate the soil carbon stock of two different coconut based intercropping systems.

MATERIALS AND METHODS

Experimental Location

The experiment was conducted in Makandura Research Station (IL1a) from August to November 2015. The age of the coconut stand is around 30 years and the variety is Sri Lanka Tall, *Cocos nucifera* L. Coconut stand has intercropped with several annual and perennial crops, allocating higher proportion of the area for Cocoa (*Theobroma cacao*) and Gliricidia (*Glyricidiasepium*) in Makandura.

Selection of Intercropping Systems, Management and Data Collection

Two coconut based agroforestry systems were selected for the experiment and all the systems and coconut palms were managed with recommended inorganic fertilizers and recommended agronomic practices.

- Intercropping system 1: Coconut intercropped with cocoa (T_1)
- Intercropping system 2 : Coconut intercropped with gliricidia (T_2)
- Monoculture: Coconut only/control (T_3)

Spacing of the gliricidia was 1m x 1m with triangular double row system while cocoa was having 8m single row system, therefore, planting density was higher than cocoa (520 trees/ha) in gliricidia (2400 trees/ha). Age of the cocoa stand was around four years, gliricidia was six years and glyricidia stand was pruned in six months intervals. Three experimental plots were selected consisting six palms for each plot in each intercropping system and three monoculture plots were selected consisting six palms per each as the control. Data collection was done in randomly selected nine coconut palms in each agroforestry system and monoculture stand, and data collection of cocoa and gliricidia was done using 18 trees from each system.

Determination of Carbon Stock of Coconut

For the estimation of carbon stock in coconut, the methods followed by Ranasinghe and Thimothias (2012) were used.

The palms were climbed every month to count the number of nuts in each developing bunch and measured the length of nuts along the long axis (two nuts per bunch). In each bunch, the dry weight per nut was estimated non-destructively by a fitted empirical equation developed for the Tall variety of coconut (Ranasinghe, 2008).

$DM \log = 0.1486+(0.1472 (L\text{-vertical})) – (0.000741(L\text{-vertical})^2)$

DM - Total dry matter content of the nut (g)

L- Vertical; Length of the nut along the vertical axis (cm)

The dry weight of each bunch was estimated by the mean nut weight and number of nuts per bunch and the total dry weight of nuts on a palm were obtained by summing up the weight of all the bunches.

Stem density of coconut was estimated using the age of plantation. Stem dry weight of a palm was estimated by multiplying the volume of the stem with the density (the shape of the coconut stem was assumed to be cylindrical and tapering of the stem towards the top was not taken into account).

$D = 0.0079t + 0.18$

Where, D is density, in g cm^3, and t is age in years after field planting (Friend and Corley, 1994).

Dry weights of total fronds per palm were estimated by using cross-section area of the petiole at the point of attachment of the lowest leaflet and measured width and depth of the petiole on the coconut leaves. Finally multiply from crown leaf load to calculate total dry weight of crown.

$W= 0.13C- 0.25$

Where, C is width × depth of the petiole (Friend and Corley, 1994).

The carbon content of the dry mass was assumed to be 0.5 g C g DM^{-1} (Matthews, 1993; Navarro *et al*., 2008).

The total carbon stock per ha was determined by extrapolating the stock per palm for number of palms available in a given ha of land.

Determination of Carbon Stock of Cocoa and Gliricidia

Trunk diameter at 50 cm height was measured, averaged and used in an allometric equation in the form of $y = da^b$ as derived by Smiley and Kroschel (2008). Following formulae were used to determine the dry mass of gliricidia and cocoa. For the conversion of above ground tree mass to Carbon, the factor 0.45 was used.

Allometric formulae for cocoa and gliricidia dry mass estimations are

Cocoa	0.202kg $Diameter^{2.112}$
Gliricidia	0.294kg $Diameter^{2.269}$

Determination of Carbon Stock in Grass Cover

Cocoa intercropped area and the monoculture was covered with *Brachiariamilliformis* and gliricidia intercropped area was with *Brachiariaruziziensis*. A quadrant of 0.5 x 0.5m was used to take the grass samples and were analysed to determine the carbon content using the wet oxidation method proposed by Walkey& Black (1934), Fernando (1999).

Determination of Soil Organic Carbon Stock

Soil samples were collected from centre of square of coconut at 0 –20 cm depth, using soil augurs in makandura estate and organic carbon content was analysed using the wet oxidation method proposed by Walkey & Black (1934); Fernando (1999).

Using the soil organic carbon percentage, bulk density of the respective soils and total soil volume, total carbon stock per ha (0 –20 cm depth) was determined. The total carbon stock in the ecosystem was determined by the summation of carbon in coconut palms and selected intercrops, with the carbon content of soil.

Due to practical difficulties below ground root biomass and root carbon contents were not taken to the account. Data were analysed using SAS statistical software package (version 9.1).

RESULTS AND DISCUSSION

Total Carbon Stock of Coconut

Coconut in two intercropping systems has not shown a significant (P>0.05) difference in total carbon stock of whole palm comparatively with monoculture and each other (Table 1). Further, nuts, leaves and stems have not shown a significant difference indicating that the introduction of intercrops in to coconut monocultures may not have any negative effect on the potential carbon sequestration of coconut. However, it may depend on the selection of appropriate intercrop, age of the system, the competition of each crop component for the resources of the environment. Cocoa and gliricidia, never reach the height of the crown of coconut, remain as two vertical layers for the rest of the life time and therefore, there was no competition for above ground resources and survive well under the mild shade conditions of the palms. Also, when considering the competition for below ground resources, soil fertility and moisture may not an issue due to the age of the intercrops (cocoa – 4 years and gliricidia – 6 years), and provision of optimum management practices such as application of nutrients, and due to the reasons roots of each crops may not have still invaded each other's root zones.

Table 1: Carbon Stock of Nuts, Leaves, Stem and Whole Palm in T1, T2 and T3 (MgC/ha)

Treatment	Nut (Mg C/ha)	Leaves (Mg C/ha)	Stem (Mg C/ha)	Whole Palm (Mg C/ha)
Coconut + cocoa (T_1)	1.59 ± 0.48^a	7.45 ± 1.16^a	29.18 ± 8.6^a	39.28 ± 7.90^a
Coconut + gliricidia (T_2)	1.81 ± 0.57^a	7.73 ± 0.31^a	27.14 ± 7.05^a	38.23 ± 6.17^a
Coconut monocrop (T_3)	1.99 ± 0.47^a	8.17 ± 0.68^a	28.72 ± 4.73^a	38.88 ± 4.93^a

Means with same letter are not significantly different at p=0.05.

A similar study has been done by Ranasinghe and Thimothias (2012) for the same coconut variety in three different agro ecological regions and two land suitability classes and according to the study carbon stock of coconut was varied in between 17.09 and 25.96 MgC/ha for 25 years old coconut palms and total ecosystem carbon stock was in between 32 and 72 MgC/ha.

Total above Ground Carbon Stock of Cocoa and Gliricidia (MgC/ha)

As results indicated, above ground carbon stocks of cocoa and gliricidia trees were significantly (P>0.05) different (Table 2). Due to comparatively higher planting density and remarkable growth rate, gliricidia has performed better than cocoa. Inheritantly cocoa was not a fast growing crop, due to several beneficial ecological adaptations gliricidia performed contrastingly. Fast regeneration ability after lopping, nitrogen fixation, less space requirement, canopy architecture, requirement of marginal management conditions lead gliricidia to a higher position as a high potential carbon sink under coconut. According to Smiley and Kroschel (2008), in the initial years after the establishment of a cocoa based agroforest, the system biomass and carbon fixation were dominated by gliricidia. Any how it is important to draw the attention on industrial use of gliricidia with the emission of CO_2 while cocoa is acting as long term carbon storage.

Table 2: Above Ground Carbon Stock of Intercrops and Grass Cover (MgC/ha)

Intercropping System	Intercrop	Carbon Stock(MgC/ha)	Grass Cover	Carbon Stock(MgC/ha)
T1	Cocoa (520 trees/ha)	6.95^b	*Brachiaria milliformis*	1.42^a
T2	Gliricidia (2400 trees/ha)	78.6^a	*Brachiaria ruziziensis*	1.29^a
T3	-	-	*Brachiaria milliformis*	1.6^a

Majority of the land extent was covered with *Brachiaria* grass species, which are also having an appreciable potential of carbon sequestration due to its fast growth. With comparing perennials, grasses are having shallow adventitious root systems functioning in uppermost one or two feet in the soil which are having greater impact on soil organic carbon, remaining in the soil while removing the above ground component as livestock feed. The addition of dead leaf materials and roots were significantly contributed to increase the physical, chemical and biological functions of the soil due to high decomposition rate. In this study *Brachiaria milliformis* and *Brachiaria ruzizien*sis were found as the grass covers which have not shown significant (P>0.05) difference in its carbon stock. Anyhow grass cover in monoculture has shown a slight higher carbon stock per unit area and it might be due to higher availability of solar radiation than intercropping systems (Table 2).

Total above ground carbon stock is highly significantly (P>0.05) different in gliricidia intercropped coconut system, mainly due to higher performance of gliricidia than cocoa (Figure 1).

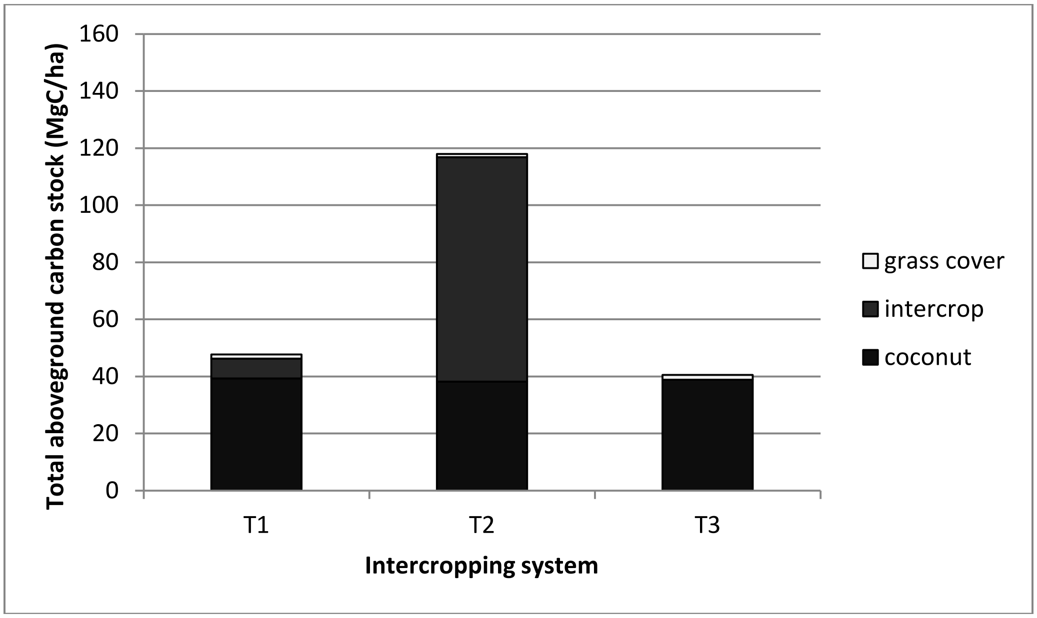

Figure 1: Total above Ground Carbon Stock in Intercropping Systems (MgC/ha)
(T1: Coconut + Cocoa + Grass, T2: Coconut + Gliricidia + Grass, T3: Coconut + Grass)

Soil Organic Carbon Stock in Intercropping Systems

There was no significant (P>0.05) difference in soil organic carbon content in intercropping systems (Table 3). Agroforestry systems in which high amounts of organic materials are added to the soil, such as the shaded perennial-crop systems, have special relevance because of their high potential for sequestering carbon in soil (Muñoz and Beer, 2001; Montagnini and Nair, 2004; Oelbermann and Voroney, 2007).

Organic carbon occurs insoils in a number of different forms including living roots and hyphal biomass, microbial biomass, and as soil organic matter (SOM) in labile and more recalcitrant forms. Therefore, soil organic carbon percentage or content clearly indicates the impact and contribution of vegetation on enhancing soil properties.

In coconut lands the main crop; coconut is not heavily contributing to the carbon pool of coconut square due to not adding enough dead materials and below ground roots to the avenue in between coconut rows. Therefore introducing intercrops into coconut lands is having high influence in above and below ground carbon sequestration. Recorded soil carbon percentages in each three systems were not comparatively high due to both intercropping systems are still in younger stage (4-6 years). According to the Ranasinghe and Thimothias (2012) soil carbon stock in monoculture coconut systems varied between 14.15 to 44.17 MgC/ha while present study also recorded comparative values in monoculture and in intercropping systems.

Table 3: Soil Organic Carbon Stock of Coconut Based Intercropping Systems (0-20 cm) (MgC/ha)

Treatment	Bulk Density(g/cm^3)	Total Soil Carbon Content (MgC/ha)
Coconut + cocoa (T_1)	1.52±0.03^a	20.59^a
Coconut + gliricidia (T_2)	1.52±0.02^a	20.87^a
Coconut monocrop (T_3)	1.54±0.02^a	19.53^a

Means with same letter are not significantly different at p=0.05

The extent to which the C released from the decomposition of the high amounts of litter fall that is continuously deposited on the soil surface in cacao-based Agroforestry systems (and other shaded perennial crop systems) is retained (sequestered) in the soil depends to a large degree on the soil properties, especially soil aggregation (Six *et al.*, 2004; Gama-Rodrigues *et al.*, 2010; Nair *et al.*, 2010). Due to continuous addition of leaf litter and dead biomass in agroforestry systems, microbial biomass and decomposition rate are higher and therefore with the time soil carbon percentage is increased.

Table 4: Total Ecosystem Carbon Stock in Intercropping Systems (MgC/ha)

Intercropping System	Total Ecosystem Carbon Content (MgC/ha)
Coconut + cocoa (T_1)	68.24^b
Coconut + gliricidia (T_2)	138.79^a
Coconut monocrop (T_3)	60.01^b

Means with same letter are not significantly different at p=0.05

The extent to which such organic materials are deposited depends on both species (the crop and the shade tree) and the management systems involved. Due to higher intensities of harvesting soil carbon pool may not lead to increase significantly with the time comparatively with species which having lower harvesting intensities, therefore, due to higher lopping intensities in gliricidia intercropped lands may not exhibit outstanding performance than cocoa and others even it provide high nutrient litter.

Total Ecosystem Carbon Stock in Intercropping Systems

Total ecosystem carbon stock was significantly ($P>0.05$) higher in gliricidia intercropped system. This was mainly attributed to above ground carbon stock of intercrops (Table 4). Therefore, with lower lopping intervals gliricidia is performing remarkably as carbon storage in coconut lands while cocoa is performing somewhat slower.

Conclusion

Nuts, leaves, stem and whole palm carbon stock of coconut palms in three systems were not significantly different indicating that there is no significant effect on coconut by intercrops with respect to carbon sequestration. Total above ground carbon stock was highest in gliricidia intercropped system and total soil carbon stock was not different among three systems. Total ecosystem carbon stock was highly significantly different due to outstanding performance of gliricidia intercropping system compared to monocrop. Results of the study have clearly quantified and indicated the high potential of coconut based intercropping systems as carbon sinks with long turnover time.

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