REVIEW PAPER

Coconut-based agroecosystem for carbon sequestration

[1,3]Osayomore E. Ekhorutomwen, [2]Eluwan S. Inikio, & [3]Olalekan H. Shittu

Affiliation
[1]Plant Pathology Division, Nigerian Institute for Oil Palm Research (NIFOR), Benin City, Edo State, Nigeria.

[2]Agronomy Division, Nigerian Institute for Oil Palm Research (NIFOR), Benin City, Edo State, Nigeria.

[3]Department of Plant Biology and Biotechnology, University of Benin, Benin City, Edo State, Nigeria.

***For Correspondence**
E-mail: martinsdonsteve@yahoo.com, endurance.ekhorutomwen@nifor.org.ng

Abstract

Coconut (*Cocos nucifera* L.) is a perennial crop that provides a staple food and serves as a cash crop in many developing countries. Its production is mostly affected by climate, soil and diseases. The threat posed by greenhouse gases (GHGs) emissions especially carbon dioxide (CO_2) responsible for global warming and climate change, has called for the urgent need to mitigate climate change, by exploring environmental friendly ways to sequester CO_2 from the atmosphere. The coconut farming and its agroecosystem is one of the ways that could substantially store CO_2 through sequestration and will help to reduce the current increase in CO_2 present in the atmosphere. Although, coconut plantations have similar characteristics and functions with tropical forests, it has ability to sequester carbon better than tropical forests. Besides coconut farming is improving income and livelihood of farmers, it's therefore, paramount to utilize the potential of coconut-based agroecosystem for carbon sequestration, and investment opportunity needed for carbon trading, and as well help in climate change adaptation and mitigation plan.

Keywords: *Coconut, agroecosystem, carbon, sequestration.*

Introduction

Coconut (*Cocos nucifera* L.) is a perennial crop that produces edible fruits, that serves both of household and commercial demand. It is grown in over 90 countries around the world, by an estimated 11 million farmers across 12 million hectares (FAO, 2014; Gurr *et al.*, 2016). It also provides staple food and serves as a cash crop in many developing countries, providing a great foreign exchange to producer countries across the world (Bourke and Harwood, 2009). Furthermore, production of coconut is mostly affected by climate, soil, and diseases (Ekhorutomwen *et al.*, 2019). Agroecosystem is coined from agriculture and ecosystem, it is defined as a spatial and functional coherent unit of agricultural activity, containing living and non-living things that works together. Agroecosystem is made up of abiotic (soil, water, air) and biotic components (flora, fauna) (www.nhptv.org/natureworks/nwepecosystems.htm). A healthy agroecosystem has lots of species, and negative interference by human interaction, natural disasters and climate changes can damage both the agricultural activity and the ecosystem parts. Every species has a niche in the ecosystem that helps to keep the system healthy (en.wikipedia.org/wiki/Ecosystem). Carbon is a chemical element, that is nonmetallic and tetravalent in nature. Its tetravalent nature provides the ability to form covalent chemical bonds with other elements in nature (en.wikipedia.org/wiki/Carbon). Carbon can either occur as organic form or inorganic form. The inorganic carbon, precisely CO_2 will be the main focus in this article, because of its role in ozone depletion and also acts as a blanket, thereby, trapping heat waves escaping from the earth leading to global warming and subsequently climate change.

Climate change is as a result of emissions of greenhouse gases (GHGs) mainly carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other volatile organic compounds, through anthropogenic activities including land-use change, deforestation, biomass burning, draining of wetlands, soil tillage/cultivation and fossil fuel combustion (Lal, 2008). As mentioned earlier, GHG emission is increasing steadily due to anthropogenic activities, resulting in global warming and climate change, hence, the strong need to stabilize the atmospheric abundance of CO_2 (as the leading cause of global warming) and other GHGs to mitigate the risks of global warming (Kerr, 2007; Kintisch, 2007b; Kluger, 2007; Walsh, 2007). There are three theoretical strategies suggested that could lower CO_2 emissions to mitigate climate change (Schrag, 2007), namely; (i) to reduce the global energy use from fossils, coal, or explore renewable energy, (ii) to develop low or no-carbon fuel for machines and vehicles, and (iii) to sequester CO_2 from point of production or atmosphere through natural and engineered techniques.

More so, carbon sequestration is used to describe both natural and controlled (deliberate) processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations (USGS, 2008) required to reduce the net rate of increase in atmospheric CO_2 (Lal, 2008). Before human-caused CO_2 emissions began, the natural processes that make up the global “carbon cycle” maintained a near balance between the uptake of CO_2 and its release back to the atmosphere. However, existing CO_2 uptake mechanisms (sometimes called CO_2 or carbon “sinks”) are insufficient to offset the accelerating pace of emissions related to human activities (USGS, 2008). Hence, the need to develop more environmental friendly deliberate process, that will help to offset CO_2 from the atmosphere for climate benefit for living things.

Furthermore, ecosystem plays a crucial role in mitigating the climate change effects by fixing carbon from the atmosphere and storing it in the form of organic matter in biomass (Lal, 2008). The carbon sequestered in the ecosystem is the amount of carbon removed from the atmosphere and stored in the ecosystem over a period of time (Sierra *et al*., 2021). CO_2 sequestered in the ecosystem can be classified as geologic, oceanic, and terrestrial (Lal, 2008; USGS, 2008). Among these, the carbon captured by terrestrial sequestration is a natural process with several benefits besides cost-effectiveness (Boomiraj *et al*., 2020; Lal, 2008). Terrestrial uptake of CO_2 is governed by net biome production (NBP) (NBP:

which is the carbon accumulated by the terrestrial biosphere) (Schulze and Heimann, 1998). Also, it can be said to be the balance of net primary production (NPP) (NPP: which is the sum of visible growth plus litter production of the plant) and carbon losses due to heterotrophic respiration (decomposition and herbivory) and fire, including the fate of harvested biomass (Boomiraj *et al.*, 2020; Prentice *et al.*, 2000). The quantity of CO_2 produced by anthropogenic activities exceed the overall CO_2 absorbed by ocean and atmosphere. To account for this budget imbalance, there should be other CO_2 sink, identified as the world's terrestrial plants and soils (Sundquist, 1993). The plantation crops (coconut inclusive) with perennial nature play a key role in the terrestrial carbon sequestration by efficiently converting the CO_2 into huge biomass besides improving the soil carbon pools (Boomiraj *et al.*, 2020; Prentice *et al.*, 2000; Sundquist, 1993).

Carbon sequestration potential of coconut-based agroecosystem

The potential of carbon sequestration in coconut-based ecosystem may vary with age, cultivar (variety), soil fertility, agro-climatic condition, management practices, type of intercropping system for coconut and other weeds/plants present in coconut plantation. Furthermore, studies carried out by Naveenkumar and Maheswarappa (2019), to determine the net ecosystem carbon exchange revealed that the net ecosystem carbon exchange of a twenty-year old coconut plantation grown under near-optimal conditions (high fertility, no drought, and high yielding variety) in Santo, Vanuatu was between 4.7 – 8.1 t C ha^{-1} yr^{-1}. For coconut plantation intercrop with baby corn, cucumber and tomato sequestered 16.13 tha^{-1} soil carbon compared to 14.48 – 16.13 tha^{-1} in mono cropping for coconut (Bhagya *et al.*, 2017). In addition, the highest total carbon stock was observed in coconut with jamun system (140.06 tha^{-1}), followed by coconut with mango (138.91 tha^{-1}), and coconut with garcinia (131.72 tha^{-1}) system, and the lowest carbon stock was recorded in coconut monocrop having a total carbon stock of 98.2 tha^{-1} (Bhagya *et al.*, 2017).

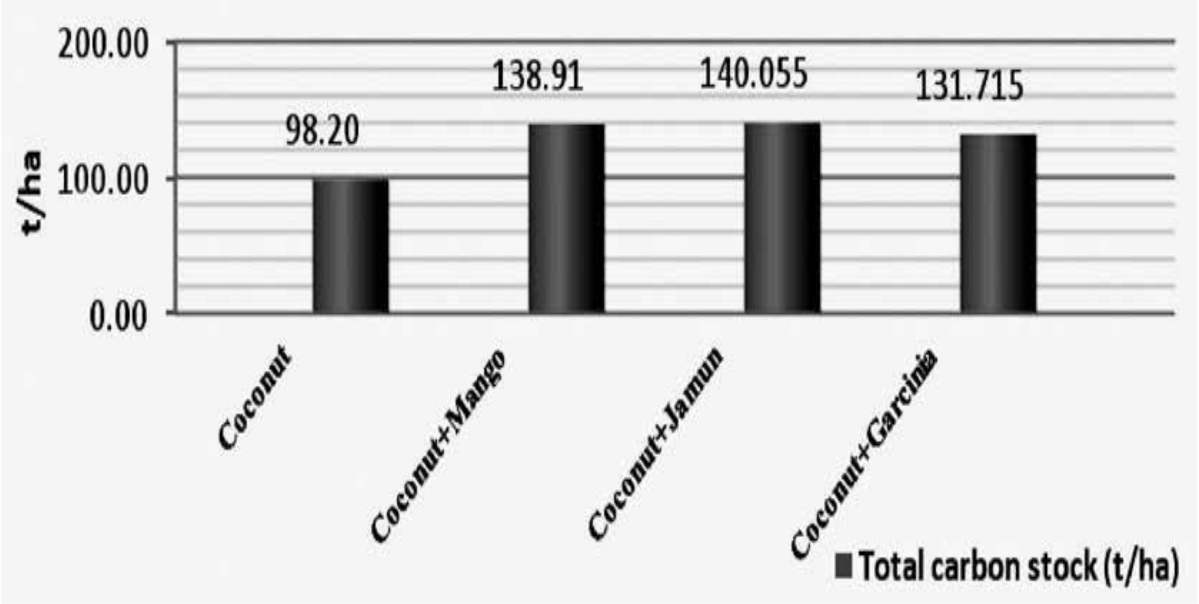

Figure 1: Total carbon stock (Above ground biomass + Soil carbon stock) in coconut-based intercropping systems. Source: Bhagya *et al.*, 2017.

Table 1. Estimated soil carbon stock of coconut and other fruit crops

Crop types	Organic carbon (%)	Soil carbon stock (tha^{-1})
Coconut	0.56 - 0.41	26.87 - 20.19
Mango	0.43 - 0.31	20.52 - 14.89
Garcinia	0.38 - 0.28	18.31 - 12.18
Jamun	0.40 - 0.25	19.45 - 13.76
Interspace (no crop cultivation)	0.36 - 0.28	17.09 - 13.87

Source: Bhagya *et al.*, 2017.

In addition, several studies have shown that coconut grown in tropical climate will sequester atmospheric carbon dioxide at an average amount of 50 pounds of carbon dioxide (CO_2) per tree per year (Boomiraj *et al.*, 2020; Bhagya *et al.*, 2017; Pearson, 2005). The CO_2 sequestration potential of coconut tree is determined by the carbon content in the tree (which is generally 50% of the tree's total volume, that is, the dry weight of the tree multiply by 50%.). Therefore, to determine the carbon sequestered in coconut tree; firstly, the weight of carbon is determined, this is done by multiplying the ratio of the atomic weight of CO_2 to C {i.e., CO_2 is made up of one molecule of carbon and two molecules of oxygen. The atomic weight of carbon and oxygen is 12.001115 and 15.9994, respectively. Hence, the weight of CO_2 is $C + (2xO)$ = 43.999915. The ratio of CO_2 to C is $43.999915/12.001115 = 3.666319$. Hence, to determine the weight of carbon dioxide sequestered in the tree, the weight of carbon in the tree is multiplied by 3.666319 (Jackson, 1967)}.

Furthermore, the rate of carbon sequestration also depends on the growth characteristics of the coconut varieties, the growing conditions, the density of other crops, weeds and trees in the immediate coconut plantation (Houghton,1990). More so, because coconut does not exist in isolation, but interact with other plants and soil in its immediate environment, hence, the need to determine the above ground carbon sequestration and the below ground carbon stock/soil carbon stock of coconut, required to determine the "coconut ecosystem productivity" (CEP) which encompasses the "net primary productivity" (NPP) (NPP: which is the sum of visible growth plus litter production of the plant), "gross primary productivity" (GPP) (GPP: which is the CO_2 entry into the ecosystem by photosynthesis) and "net ecosystem productivity" (NEP) (NEP: which is the CO_2 balance of the ecosystem) (Roupsard *et al.*, 2008; Houghton,1990).

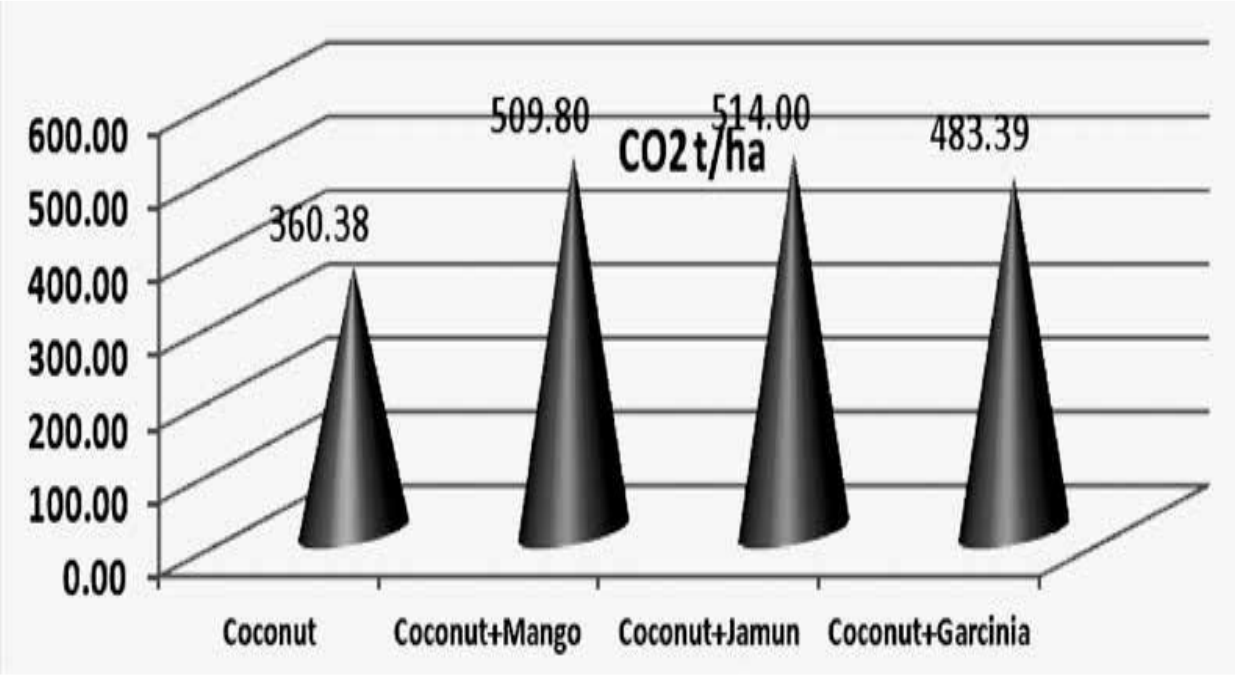

Figure 2: Total amount of CO_2 sequestered in coconut-based intercropping systems. Source: Bhagya *et al.*, 2017.

Determination of above ground carbon sequestration of coconut

To determine the above ground carbon sequestration as described previously, where the carbon stock for any plant species is generally considered as 50% of its biomass (Boomiraj *et al.*, 2020; Pearson, 2005).

Hence, $the\ Carbon\ stock\ \left(\frac{kg}{palm}\right) =$
$Biomass\ (SDW\text{: }stem\ dry\ weight)\ x\ 0.5\ (50\%\ of\ wood\ biomass\ is\ considered\ as\ the\ carbon\ stored)$.

While the above ground standing biomass i.e., SDW (kg) = height (m) x (girth (m))2 x 41.14 (Naresh *et al.*, 2008).

To determine CO_2 (tha^{-1}) sequestered, is by multiplying carbon stock (tha^{-1}) with 3.67 as a factor (Jackson, 1967).

$C\ (tha^{-1}) = C\ (kgha^{-1})\ x\ 1000^{-1}$
$CO_2\ (tha^{-1}) = C\ (tha^{-1})\ x\ 3.67$
Note:
1 kg CO_2 = 0.27 kg carbon
1 kg C = 3.67 kg CO_2
1 Mega gram (Mg) = 1 t (Ghavale *et al.*, 2020).

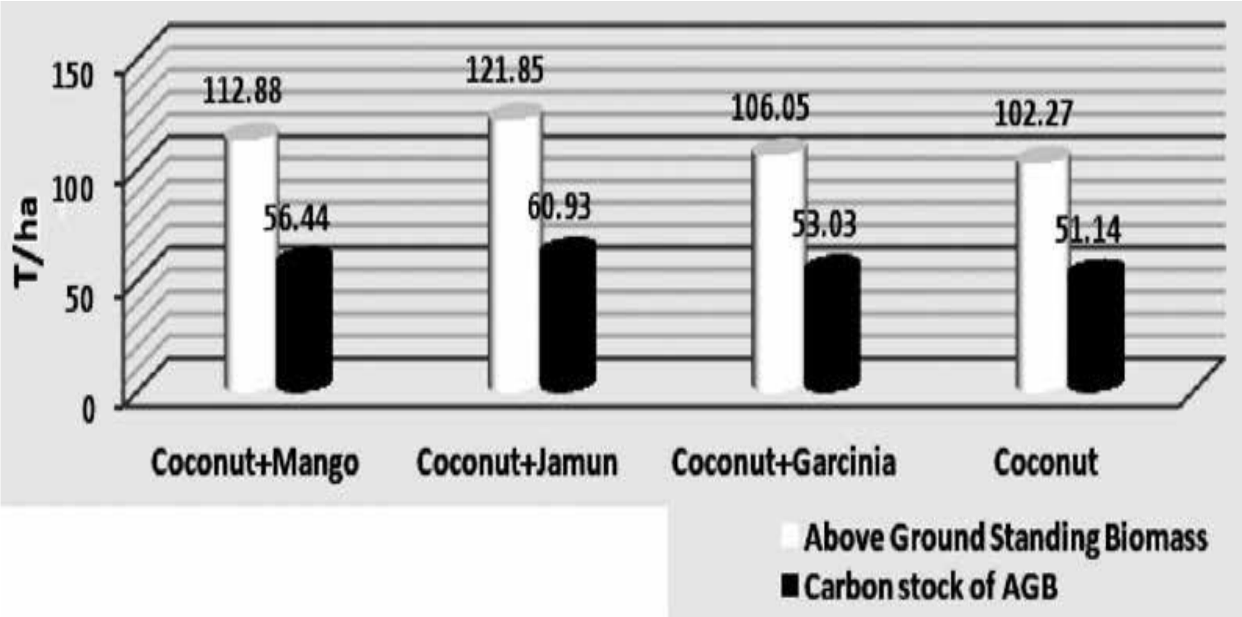

Figure 3: Above ground biomass and carbon stock in coconut-based intercropping systems.
Source: Bhagya *et al.*, 2017.

Determination of below ground carbon stock/soil carbon stock of coconut

The soil carbon stock is determined by following standard formula described by (Srinivasan *et al.*, 2012).
Soil organic carbon stock (0-30, 31-60) (Mg ha^{-1})= {(C concentration layer (kg Mg^{-1})
x (Bulk density) layer (Mg m^{-3}) x Depth (m) x 10^{-3} Mgkg^{-1} x 104 (m^{2}ha^{-1})}.

Note: Bulk density of the soil under test can be estimated by using core sampler at 0-30 and 31-60 cm depth (Ghavale *et al.*, 2020).

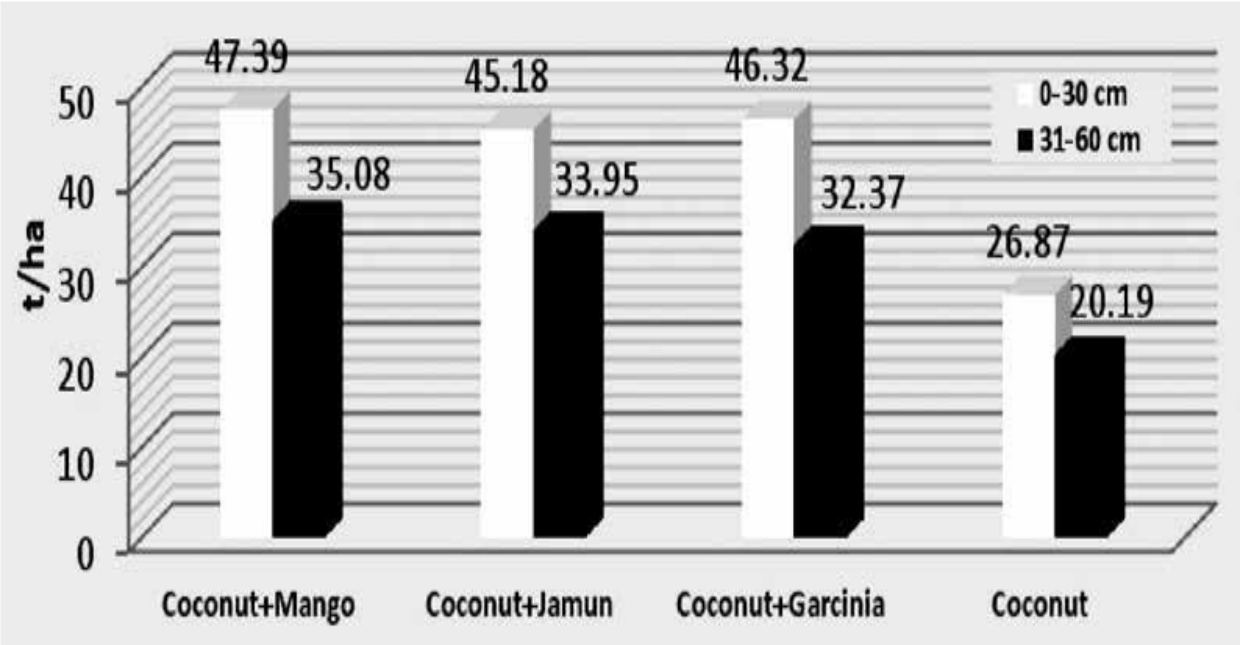

Figure 4. Soil carbon stock in coconut-based intercropping systems.
Source: Bhagya *et al.*, 2017.

Carbon cycle theory of coconut-based agroecosystem as a terrestrial carbon sequester process

Coconut as a tree crop or a higher plant acquires carbon dioxide (CO_2) by diffusion via tiny pores (stomata) into leaves, and to areas of photosynthesis. The total amount of CO_2 that dissolves in leaf water build-up to about 270 PgC/yr, i.e., more than one-third of all the CO_2 in the atmosphere (Farquhar *et al.,* 1993; Ciais *et al.,* 1997). Majority of this CO_2 diffuses out again without involving in photosynthesis. The amount that is fixed from the atmosphere, i.e., converted from CO_2 to carbohydrate during photosynthesis, known as GPP. Terrestrial GPP has been estimated to be around 120 PgC/yr based on ^{18}O measurements of atmospheric CO_2 (Ciais *et al.,* 1997). This is also the approximate value needed to support the observed plant growth, assuming that one part of GPP is absorbed into the plant tissues in the leaves, roots and wood, and the second part is converted back to atmospheric CO_2 by autotrophic respiration (R_a: respiration by the plant tissues) (Lloyd and Farquhar, 1996; Waring *et al.,* 1998).

The annual plant growth is said to be the difference between photosynthesis and autotrophic respiration and is also referred to as NPP. NPP is measured in most ecosystem types by sequential harvesting or by measuring plant biomass (Hall *et al.,* 1993). Global terrestrial NPP is estimated around 60 PgC/yr through integration of field measurements (Atjay *et al.,* 1979; Saugier and Roy, 2001). Eventually, nearly all of the carbon fixed in NPP is returned to the atmospheric CO_2 pool through two processes; i) heterotrophic respiration (R_h) by herbivores and decomposers (bacteria and fungi feeding on dead tissue and exudates) and, ii) combustion in natural or human bush-burning (fire) (Prentice *et al*., 2000). In addition, majority of dead biomass enters into debris forming soil organic matter, where it is respired at a rate that depends on the chemical composition of the dead tissues and environmental conditions, these distinguishes several soil carbon pools (Prentice *et al*., 2000). More so, debris and microbial biomass have a short turnover time (<10 years), while for modified soil organic carbon, it has a longer turnover time (>10 – 100 years) (Prentice *et al*., 2000). Furthermore, inert (stable or recalcitrant) soil organic carbon is composed of molecules more or less resistant to further decomposition. A very small fraction of soil organic matter, and a small fraction of burnt biomass, are converted into inert forms (Schlesinger, 1990; Kuhlbusch *et al.,* 1996). Natural processes and management regimes may increase or reduce the amount of carbon stored in pools with turnover times in the range of tens to hundreds of years (living wood, wood products and modified soil organic matter) and thus influence the time evolution of atmospheric CO_2 over the century (Prentice *et al*., 2000).

The difference between NPP and R_h determines how much carbon is gained or lost in the ecosystem, in the absence of disturbances that remove carbon from the ecosystem (such as harvest or fire). This carbon balance, or NEP, can be estimated from changes in carbon stocks, or by measuring the fluxes of CO_2 between patches of land and the atmosphere. Annual NEP flux measurements are in the range of 0.7 to 5.9 MgC/ha/yr for tropical forests, and 0.8 to 7.0 MgC/ha/yr for temperate forests, while boreal forests can reach up to 2.5 MgC/ha/yr, although these forests have been shown to be carbon neutral or to release carbon in warm and/or cloudy years (Valentini *et al.,* 2000). Integration of these and other results leads to an estimated global NEP of about 10 PgC/yr, although this is likely to be an overestimate because of the current biased distribution of flux measuring sites (Bolin *et al.,* 2000). More so, when other losses of carbon are accounted for, including fires, harvesting/removals (eventually combusted or decomposed), erosion and export of suspended or dissolved organic carbon (DOC) by rivers to the oceans (Schlesinger and Melack, 1981; Sarmiento and Sundquist; 1992), what is left is the Net Biome Production (NBP), i.e., which is the carbon accumulated by the terrestrial biosphere (Schulze and Heimann, 1998). This is what the atmosphere ultimately sees as the net land uptake on a global scale over periods of a year or more. NBP is estimated to have an average of about -0.2 ± 0.7 PgC/yr during the 1980s and -1.4 ± 0.7 PgC/yr during the 1990s, based on atmospheric measurements of CO_2 and O_2 (Prentice *et al*., 2000).

Defining an ecosystem in stable state, R_h and other carbon losses would just balance NPP, and NBP would be zero. In reality, human activities, natural disturbances and climate variability alter NPP and R_h, causing transient changes in the terrestrial carbon pool and thus non-zero NBP. If the rate of carbon input (NPP) changes, the rate of carbon output (R_h) also changes, in equal proportion to the altered carbon content; but there is a time lag between changes in NPP and changes in the slower responding carbon pools. An increase in NPP, NBP is expected to increase at first but relax towards zero over a period (decades) as the respired pool meet up (Prentice *et al*., 2000; Roupsard *et al*., 2007). The globally estimated averaged lag required for R_h to meet up with a change in NPP is estimated to be around 10 to 30 years (Raich and Schlesinger, 1992). A continuous increase in NPP is expected to produce a sustained positive NBP. Therefore, as long as NPP is still increasing, meaning that the increased terrestrial carbon is not processed through the respired carbon pools (Aubinet *et al*., 2000; Taylor and Lloyd, 1992; Friedlingstein *et al.,* 1995a; Thompson *et al.,* 1996; Kicklighter *et al.,* 1999), and provided that the increase is not outweighed by compensating increases in mortality or disturbance.

The terrestrial system is currently acting as a global sink for carbon despite large releases of carbon as a result of deforestation in some regions. Likely mechanisms for the sink are recognized, but their relative contribution is not certain. Natural climate variability and disturbance regimes (fire and herbivores inclusive) affect NBP through their impacts on NPP, allocation to long- versus short-lived tissues, chemical and physical properties of litter, stocks of living biomass, stocks of debris and soil carbon, environmental controls on decomposition and rates of biomass removal (Prentice *et al*., 2000; Schlesinger, 1990; Kuhlbusch *et al.,* 1996). Human impacts occur through changes in land use and land management, and through indirect mechanisms including climate change, and fertilization due to elevated CO_2 and deposition of nutrients (most importantly, reactive nitrogen). Once more, if there are no inputs from organic fertilizers, all the carbon inputs come from GPP. A significant part of this carbon uptake is lost through Autotrophic Respiration (R_a) which can be arbitrarily divided into two main components: Root Respiration, (R_{ar}) and Respiration from Aboveground (R_{aa}), i.e., plant compartments (leaves, branches, stems). The fraction of GPP that is not lost through plant respiration is used to produce new biomass, thus contributing to NPP; expressed mathematically as;

$$\mathbf{NPP = GPP - R_a}$$

Allocation of NPP to the different plant compartments contributes to tree growth and litter production (L). Among the various plant compartments, one may distinguish between compartments with high turnover rate (fruits, peduncles, leaves, fine roots), contributing to litter production, and compartments with low turnover rate (stem, coarse roots), contributing mostly to biomass accumulation (Prentice *et al*., 2000; Roupsard *et al*., 2007; Aubinet *et al*., 2000; Raich and Schlesinger, 1992; Kuhlbusch *et al.,* 1996). The stand growth, i.e., carbon accumulation in biomass (ΔC_B) is the difference between NPP and L:

$$\mathbf{\Delta C_B = NPP - L}$$

Litter inputs to the soil are decomposed by soil microorganisms. The part that is not oxidized is taken to the soil organic matter (SOM) pool. Emission of CO_2 through litter decomposition, and subsequent SOM oxidation by soil microorganisms both contribute to the so-called 'heterotrophic Respiration' (R_h). A proportion of the litter produced through NPP is thus lost through R_h (Roupsard *et al*., 2007; Raich and Schlesinger, 1992; Schlesinger, 1990; Kuhlbusch *et al.,* 1996). The difference between the rate of NPP and R_h controls the rate of net ecosystem productivity (NEP), which is defined mathematically as;

$$\mathbf{NEP = NPP - R_h = \Delta C_B + \Delta C_s + \Delta C_l}$$

where ΔC_s is the carbon accumulation in soil, and ΔC_l is the carbon accumulation in litter (Roupsard *et al*., 2007; Raich and Schlesinger, 1992; Schlesinger, 1990; Kuhlbusch *et al.,* 1996).

The total respiratory carbon loss by the ecosystem (R_e: ecosystem respiration) results from plant respiration (R_a) and respiration of soil and litter decomposers (R_h). The 'net ecosystem exchange' (NEE) of CO_2 between the plantation or forest and the atmosphere is the difference between CO_2 uptake through photosynthesis, and CO_2 emission through ecosystem respiration. This net flux is highly variable both diurnally (due to variability in light, temperature, and air relative humidity), and seasonally, but it can be monitored continuously with the eddy-covariance methods, and cumulated over time for estimating monthly or annual NEP: expressed mathematically below;

$$\mathbf{NEP = GPP - R_e = GPP - R_a - R_h = \Sigma NEE}$$

Where R_e is the Respiration (ecosystem), R_a is the Respiration (autotrophic), net ecosystem exchange (instant carbon balance).

According to the formula above, the variations of carbon stocks in soil plus biomass plus necromass (litter) account for the carbon sequestration (Stock Method). However, the main impediment when measuring soil carbon stock either within-plot or between-plots on a long-term basis, is to cope with the large variability of soil carbon stock (carbon sequestration), and this can be done with a synchronizing approach, using chronosequences (or time series) (Roupsard *et al*., 2007; Aubinet *et al*., 2000; Raich and Schlesinger, 1992; Schlesinger, 1990; Kuhlbusch *et al.,* 1996). However, there are no methods accurate enough for the measurement of soil carbon stocks variations on short term (from minutes to a few years) basis, although, the "Flux Method" can be adopted, using direct measurements of the fluxes with the eddy-covariance methods (by measuring the fluxes of CO_2, H_2O and energy above plantation of coconut using a flux-tower (Roupsard *et al*., 2007; Aubinet *et al*., 2000).

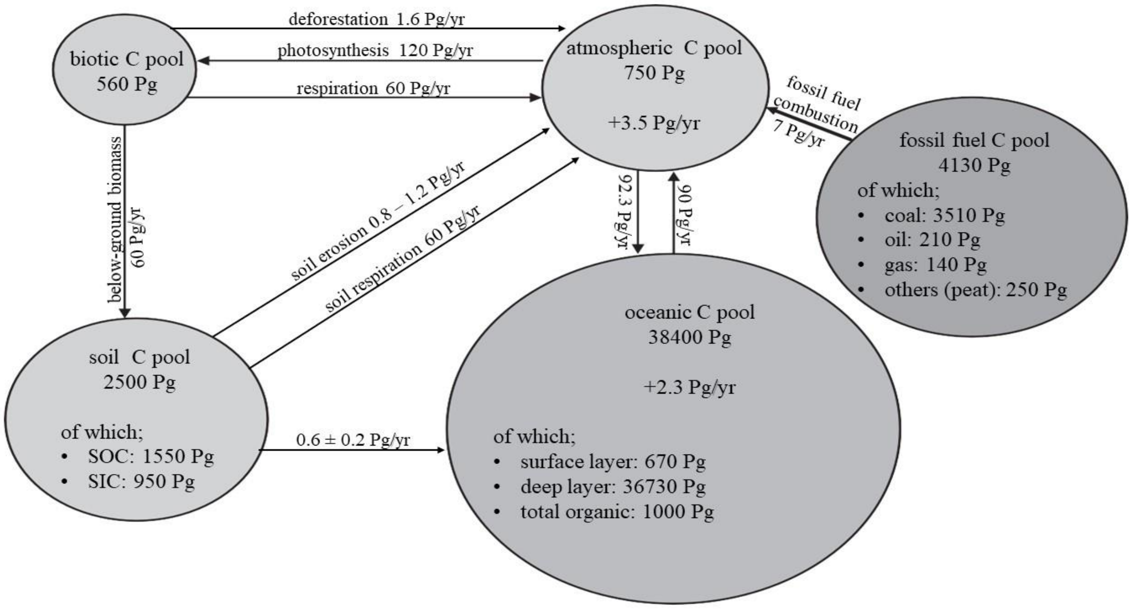

Figure 5: Global carbon pools and fluxes between them.

Source: modified from Lal, 2008.

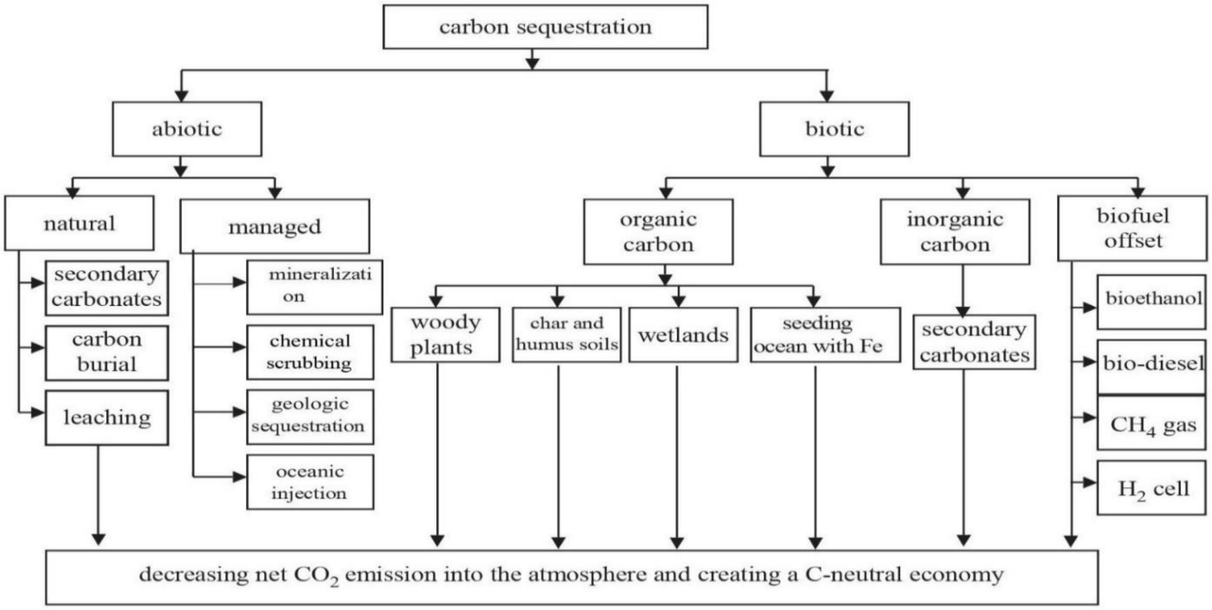

Figure 6: Processes and technological options for carbon sequestration in agricultural, industrial and natural ecosystems.

Source: Lal, 2008.

Net ecosystem productivity (NEP) of coconut-based agroecosystem as compared to tropical forest

The main factors that is used for ranking ecosystem productivity include; climate, fertility, leaf area index and phenology, irrespective of their status (from artificial to natural). Supporting these facts in a report by Roupsard *et al*., (2007) when comparing the

NEP of coconut plantation to that of tropical evergreen humid forest, i.e., a tropical plantation of coconut tree with a grass under-storey with total leaf area index of around 6 for two layers, placed in close-to-optimum growing conditions (assuming there is high level of fertility, no seasonal drought, evergreen, continuous growth) displayed productivity characteristics (GPP and NPP) close to tropical evergreen humid forest, i.e. amongst the highest levels encountered in global forest biomes. Furthermore, in their report, a three-year average apparent NEP (the actual ecosystem carbon balance for the coconut plantation), was 8.1 tC ha^{-1}yr^{-1} as compared to the average 4 tC ha^{-1} yr^{-1} for a tropical humid evergreen forest. Both results have a differential of approximately 4. The results from their studies revealed that coconut plantation sequestered more carbon than the tropical humid evergreen forest, although the coconut plantation was younger (19 – 21-year-old) as compared to tropical humid evergreen forest that has been existing over century(s). Thus, this could make coconut plantation to be further from equilibrium between GPP and Re than the tropical humid evergreen forest during their studies.

Table 2: Global aggregated values by biome of estimated terrestrial carbon stocks and NPP.

Biome	Area (10^9 ha)		Global Carbon Stocks (PgC)						Carbon density (MgC/ha)				NPP (PgC/yr)	
			Plants	Soil	Total	Plants	Soil	Total	Plants	Soil	Plants	Soil		
Tropical forests	1.76	1.75	212	216	428	340	213	553	120	123	194	122	13.7	21.9
Temperate forests	1.04	1.04	59	100	159	139	153	292	57	96	134	147	6.5	8.1
Boreal forests	1.37	1.37	88	471	559	57	338	395	64	344	42	247	3.2	2.6
Tropical savannas and grasslands	2.25	2.76	66	264	330	79	247	326	29	117	29	90	17.7	14.9
Temperate grasslands and shrublands	1.25	1.78	9	295	304	23	176	199	7	236	13	99	5.3	7.0
Deserts and semi deserts	4.55	2.77	8	191	199	10	159	169	2	42	4	57	1.4	3.5
Tundra	0.95	0.56	6	121	127	2	115	117	6	127	4	206	1.0	0.5
Croplands	1.60	1.35	3	128	131	4	165	169	2	80	3	122	6.8	4.1
Wetlands	0.35	–	15	225	240	–	–	–	43	643	–	–	4.3	–
Total	15.12	14.93	466	2011	2477	654	1567	2221					59.9	62.6

Source: Prentice *et al.*, 2000.

Coconut tree reserves for hydrate of carbon

Report by Mialet-Serra *et al.*, (2005), on the average stock of non-structural carbohydrate (precisely sucrose reserves) in coconut tree was estimated to be 25 kg per tree {20-year after planting of the coconut tree}, which is around 8% of active biomass. Although, the physiological function of the large quantity of sucrose stored mainly in the coconut tree stem is not known (Roupsard *et al.*, 2008). However, reserve storage or de-storage might play a major role in explaining intra-annual schedule in NPP, allowing NPP to become rather independent from the seasonal fluctuations of the carbon supply (GPP) (Roupsard *et al.*, 2008). The reserve dynamics for hydrated carbon were also reported by Mialet-Serra *et al.*, (2008), where they studied the dynamics of dry matter production, yield and yield components, and the concentrations of non-structural carbohydrate reserves. The bottom-line hypothesis was that reserve storage and mobilization help the crop to adjust to variable sink-source relationship at the expense of the whole plant. Sink-source imbalances were partly compensated by transitory reserve, and more importantly by variable light-use-efficiency in the short-term, and by adjustment of fruit load in the long-term (Roupsard *et al.*, 2008).

In addition, contrary to dicot trees, coconut trees do not allocate much of its NPP into long-lasting structures (like stems, and coarse roots), but allocates over 85% of its NPP into easily degradable structures (like fruits, leaves, peduncles, and fine roots) that will easily turn into litter, and respired by the ecosystem or contribute to the build-up of soil organic matter (SOM) (Roupsard *et al.*, 2008; Mialet-Serra *et al.*, 2008). This litter-oriented fate of carbon is very peculiar, and cannot be properly accounted for, using regular forestry inventories of carbon sequestration, such as simple evaluation of carbon build-up in the stems. It will certainly require detailed studies of carbon accumulation in the SOM, in addition to the carbon accumulated in the biomass and in litter (necromass) (Roupsard *et al.*, 2008; Mialet-Serra *et al.*, 2008).

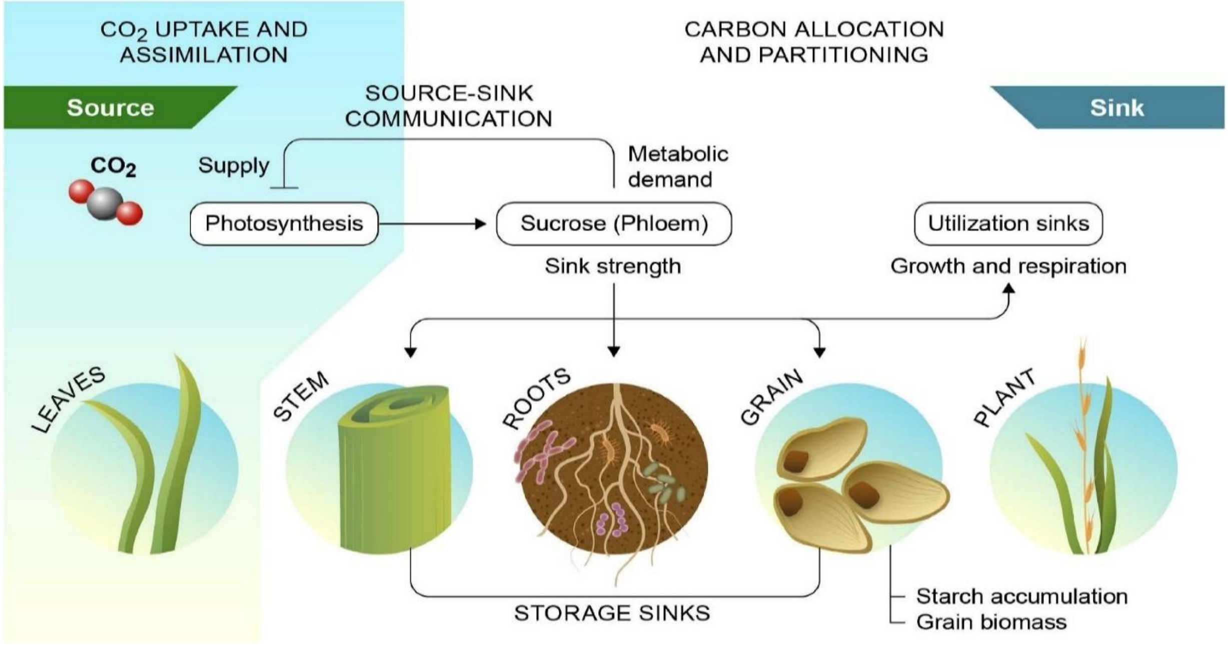

Figure 7: Source-sink interactions of photosynthate production and utilization.

Source: Fan *et al.*, 2008

Brief impact of climate change on coconut industry

If global emissions of carbon dioxide and other GHGs responsible for global warming, and climate change is not reduced, it will definitely affect coconut production and yield. Climate change will result in extreme of weather (climate) events, and the direct effects of extreme weather are cold wave, fog, snow storms and avalanches, hailstorm, thunderstorm, wind storms, tropical cyclones and tidal waves, floods, heavy rain, landslides, heat wave, and droughts (Balasubramanian, 2018), while the indirect effect of extreme weather are emergence of weeds, diseases and pest attack (Ekhorutomwen *et al.*, 2019; Aneni *et al.*, 2015).

Reduced coconut productivity will force coconut growers (farmers and breeders) to use fertilizer, herbicides, pesticides, fungicides more indiscriminately and excessively (Ekhorutomwen *et al.*, 2019; Griffith *et al.*, 2017; Aneni *et al.*, 2015). Other practice such as moisture conservation and irrigation is also expected to increase (Griffith *et al.*, 2017). These practices will be too expensive and laborious for coconut growers resulting in coconut shortage, and high inflation rate for coconut and its products (Ekhorutomwen *et al.*, 2019). Hence, the loss of coconut productivity and yield due to climate change will force coconut growers to relocate, with loss of export earnings and rural livelihoods, including key components of household income, nutrition and shelter. Furthermore, large scale crop loss and the resulting lack of income will force more rural coconut growers to migrate to urban areas, so escalating rural poverty (Ekhorutomwen *et al.*, 2019).

Table 3: Top CO_2-emitting and CO_2-reducing countries.

S/N	Top countries emitting CO_2	CO_2 emissions (Mt)	Top countries reducing CO_2 emissions	CO_2 reduction (%)
1	China	11680.42	Denmark	-30
2	United States	4535.30	Ukraine	-29
3	India	2411.73	Hungary	-24
4	Russia	1674.23	Portugal	-23
5	Japan	1061.77	Romania, Slovakia	-22
6	Iran	690.24	United Kingdom	-20
7	Germany	636.88	France	-19
8	South Korea	621.47	Finland	-18
9	Saudi Arabia	588.81	Czech Republic, Spain	-14
10	Indonesia	568.27	Belgium	-12
	Nigeria	Not classified	Nigeria	Not classified

Conclusion

Carbon sequestration into coconut organic matter is a promising solution that will help to reduce the current increase in carbon dioxide present in the atmosphere. Due to the fact that coconut has a high gross primary productivity (GPP) and net primary productivity (NPP), and because the coconut tree does not behave like dicot, it surely converts most of its NPP to leaves, fruits, peduncle and fine roots, which are easily degraded in nature. Therefore, most of this degradable material would be decomposed by microbes and transformed into soil organic matter (SOM). Although, coconut plantations have similar characteristics and functions with tropical forests, it has ability to sequester carbon better than tropical forests. Besides coconut farming is improving income and livelihood of farmers, it's therefore, paramount to utilize the potential of coconut-based agroecosystem for carbon sequestration, and investment opportunity needed for carbon trading, and as well help in climate change adaptation and mitigation plan.

References

Aneni TI, Aisagbonhi CI, Adaigbe VC, & Iloba BN (2015). Impact of temperature, rainfall, and relative humidity on the population of leaf miner, a pest of the oil palm in Nigeria. *European Journal of Physical and agricultural Sciences*, 3(1): 58-79.

Atjay GL, Ketner P, & Duvigneaud P (1979). Terrestrial primary production and phytomass. In: *The Global Carbon Cycle* [Bolin, B., E.T. Degens, S. Kempe, and P. Ketner (eds.)], John Wiley and Sons, Chichester, pp. 129 – 181.

Aubinet M, Grelle A, Ibrom A, Rannik U, Moncrieff J, Foken T, Kowalski AS, Martin PH, Berbigier P, Bernhofer C, Clement R, Elbers J, Granier A, Grunwald T, Morgenstern K, Pilegaard K, Rebmann C, Snijders W, Valentini R, & Vesala T (2000). Estimates of the annual net carbon and water exchange of forests: The EUROFLUX methodology. *Advances in Ecological Research*, 30:113 – 175.

Balasubramanian A. (2018). Extreme climatic (weather) events. Technical Report, 11 pp.

Bourke RM & Harwood T (Eds.) (2009). Food and Agriculture in Papua New Guinea. Australian National University. 327pp.

Bhagya HP, Maheswarappa HP, & Surekha BR (2017). Carbon sequestration potential in coconut-based cropping systems. Indian Journal of Horticulture, 74(1): 1 – 5.

Bolin B, Sukumar R, Ciais P, Cramer W, Jarvis P, Kheshgi H, Nobre C, Semenov S, & Steffen W (2000). Global Perspective. In: *IPCC, Land Use, Land-Use Change, and Forestry. A Special Report of the IPCC* [Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo and D.J. Dokken (eds.)]. Cambridge University Press, Cambridge, UK, pp. 23 – 51.

Boomiraj K, Jagadeeswaran R, Karthik S, Poornima R, Jothimani S, & Sudhagar RJ (2020). Assessing the Carbon Sequestration Potential of Coconut Plantation in Vellore District of Tamil Nadu, India. *International Journal of Environment and Climate Change*, 10(12): 618-624.

Ciais P, Denning AS, Tans PP, Berry JA, Randall DA, Collatz GJ, Sellers PJ, White JWC, Trolier M, Meijer HAJ, Francey RJ, Monfray P, & Heimann M (1997), A three-dimensional synthesis study of $\delta^{18}O$ in atmospheric CO_2. 1. Surface Fluxes. *Journal of Geophysical Research – Atmosphere*, 102: 5857 – 5872.

Ekhorutomwen OE, Udoh ME, & Esiegbuya DO (2019). A survey report on the incidence of fruit rot and premature nut fall diseases of coconut in Badagry, Lagos State, Nigeria. *NIFOR Annual Report*, 58: 157 – 158.

en.wikipedia.org/wiki/Ecosystem

en.wikipedia.org/wiki/Carbon

Fan FL, Zhang FS, Qu Z, & Lu YH (2008). Plant carbon partitioning below ground in the presence of different neighboring species. *Soil Biol. Biochem.*, 40: 2266 – 2272. doi: 10.1016/j.soilbio.2008.05.003

FAO (2014). *FAOStat. Vol. 2014*. Rome: Food and Agriculture Organisation of the United Nations.

Farquhar GD, Lloyd J, Taylor JA, Flanagan LB, Syvertsen JP, Hubick KT, Wong SC, & Ehleringer JR (1993). Vegetation effects on the isotope composition of oxygen in atmospheric CO2. Nature, 363: 439 – 443.

Friedlingstein P, Fung I, Holland E, John J, Brasseur G, Erickson D, & Schimel D (1995a). On the contribution of CO_2 fertilization to the missing biospheric sink. *Global Biogeochemical Cycles*, 9: 541 – 556.

Ghavale SL, Shinde VV, Wankhede SM, Maheswarappa HP, & Haldankar PM (2020). Carbon Sequestration and Productivity Potential of Coconut (*Cocos nucifera* L.) Hybrids and Varieties under Coastal Eco-System of Maharashtra. *Current Journal of Applied Science and technology*, 39(22): 30-37.

Griffith G, Pathiraja E, Farquharson B, & Faggian R (2017). The Economic Cost of Climate Change and the Benefits from Investments in Adaptation Options for Sri Lankan Coconut Value Chains. *Proceedings in System Dynamics and Innovation in Food Networks*, 5: 460 – 485.

Gurr GM, Johnson AC, Ash GJ, Wilson BAL, Ero MM, Pilotti CA, Dewhurst CF, & You MS (2016). Coconut Lethal Yellowing Diseases: A phytoplasma threat to palms of global economic and social significance. *Front. Plant Sci*., 7: 1521.

Hall DO, Scurlock JMO, Bolhar-Nordenkampfe HR, Leegood PC, & Long SP (1993). Photosynthesis and Production in a Changing Environment: A Field and Laboratory Manual, (eds.)]. Chapman and Hall, London, 464pp.

Houghton RA (1990). 'The future role of tropical forests in affecting the carbon dioxide concentration of the atmosphere', *Ambio*., 19: 204 – 209.

Jackson ML (1967). Soil chemical analysis. Prentice Hall of India, Pvt. Ltd., New Delhi. 498pp.

Jansson C, Vogel J, Hazen S, Brutnell T, & Mockler T (2018). Climate-smart crops with enhanced photosynthesis. *J. Exp. Bot.* 69, 3801–3809. doi: 10.1093/jxb/ery213

Kerr RA (2007). Scientists tell policy makers we're all warming the world. *Science*, 315: 754 – 757.

Kintisch E (2007b). New congress may be warming up to plans for capping emissions. *Science*, 315: 444.

Kicklighter DW, Bruno M, Dönges S, Esser G, Heimann M, Helfrich J, Ift F, Joos F, Kadku J, Kohlmaier GH, McGuire AD, Melillo JM, Meyer R, Moore III B, Nadler A, Prentice IC, Sauf W, Schloss AL, Sitch S, Wittenberg U, & Würth G (1999). A first order analysis of the potential of CO_2 fertilization to affect the global carbon budget: A comparison of four terrestrial biosphere models. *Tellus*, 51B: 343 – 366.

Kluger J (2007). Global warming: what now? Our feverish planet badly needs a cure. *Time Magazine*, 9: 50 – 109.

Kuhlbusch TAJ, Andeae MO, Cahier H, Goldammer JG, Lacaux JP, Shea R, & Crutzen PJ (1996). Black carbon formation by savanna fires: Measurements and implications for the global carbon cycle. *Journal of Geophysical* Research, 101: 23651 – 23665.

Lal R (2008). Carbon sequestration. *Philosophical Transactions of the Royal Society B*, 363: 815 – 830.

Naveenkumar KS & Maheswarappa HP (2019). Carbon sequestration potential of coconut based cropping systems under integrated nutrient management practices. *Journal of Plantation Crops*, 47(2): 107 – 114.

Lloyd J & Farquhar GD (1996). The CO_2 dependence of photosynthesis, plant growth responses to elevated atmospheric CO_2 concentrations, and their interaction with soil nutrient status. I. General principles and forest ecosystems. *Functional* Ecology, 10: 4 – 32.

Mialet-Serra I, Clément-Vidal A, Roupsard O, Jourdan C, & Dingkuhn M (2008). Whole-plant adjustments in coconut (*Cocos nucifera* L.) in response to sink-source imbalance. *Tree Physiology* (Accepted).

Mialet-Serra I, Clement A, Sonderegger N, Roupsard O, Jourdan C, Labouisse JP, & Dingkuhn N 2005. Assimilate storage in vegetative organs of coconut (Cocos nucifera). *Experimental Agriculture*, 41(2): 161 – 174.

Naresh KS, Kasthuri BKV, & George JA (2008). Method for non-destructive estimation of dry weight of coconut stem. *Journal of Plantation Crops*, 36: 296 – 99.

Pearson TRH, Brown S, & Ravindranath NH (2005). Integrating carbon benefits estimates into GEF Projects. 1: 1-56.

Prentice IC, Heimann M, & Sitch S (2000). The carbon balance of the terrestrial biosphere: Ecosystem models and atmospheric observations. *Ecological* Applications, 10: 1553 – 1573.

Raich JW & Schlesinger WH (1992) The global carbon-dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus Series B-Chemical and Physical* Meteorology, 44: 81 – 99.

Roupsard O, Lamanda N, Jourdan C, Navarro M, Mialet-Serra I, Dauzat J, & Sileye T (2008). Coconut carbon sequestration Part 1/Highlights on carbon cycle in coconut plantations. *Part 1 Coconut Research and Development (CORD)*, 24:1 – 14.

Roupsard O, Bonnefond J, & Luyssaert S (2007a). Productivity of a tropical plantation of coconut tree (*Cocos nucifera,* L.), compared with tropical evergreen humid forests. *Asiaflux Newsletter*, 23: 4 – 9.

Sarmiento JL & Toggweiler JR (1984) A new model for the role of the oceans in determining atmospheric *p*CO2. Nature, 308: 621 – 624.

Saugier B & Roy J (2001). Estimations of global terrestrial productivity: converging towards a single number? In: *Global terrestrial productivity: past, present and future* [Roy, J., B. Saugier and H.A. Mooney (eds.)]. Academic Press, (in press). pp. 35 – 62.

Schlesinger WH & Melack JM (1981). Transport of organic-carbon in the worlds rivers. *Tellus*, 33**:** 172 – 187.

Schlesinger WH (1990). Evidence from chronosequence studies for a low carbon-storage potential of soils. *Nature*, 348: 233 – 234.

Schrag DP 2007. Preparing to capture carbon. *Science*, 315: 812 – 813.

Schulze ED & Heimann M (1998). Carbon and water exchange of terrestrial ecosystems. In: *Asian change in the context of global change* [Galloway, J.N. and J. Melillo (eds.)]. Cambridge University Press, Cambridge.

Sierra CA, Crow SE, Heimann M, Metzler H, & Schulze ED (2021). The climate benefits of carbon sequestration. *Biogeosciences*, 18: 1029 – 1048.

Srinivasan V, Maheswarappa HP, & Lal R (2012). Long term effects of topsoil depth and amendments on particulate and non-particulate carbon fractions in a Miamian soil of Central Ohio. *Soil and Tillage Research*, 121: 10 – 17.

Sundquist ET. (1993). The global carbon dioxide budget. *Science*, 259: 934 - 941.

Taylor JA & Lloyd J (1992). Sources and sinks of atmospheric CO_2. *Australian Journal of* Botany, 40: 407 – 418.

Thompson MV, Randerson JT, Malmstrom CM, & Field CB (1996). Change in net primary production and heterotrophic respiration: How much is necessary to sustain the terrestrial carbon sink? *Global Biogeochemical Cycles*, 10: 711 – 726.

Valentini R, Matteucci G, Dolman AJ, Schulze ED, Rebmann C, Moors EJ, Granier A, Gross P, Jensen NO, Pilegaard K, Lindroth A, Grelle A, Bernhofer C, Grunwald T, Aubinet M, Ceulemans R, Kowalski AS, Vesala T, Rannik U, Berbigier P, Loustau D, Guomundsson J, Thorgeirsson H, Ibrom A, Morgenstern K, Clement R, Moncrieff J, Montagnani L, Minerbi S, & Jarvis PG (2000). The Carbon Cycle and Atmospheric Carbon Dioxide: Respiration as the main determinant of carbon balance in European forests. Nature, 404: 861 – 865.

Walsh B. (2007). Greenhouse airlines: traveling by jet is a dirty business. As passenger load increases, enviros look for ways to cut back the carbon. *Time*, 12: 57.