Productive and Sustainable Coconut Farming Ecosystems as Potential Carbon "Sinks" in Climate-Change Minimization: (A Review and Advisory Notes) [a]

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INTRODUCTION AND SIGNIFICANCE

1. **"Climate-Change"** as defined in **RA 9729** known as the Philippine **Climate-Change Act of 2009** refers to **a change in climate that can be identified by changes in the mean and/or variability of its properties and that persists for an extended period, typically decades or longer, whether due to natural variability or as a result of human activity**. Generally, it is widely claimed to result in global warming, and unpredictable rainfall patterns, floods and droughts impacts on food security and agricultural productivity as climate affects the capacity of a country to feed its people and generate adequate quantity and acceptable quality of crops in a sustained way (Goh 2009; Donovan 2008).

2. As agriculture is both a cause and victim of climate-change, the solution of climate-change caused by agriculture depends on selecting the best agriculture or farming practices to provide the cost-effective agricultural production system with minimum adverse effects on the environment , particularly its resultant climate. Coconut farming and/or coconut agro-ecosystem is one of the major agricultural sectors/systems in the country since the post-Spanish regime. Also, the landscape of the Philippines from the seacoast to elevated uplands and low mountains had been devoted to coconut farming and coconut agro-ecosystem as one of the major cropping/system in the country had been dominated by rice lands, corn lands and coconut lands with around 3.3 million (M) ha for decades already. Our natural and managed (plantations) forest lands had been reduced from over 10 M ha many decades ago to a low of at least 1 M ha today.

3. Global warming, or climate-change in general, and its consequences are among the pressing issues today. In recent years, many believe that climate changes have been strongly attributed to greenhouse gasses (GHGs) in the earth's atmosphere like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO2), and fluorocarbons (FCs). These GHGs absorb the thermal radiation emitted by the earth's surface, thus rising concentrations of GHGs in the atmosphere could lead to a change in energy balance and eventually the world's climate. The CO_2 is by far the largest contributor to the man-made enhanced greenhouse effect (IPCC 2007)

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4. Forest ecosystems play a significant mitigating role in climate-change because they can both be sources and "sinks" of CO2 (Trexler and Haugen 1995 cited by Lasco et al 1998). The net ecosystem exchange of CO2 between coconut and the atmosphere is the difference between CO2 uptake via photosynthesis and CO2 emission through ecosystem respiration (release or loss of CO2) by plant leaves and soil roots and plant litters (Roupsard et al 2008).

5. As to the net ecosystem carbon production (NEP) or carbon sequestration (CS) by the carbon stock method (CSM), accounted are the variations of C stocks in the soil + biomass + necro-mass (litters). This assessment method could be acceptable on the long term, but for C stocks for a short term (a day or few years, no accurate method is yet available (Roupsard et al 2008). In coconut plantations with intercropping or under-storey cropping, the applicability of the CSM (C storage or sink) assessment requires more studies to have an objective, location-specific and highly acceptable quantification of carbon inputs and balance, eventually for C credits and carbon stock marketing.

6. The Philippines is one of the tropical countries that have a high potential to mitigate global warming, specifically carbon emissions. Like forest lands, the country's extensive coconut lands of about 3.2 M ha with at least 325 M coconut fruit-bearing trees could be developed for income generating carbon sequestration projects and carbon credit market.

7. Earlier, workers (Lales et al 2001) in the country studied the C storage capacities (CSC) of agricultural and grassland ecosystems in Leyte, Philippines. CSC is a function (based) on the annual total above ground biomass (dry matter mass) multiplied by the average C content (e.g. 44.7% C, coconut trunks, leaves without nuts). They found that among the crops studied, banana and coconut had an average C storage of 5.7 t C/ha and 24.1 t C ha per year, respectively . Coconut farming and coconut agro-ecosystem is one of the major cropping systems in the country). And among the four crops studied (wetland rice, banana, sugar cane and coconut), coconut was also found to have the most stable C storage, being a perennial crop with almost nil burning of crop residues in place at the farm (compared to that in rice and sugar cane farming). The same workers did not mention the levels of C sequestration in the soil. On net ecosystem production or NEP, an actual ecosystem C balance value of 4.7 to 8.1 t C/ha per year was reported recently (Roupsard et al 2008) from a three years work (2001-2003) in the South Pacific (Vanuatu). If coconut meat (1.3 t copra/ha) is transported from the field, the corrected NEP decreases to 3.4 – 6.8 t C/ha per year. These positive values of actual ecosystem C balance indicates that C (CO_2) is sequestered from the atmosphere and stored in the plantation. It appears, the C sequestered in the soil was not included. This variability in findings indicates more refinements of methodologies and collaborative works are essential to provide accurate and objective information and data for a carbon credit/ market generated in coconut-based agro-ecosystems.

8. Under the 1997 Kyoto Protocol, which is an amendment to the United Nations Framework Convention on Climate-Change (UNFCCC), industrialized countries have committed to reduce their emissions of carbon dioxide and other green house gases (e.g. methane, nitrous oxide, sulfur hexafluoride) or engage on emissions trading if they maintain or increase emissions of their gases. In the Clean Development Mechanism (CDM) of this protocol, they can meet part of their target in reducing CO_2 emission to the 1990 levels over a five-year period (i.e.,2008-2012) by purchasing emission reduction credits from developing countries like the Philippines in the form of planted forest which is achievable in the Philippines due to its vast tracts of open land for the establishments of plantations like yemane (*Gmelina arborea* Roxb.(Tandug 2006).

Due to the apparent complexity and involvement or interactions of many aspects of our land resources, biological diversity, crop diversity, environment and man's practices and interventions in response to his social and economic needs, this review paper should be significant in deciding our best individual, community, sector, and country's option in facing or dealing with the climate change impacts today and the years ahead.

SIGNIFICANT GLOBAL FACTS, OBSERVATIONS AND MAIN STRATEGIES

Carbon dioxide (CO_2) is the most significant and reference "green house" gas (GHG) among GHGs produced by human activities, primarily through the combustion of fossil fuels. The earth's atmosphere has risen by more than 30% since industrial revolution (1744 -2005). From 275 ppm (0.0275%) to 380 ppm (0.038%), the trend is an exponential one during the past 800,000 years (Reay and Pidwirny 2006). The current rate of increase is estimated at 2 ppm annually.

Mankind and ecological systems rely on the soil for the natural supply of water and nutrients for plant growth, the regulation of the water cycle, and the storage of carbon. Climate change (CC) and its impacts ---------- e.g., increases in temperature (heat), changing rainfall patterns, floods, droughts ------ will not only affect us but may also affect how soil provides services. It is well known that it has highest C pool/supply, after the ocean and sea (European Environment Agency (2009).

A. <u>The Carbon Cycle</u>

There is a biological side to global warming (one of major the outcomes of and the carbon cycle . Carbon is a main component or ingredient of all life, and of its remains (Donovan 2008). It was mentioned that **while planting trees is a way to reduce atmospheric CO_2, we could increase soil organic matter (i.e., 58% C by dry weight),** rapidly and cheaply. This will pull the excess Cout of the atmospheric (CO2 emission), while also enhancing soil fertility, water quality, food quality and human health, likewise, minimizing floods, droughts and agriculture's dependence on fossil fuels and farm chemicals.

How it works? Through the biological processes such photosynthesis and respiration, about 99% of the C cycle is driven. There is more C in stored in the soil than in the vegetation (plants) and atmosphere combined. And soil C can be stable than plant C as the former is less subject to oxidation or burning, thus a good topsoil. It is characterized with the combined components of different levels of solid mineral matter, air, water, living organisms in the soil and organic matter.

Respiration, both on land and in the sea is the key component of the global carbon cycle. On land, the estimated terrestrial emission by autotrophic respiration: 60 billion (B) t (Pg) C per year; heterotrophic respiration: 55 B t C/yr (Reay and Pidwirny 2006). While in the sea: autotrophic respiration: 58 B t C/yr and heterotrophic respiration: 34 B t C/yr. The land use-changes in the tropics is currently 1.7 B t C/yr, mainly due to deforestation. Stationary energy sources (coal-fired) had CO2 emissions of 6.5 B t C/yr.

B. <u>Bio-fuels</u>

Converting biomass-derived sugars to ethanol and plant oils and fats into bio-diesel is a viable strategy to reduce use of fossil fuels and develop alternate and sustainable sources of energy (Himmel et al 2007; Stephanopoulos 2007 and Wald 2007). Of the renewable sources, 2.48% was contributed by traditional bio-fuels (e.g. animal dung, crop residues, wood products, and 1.91% by modern bio-fuels.

Recently, bio-fuels have been high on the political and scientific agenda. Why? It is associated with C sequestration in two distinct but interrelated concerns (Lal 2007, in Royal Society 2007):

(i) soil C sequestration through restoration of the depleted soil organic carbon (SOC) pool, particularly when agriculturally degraded/marginal soils are converted to energy plantations; and

(ii) recycling of atmospheric carbon dioxide (CO_2) into biomass-based bio-fuels. With choice of the appropriate species and prudent management, bio-fuels produced from energy plantations established by dedicated crops (as coconut, sugar cane and selected cereal crops in the tropics) can sequester or store C in the soil (as C "natural sink"), offset fossil fuel emissions and reduce the rate of abundance of atmospheric CO_2 and other GHGs.

Nevertheless, against the beneficial impacts of bio-fuels, some people have argued that there could be an increase in competition for land and water in establishing energy tree plantations aimed for carbon farming.

Coconut Biodiesel Fuel Initiatives in the Phillipines

An extensive study and cross-checking of the properties and performance of coconut oil-based methyl ester (CME) was done in the country and in some concerned and interested countries. With very positive results favoring CME as a coconut oil-derived bio-fuel, a law was enacted in the country now called RA 9367, the bio-fuels law of 2006, enforced as a law effective February 6, 2007. It shall support the government's objectives and goal of reducing the dependence of the country and fossil oil users on imported fuels. Moreov**er, among the many other socio-economic beneficial concerns are:** the protection of pubic health against hazardous air pollution; the conservation of sustainable environment and natural resources; and utilization of the coconut crop as a renewable bio-fuel source (Ables 2009).

In more specific terms for diesel- fed mobile and stationary engines, the bio-fuels act mandates the blending at least 1 % CME in the coconut bio-diesel fuel, starting May 2007, followed by 2% blending with CME Based on the country's compliance monitoring on RA 9367 managed by the government through the joint efforts of Department of Energy (DOE), and the National Bio-diesel Board (NBB), Table 1 shows the important indicative coconut bio-diesel early growth indices from 2007- 2009.

Table 1. Important milestones and growth indices on the utilization of coconut oil as bio-fuel in the Philippines (2007 – 2009)

Date/Year	Total Quantity of Coconut Bio-diesel Sold in the market	Remarks/Notes
May to end 2007	44.46 million (M) liters	Initial year of implementation. Sold to/or bought by various sectors/users
First semester (Jan –June) 2008	32.50 M liters	-ditto-
End 2008	64.48 M liters	Still at 1% CME blend
End of 2009	133.68 M liters (forecast by DOE and NBB)	At 2% CME blend starting February 2009; Note: combine capacity of 10 bio-diesel plants = 323.620 M liters

Source: Ables, R.C. (2009)

C. Carbon Farming and Trading of Carbon Credits

Carbon sequestered or stored in soils and trees can be traded, just as any farm produce (crops, meat, fish, milk, etc). Trading C credits is a rapidly growing industry (Gressel 2007; McGowan 2007 cited by Lal 2007). The market is now well established in Europe (Johnson & Heinen 2004; Brahic 2006, as cited by Lal 2007) and the USA through Chicago Climate Exchange (Breslau 2006). The 'cap and trade' movement is gaining momentum in the USA (Schlesinger 2006 and McGowan 2007), with attention focused on policy options fro slowing emissions of GHGs (cited by Lal 2007, Koferr 2007 and Kintisch 2007b). Lai (2007) mentioned the following options: (i) imposing tax on C emissions called C tax; (ii) providing government subsidies; and (iii) trading C credits (net C).

As stressed by Lai (2007), while the market for trading C sequestered in soils and biota (trees and other living organisms) is being developed in North America and Europe, the strategy will likely be beneficial to the resource-poor and small landholders (as coconut farmers) of developing countries of Asia and Africa. This is significant as trading C credits generated by these countries can provide a much needed income for the farmer, and serves as an essential incentive to invest in soil restoration (e.g. erosion control, fertilizers, irrigation and other farm improvements), breaking the agrarian stagnation and advancing food security.

D. Basic Natural Biological Processes in Carbon Sequestration

To understand climate change (CC), carbon sequestration, agricultural productivity and environmental productivity responses, it is important know well the key plant physiological processes, especially, photosynthesis and metabolic respiration which involves, respectively, the CO2 plant intake from and CO_2 release to the atmosphere. Generally, the balance of the two biological processes is considered as the net photosynthetic assimilation rate (indicated or measured by biomass density index through the dry matter mass/yield). With the aid of a formula or equation, these are shown as :

D.1 Plant Photosynthesis – the basic process of natural food manufacture in plants of which carbohydrates are produced and with the combination with mineral/inorganic materials and substances, other foods are made (proteins, fats and oils)

The basic photosynthetic reaction:

$$12\,H_2O + 6\,CO_2 \xrightarrow[\textit{chlorophyll}]{\textit{light}} C_6H_{12}O_6 + 6\,O_2 + 6\,H_2O$$

Consider that:

1) The first part of the total photosynthetic reaction is essentially light-driven (light absorption), water-splitting (with aid of Cl ions) to generate hydrogen ions for the production of energy-rich compounds (ATP and $TPN.H_2$), needed by the plant for the next metabolic reaction;

2) The next reaction involves the incorporation of CO_2 plus water to produce the basic product glucose carbohydrate):

Like biological reactions in general, the reduction of carbon dioxide (CO_2) and the production of carbohydrates (CHOs) is a continuing process only as long the favorable plant physiological factors and conditions are met.

Hence, trees naturally take up CO_2 from the atmosphere and store the converted carbon (C) in their biomass through photosynthesis. With the increasing serious concern over the increasing CO_2 in the atmosphere, the role of trees in the removal of atmospheric CO_2 for the build-up pf their biomass should be extremely relevant in environmental management. The planting of trees including palm trees as coconut to sequester atmospheric C has been considered as one of the most cost-effective and long lasting means or significant strategy to mitigate the global problem of increasing excessive amounts of CO_2 in the atmosphere.

D.2. Plant Respiration – a general metabolic term covering varied series of biological phenomena by which the chemical energy of foods is converted to the chemical energy of some compounds, usually the adenosine tri-phosphate (ATP), accompanied by the release of CO_2 and water. Cells use ATP to do work, hence, referred to as “the energy currency of cells”.

The over-all equation of respiration:

$$C_6H_{12}O_6 + 6\,O_2 \; >>>>>>>>>> \; 6\,CO_2 + 6\,H_2O + \text{energy}$$

D.3 Net Assimilation Rate (resultant biomass or Dry Mass/ Matter Yield)

In an earlier study on coconut in India reported by Nair (1979) as estimated from the works of Nelliat et al (1974) and Khanna and Nair (1977) as cited by Magat (1990), an indicative value of annual net assimilation rate (NAR) of the coconut crop was reported, indicated in Table 2. This is an important index in the determination of the sequestration of C of the coconut crop.

Table 1. Total annual biomass yield (t/ha) at different tree productivity levels

Plant Part	Annual Nut Yield (nut/palm)		
	60	100	250
Whole nut	6.70	11.20	28.00
Spathes and rachis	0.15	0.15	0.15
Leaves	4.60	4.60	4.60
Stem	1.25	1.25	1.25
Roots	1.25	1.25	1.25
Total biomass	14.20	18.70	35.20
Estimated annual biomass C (t C/ha)[a]	6.34	8.35	15.73
Equivalent CO_2 (t/ha)[b]	20.58	31.06	58.51

Source: Nair (1979) cited by Magat (1990)

[a] calculated based on the formula: biomass C = (biomass yield x 44 %C)
[b] calculated based on the formula: biomass CO_2 sequestered (fixed) = (biomass C x 3.72)

From this data, using an average 44%C content of coconut biomass, it can be noted that the biomass yield, biomass C generated , and level of atmospheric CO2 sequestered or fixed by bearing coconut increases with increasing yield of the palm, with the whole nut biomass yield as a strong significant factor in the NAR of the coconut. Most of the biomass of the palm is generated by the easily decomposed parts of the palms (whole nut and leaf fronds).

While, in a recent work in India, the biomass production of coconut under a high density multi-species cropping system (HDMSCS) was investigated by the workers of the CPRI (Kasaragod, India), with other crops (banana, pineapple and cloves), as reported by Subramanian et al (2005). Table 2 shows the different annual dry matter yields (t/ha) under different fertilization levels compared to unfertilized condition.

Table 2. Average total biomass (t/ha)[a] of coconut and other crops under the HDMSCS in India (CPCRI-Kasaragod, 1998-1999).

Fertilization Level	Coconut [b]	Banana
Full of recommended rate (RR)	23.55	1.767
2/3 RR	24.80	1.407
1/3 RR	21.98	1.329
¼ RR	19.94	1.124
1/5 RR	18.49	0.851
Unfertilized (Control)	17.72	0.716

[a]18-yr old West Coast Tall, 8 x 8 m square planting (156 trees/ha)
[b] dry matter mass of leaves, inflorescences and nuts (husk, meat and shell).

Table 1 indicates that the annual biomass yield (dry matter yield without the stem) as a measure of the net assimilation rate of the coconut varies with the levels of fertilization. In these two crops, coconut and banana, the annual biomass generated were lowest under unfertilized conditions, but it was highest under 2/3 recommended fertilization rates for coconut, and in contrast to banana crop which was at the full recommended rate. This indicates that coconut's biomass yield or NAR could be optimized if proper crop nutrition and fertilization management is followed.

D.4. An estimation of Soil Organic Carbon (SOC) based on Soil Organic Matter (SOM), Canja (2009)

In forest soils of Papua New Guinea, Columbia and Venezuela, stored C could be as high as 300 t C/ha (up to 1 m soil depth) reported by Lugo and Brown (1993) . In forest ecosystems, the soil C is 30% of total forest C or a much as the biomass (Muora-Costa 1996; and Lugo and Brown 1993 cited by Lasco et al 2000). Moreover, the SOC should not ignored as a C sink because it has the longest residency time among the organic C pools in the forest.

Canja (pers.comm.) presented an estimation of SOC based on known facts about field soils from Brady and Weil (1999) : (i) SOC ranges from 40 - 58% of the SOM ; (ii) as the 58% value applies only to highly stabilized humus, especially in sub-soils, in general or most situations the reference value of 50% in more proper; (iii) only about 5% of the volume of an average ideal soil is SOM, but the influence of the organic compounds on soil properties is often greater than its low content would suggest; (iv) the organic matter is far less dense than the mineral matter, thus SOM could account for only about 2% of the mass weight of the soil; and (v) SOM = SOC x 1.72.

The table 3 below shows the estimated SOC from the estimated SOM at two levels of SOM (%) and under two soil depths or top soil thickness. The 1.0 - 2.0% soil organic matter content , the estimated SOC ranges from 10 - 40 t/ha, depending on the soil depth reference, i.e,. 15 - 30 cm. This means that for every 1% increase in SOM, at a soil depth of 15 cm, the estimated SOC produced is 10 t C/ha, a significant quantity of C stored or sequestered in the soil , usually over a long period of time.

Table 3. Estimated quantities (t/ha) of Soil Organic Matter (SOM), Soil Organic Carbon (SOM) varying SOM% and soil depths.

SOM Level	Soil Depth/top soil thickness (cm)	Wt of SOM (t/ha)	Wt of SOC (t/ha)	Soil wt/ha at 2 depth
1.0 %	0-15	20	10	2 M kg soil/ha
	0-30	40	20	4 M kg soil/ha
2.0%	0-15	40	20	2 M kg soil/ha
	0-30	80	40	4 M kg soil/ha
Assumptions:	Area= 10,000 m^2/ha Depth = 0.15 m and 0.30 m Soil Bulk Density (SBD) = 1.33 Mg/m^3			
	Soil wt at soil depth per ha = Area x Depth x SBD			

Source: Canja (pers. comm. 2009)

Example calculation: 1) for 15 cm topsoil depth

SOM = (2 kg SOM/100 g soil) (2 M kg/ha) (1 t /1000 kg) = 40 t/ha
SOC = (40 t/ha x 0.50) = 20 t/ha

2) for 30 cm soil depth

SOM = (2 kg SOM/100 g soil) (4 M Kg/ha) (1t /1000 kg) = 80 t/ha
SOC = (80 t/ha x 0.50) = 40 t/ha

However, although agricultural and degraded soils can provide significant potential sinks for atmospheric CO_2, soil C accumulation does not continue to increase with time with increasing C inputs but reaches an upper limit or “C saturation level” with controls the ultimate limit of soil C sink (Goh 2004). He stressed that understanding the influence of soil C stabilization mechanisms should be known. In this regard, the physical mechanisms such as the protection of SOC by soil minerals are better known while the chemical and biological mechanisms are less known, hence requiring more experimental data for verification and validation under different soil and climate conditions

Goh (2004) also clearly pointed out the general claim by many workers that not all the C accumulated in soils are protected against losses due to mineralization, erosion and leaching, with only a portion considered as stable soil C. In terms of soil C storage, the SOC can be divided as: (1) unprotected or labile C (that with short half lives of 1-19 years); and (2) protected C (longer half lives of 20 -100 years or more). Therefore, as C sequestration applies to C stabilization in the soil for at least 20 -50 years, the protected C provides the key to the control and regulation of soil C sequestration, as Goh (2004) emphasized.

E. Coconut Ecosystem Carbon Balance Study in Vanuatu (South Pacific)

Mostly on an extensive Coconut Ecosystem Carbon Balance Studies (2001-2007) in the South Pacific (VARTC, Santo, Vanuatu), reported by Roupsard et al (2008). Their reported studies have different aspects or components, and conducted in a more detailed manner.

E.1 **Net Primary Productivity (NPP) of Coconut**

(i **)** Using a coconut hybrid, Vanuatu Red Dwarf cross with Vanuatu Tall or VRD x VTT, grown under almost optimum crop nutrition in high a fertility level soil and without drought problem, Navarro et al (2008) reported the total NPP of coconut + grass under-storey of 32 t dry mass/ha/yr (i.e., 16 tC/ha/yr, 50% of total NPP); **NPP of coconut trees = 12 tC/ha/yr** (coconut copra yield of 2.7 t/ha/yr.

(ii) From same work area, the apparent **NEP (or the actual ecosystem C balance)** of the coconut plantation of is an average of 8.1 tC/ha/yr (3 years data) compared to a standard calculation of 4.7 tC/ha/yr. As the copra yield (11% of NPP) is taken out of the field, thus a correction has to done (i.e., less 1.3 tC/ha/yr), giving a corrected **NEP of 3.4 to 6.8 t C/ha/yr.**

(iii) Compared to forest trees (typically dicot) of which C goes into the more permanent structures (stems and coarse roots), the **coconut palm allocates more than 86% C into perishable or (easily decomposed) parts as nuts/fruits, leaves, peduncles and fine roots**, shortly converted into litter, respired by the ecosystem, eventually contributing to the soil organic matter (SOM) build-up.

(iv) If this inherent attribute of the coconut or its ecosystem is not adjusted (or just the usual C accounting in forest inventories is followed, the significant underground C in soil organic matter and litter is excluded, hence, the carbon credits and value (subsidies) in coconut farms and ecosystem is undervalued.

F. Biomass and Carbon Sequestration in a Coconut + Fruit tree Ecosystem in the Philippines

The magnitude of CO_2 removal through photosynthesis, in woody plants or managed and natural ecosystem, is likely to increase in the future due to the CO2 fertilization effect (increased levels of atmospheric CO_2 due to local and global emissions). A significant example of a managed and natural ecosystem in the Philippines is the coconut-based farming/ecosystem, such as the coconut-lanzones fruit tree agroecosystem extensively practiced in the country, and had been studied over a 15-yr long-term period (Magat et al 2009). Grown under very adequate rainfall condition, it was managed following an integrated soil fertility management (ISFM) with emphasis on application of a coconut-specific multinutrient fertilizer (MRF), supplying an adequate level and proper ratio of N, P,K, Cl, S and B, appropriate for the main crop coconut and the fruit tree intercrop.

Under the coconut and lanzones fruit tree agroecosystem, Magat et al (2009), showed a build up of soil organic C was shown to increase from 0.75 %C in 1993 (initial planting of the fruit tree intercrop), increased to 1.2% C in 1997 (4 years later) and to 1.35%C in 2003 (10 years later). This increase in soil C by 0.6% C over a 10 years period, clearly indicated significant C storage in the soil sink, via the atmospheric CO_2 fixation by the two crops of the ecosystem, generated as the combined plant biomass with most of it ending in the soil as organic matter, and eventually as the more stable stored soil organic carbon (SOC). Considering that SOM = SOC x 1.72, the 0.6% SOC increase in 10 years under this coconut-based ecosystem, means an improvement of SOM = 1.03%. Therefore, using Table 3, the estimated quantity of the increase in stored SOC amounts to 10 t C/ha and 20 t C/ha, at 15 cm and 30 cm soil depth, respectively.

Hence, it's widely known now that crops and trees are natural carbon "sinks" with both plants and soils rich in organic matter are capable of absorbing the atmospheric C. Moreover, farming practices that enhance plant diversity and organic matter in soils is very likely supportive of sustainable agriculture and also environment, and the coconut crop and its agroecoystem is a remarkable example (Magat et al 2009).

6. In a recent completed long term research work (1993-2007) in Southern Mindanao (Magat et al 2009), the remarkable improvement and sustainability of 3-4 t copra/ha per year coconut yield and very productive *lanzones* fruit trees under a coconut + *lanzones* agro-ecosystem was strongly attributed to the significant influence of proper crop nutrition and fertilization management. A general improvement in soil fertility, including soil organic matter (SOM) and soil organic carbon (SOC), over the long term period of 15 years was demonstrated (Magat et al 2009). This clearly indicates that a coconut-based agro-ecosystem or cropping practice could sequester CO2 and consequently store organic C via the tree components and its soil environment. However, further research studies are required to predict and quantify and magnitude of the contribution of coconut farming practices in the carbon sequestration mechanism of the plant-soil systems.

SUMMARY SALIENT NOTES

This review was initiated as an attempt to have a better understanding of the past events and current developments in coconut production research and practices done in the country and elsewhere, associated with global change in climate which have resulted to the observed unwanted impacts as global warming, floods, droughts and soil degradation, among many other outcomes. The excessive emissions of green house gases (GHGs) mainly carbon dioxide (CO_2), methane (CH_4), nitrous Oxide (N_2O) for the past several decades had been claimed to trigger and intensify global warming in recent years. Largely, the emissions of GHGs is globally measured in CO_2 terms as agreed upon through the International Panel in Climate Change (IPCC).

Atmospheric CO_2 gas is fixed or absorbed by terrestrial plants and converted to biological mass or biomass (the plant dry matter) via the biological process called photosynthesis, but this gas is also released or emitted back to the ecosystem via another biological process respiration. The CO_2 intake by plants and crops is considered as C sequestered and stored in different parts of the plants as forest and coconut trees. C stored in plant parts other than the stem wood or trunk are generally decomposable biomass which eventually becomes a part of the soil organic matter (SOM) of which the more stable component is the 50% soil organic C (SOC). Therefore, in coconut, similar to most tree crops, C is stored or sequestered both by the biomass (permanently and temporarily) and the soil of the ecosystem (longer time), indicating that the biomass and the soil are the main C sinks of atmospheric CO_2. And these "sinks" could be regulated and managed to a great extent by following proper cropping practices.

So far, among the important and significant findings or current knowledge, though mostly only indicative, on the subject of coconut and climate-change are the following

(1) Coconut plantations or farm ecosystems could be used in many ways to reduce CO_2 emissions via C capture or sequestration in the crop-soil system are: (1) substitution of fossil fuel using biodiesel or biomass from coconut oil; (2) sequestration of C in coconut plantation, mono-crop or with intercrops; (3) enhancing C sequestration through coconut plantation management; and (4) conserving C sink in coconut farms. The coconut tree, a woody perennial with single main stem meets the criteria of "forest" per FAO criteria. The Philippine Department of Environment and Natural Resources (DENR) Order No 2005-25 included coconut as a reforestation crop, effective Nov. 17, 2005.

(2) Workers obtained varying levels of the total biomass (15 – 50 t/ha/year) yield of mature bearing palms depending on the annual nut yield (strongly influenced by the interaction of crop variety, environmental conditions, crop nutrition or fertilization management) , growth stage or age and planting density/ha.

(3) the average % content or concentration of C biomass components (stable trunk, and temporary or unstable fruit-nuts, leaf fronds, and other vegetative parts is around 44%, lower than the 50 % C content of most hardwood forest trees

(4) With almost constant % C, the stored C averaged 24.1 t/ha and 5.74 t/ha, for productive bearing and pre-bearing palms, respectively. Compared to other the ecosystems studied: rice, sugar cane and grasslands, the coconut has the most stable C storage, being a perennial with almost no field burning of farm residues in practice.

(5) From a short term 2-year study, excluding the sequestered C in the soil (SOC) in the Philippines (Eastern Visayas), a study reported the rate of annual C sequestration in local Tall variety coconut crop of 4.78 t C/ha (equivalent to 17.54 t CO_2/ha), while in Vanuatu, South Pacific, a longer study (2001 - 2007), the potential C balance or the Net Ecosystem Productivity (NEP), showed a C sequestration rate of in a 20-year old plantation grown to coconut hybrids under optimum conditions ranging from 4.7 to 8.1 t C/ha /yr (corrected to 3.4 to 6.8 t C /ha/yr, after removing the C biomass from coconut copra exported from the field).

(7) Soil organic C (SOC) based from the soil organic matter (SOM) at two levels of SOM and soil depth showed that for every 1% increase in SOM, at 15 cm soil depth (2 M kg soil/ha), the estimated SOC stored is 10 t C/ha, and 20 t C/ha at the soil depth of 30 cm. As SOC is not protected from losses due to natural processes in soil, sequestered soil C should be the C stabilized for longer period of at least 20 years.

(8) As an indicative potential cash value of the annual coconut ecosystem C sequestration, assuming an average of 5.1 t C/ha of stable biomass and 15 t C/ha from the sequestered SOC, 50% of stored SOC, 30 cm soil depth, 4 M kg soil/ha) = 20.1 t C/ha/yr. At USD 15/t C (PhP 705 @ 1USD=47 PhP), the estimated cash benefits amounts to at least PhP 14,170.50/ha per year or PhP 14.17 M for every 1,000 ha coconut lands used in the Climate-Change CDM-Mitigation. If coconut lands are intercropped with fruit trees and other perennial crops, highly capable of C sequestration in their plant biomass and the soil, obviously, this value could easily double.

To take the full or best advantage eventually in using coconut production and its ecosystem for judicious environmental management, and social and economic benefits from the Climate Change Clean Development Mechanism-Mitigation Component CCCDMMC) through the Kyoto Protocol (UNFCCC), more formal and scientific collaborative studies by coconut producing countries and agencies concerned are urgent needs. These should be focused on achieving acceptable methodologies and empirical data for the holistic and site-specific evaluation of the certified emission credits (CERs) applied for by developing countries for project carbon credits and subsidies from developed or industrialized countries referenced to sustainable development activities on climate-change mitigation, required by the IPCC.