SOIL CARBON SEQUESTRATION AND GREENHOUSE GASES MITIGATION IN SELECTED ECOSYSTEMS IN THE PHILIPPINES

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ABSTRACT

The use of fossil fuels, deforestation and irresponsible farming practices all contribute to GHG emissions, disrupt the carbon cycle, and agitate the greenhouse effect. With CO_2 being the most abundant, there is now a need to sequester carbon and identify and enhance ecosystems that can serve as sinks. Consequently, the need to shift to climate-friendly farm management practices also arose. Thus, this study was intended to assess the SOC sequestration and greenhouse gases mitigation in selected ecosystems in the Philippines to open opportunities under the carbon trading scheme.

Existent and/or possible carbon stocks are determined in specific ecosystems using only a few studies on carbon stocks assessment relevant to climate change mitigation and adaptation as basis. Data on soil organic carbon (SOC) from these studies were assessed in relevance to the total carbon stocks in the ecosystem and to climate change mitigation. Results show that various ecosystems in the Philippines, such as secondary growth forests (57-59%), mangroves (10-11%), brushlands (77%), grasslands (96%), and degraded pasturelands (28-76%), have optimum carbon sequestration potentials. Of studied ecosystems, brushlands and grasslands have kept a large percentage of carbon in the soil.

In agricultural ecosystems, results showed that soil carbon sequestration is dependent on soil type, pH, tillage systems, and type of vegetation. Using Adtuyon and Faraon soil series in Zamboanga Penisula, it was found that no-tillage and conservation tillage systems are better alternatives compared to conventional tillage in conserving sequestered soil organic carbon.

With farming management practices involving anaerobic decomposition contributing 40% to the CH_4-GHG emissions, emissions are impacted on by various farm management methods used by farmers based on their knowledge, perceptions, resources constraints, and the amounts and economic values of GHG reduction of changing to more climate-friendly farm management practices. In lowland rice agroecosystems in Isabela Province, changing from continuous flooding to mid-season drainage will reduce 2,823.81 tons/year (a tradable CO_2 equivalent of P34.16 million/year) in CH_4 emissions, while shifting from rice straw incorporation to rice straw compost application will reduce 3,756.44 tons/year (a tradable CO_2 equivalent of PhP45.44 million/year). Simultaneous shifting to more climate-friendly farm management practices will yield 81% reduction in CH_4 emission. Incremental benefits of shifting from existing farming practices (continuous flooding and rice straw incorporation) to climate-friendly farming practices (mid-season drainage and rice straw compost application) will be 138.95 million pesos per year.

Information on carbon stocks in various ecosystems will be relevant in developing a soil carbon sequestration potential database for climate change mitigation and adaptation strategies.

Keywords: soil organic carbon, carbon sequestration, carbon stocks

INTRODUCTION

Global Warming and Greenhouses Gases

The realization that global warming will bring disastrous changes to our planet brought to fore the causes of this phenomenon. As a consequence, the greenhouse gases or GHGs, notably carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) received much attention. Radiant energy received by the earth's surface cannot be reflected into space because it gets trap in the lower levels of earth's atmosphere by these GHGs, and then reradiated back to the surface (thus the term greenhouse effect). The heat trapping action of these GHGs makes our world warmer. However, humankind has to satisfy the need for energy, food, and fiber, mostly through the use of fossil fuels and intensive agricultural production. These activities have increased the levels of the GHGs in the atmosphere. There are now efforts to reduce emission of GHGs before they reach the critical level.

One of the most important biological processes is the carbon cycle. The CO_2 in the atmosphere is converted, through photosynthesis, to carbohydrates in plants. Consumption of the carbohydrates in the plants by man and animals and its oxidation through metabolisms produce carbon dioxide and other products. Thus, CO_2 returns to the atmosphere (Encyclopedia Brittanica, 1995). A portion of this carbon pool is sequestered or taken off from the cycle and stored in soil, trees, or deep in the earth's crust. The portion of the carbon pool which has accumulated in the earth's crust or removed from the cycle during prehistoric times, mostly in the form of oil and coal, is being used now as fossil fuel. Use of fossil fuel to run industries, together with the reduction of forest cover and intensive agricultural activities, freed organic carbon in vast amounts. When the process freeing the carbon is anaerobic in nature, then the carbon escapes as methane (Encyclopedia Brittanica, 1995).

Soil Carbon Sequestration and CH_4 and N_2O Emissions

Soil carbon sequestration, according to Sundermeier et al (2009), is "the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is stable and not easily released. Carbon is primarily stored in the soil as soil organic matter''. Primarily, it is believed that such carbon sequestration will offset emissions from the use of fossil fuel and improve soil quality and agronomic productivity in the long run. Management systems that generate high biomass to be added to the soil with minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil fauna activity are good sequestration strategies.

According to the EPA of US (http://www.epa.gov/sequestration/national_analysis.html), practices that sequester carbon in forests, croplands and grazing lands can have both positive and negative effects on CH_4 and N_2O emissions. The relationship among practices that affect CO_2, CH_4, and N_2O can be especially complex in cropping and grazing systems. For instance, nitrogen-based fertilizers applied to crops increase yields and add likely to soil carbon but emissions of N_2O will increase.

Rotational grazing is beneficial since it will lead to 1) enhancement of soil carbon, 2) decline in livestock CH_4 emissions due to improved forage quality, and 3) avoidance of N_2O emissions by non-application of fertilizer. Strategies in carbon sequestration should therefore consider the complex interactions among these gases if the ultimate objective is to reduce the GHGs (http://www.epa.gov/sequestration/national_analysis.html).

Soil: Source and Sink of Carbon

The concern in global climate change has now put value on sources and sinks for carbon. Soil can either be a sink of atmospheric carbon or a source for it depending on the land use and management (Lal, 1999). The soil organic carbon (SOC) pool is about two thirds of the terrestrial biosphere carbon pool (Reicosky, 2008) and therefore is vital part of carbon sink management. However, the vast volume of carbon held in the soil should be prevented from being emitted. Through the processes of mineralization, methanogenesis, and denitrification, the SOC pool emits CO_2, CH_4, and N_2O. Further, when forests are cleared through cutting and burning, large amount of carbon is released. Agricultural practices that suppress decomposition of soil organic matter will reduce emission of carbon. A primary objective in mitigating climate change is to adopt land use and agricultural management strategies that will reduce GHG emissions and increase carbon sequestration.

SOIL CARBON SEQUESTRATION IN SELECTED ECOSYSTEMS IN THE PHILIPPINES

Ecosystems such as the secondary forests, mangroves, brushlands, grasslands, and degraded pasturelands have great potential to sequester carbon. However, there are only a few works on carbon stocks assessment in the context of climate change mitigation and adaptation. Carbon stocks assessment of various ecosystems find their importance in generating a pool of reliable information on carbon sequestration potential that will serve as guide and basis for judicious management of these ecosystems for climate change mitigation and adaptation strategies.

This portion will discuss the data and information generated by the carbon stock assessment studies done by researchers, mostly from the University of the Philippines Los Baños (UPLB), Laguna, Philippines. There are numerous researches and activities that churned out a lot of data on the organic matter content of the soils across ecosystems in different parts of the Philippines. However, these data were excluded from discussions in this paper. Included in the discussions are those soil organic carbons that were analyzed for climate change purposes and were taken relative to the total carbon stocks of an ecosystem. Further, there is still a need to validate the accuracy of the analytical procedures used by various analytical laboratories across the country.

Secondary Forest

Dela Cruz (2010) listed the following factors affecting soil organic carbon in ecosystems in forest areas in the Philipines:

1. Natural factors
   - Climate – large soil organic carbon (SOC) is associated with higher precipitation
   - Topography – higher SOC is found in higher elevation areas
   - Natural disturbance
2. Anthropogenic - the capacity of soils to capture SOC is largely affected by the land use changes, land use, and management

Lasco et al (2007) conducted a carbon stocks assessment of a watershed straddling the provinces of Quezon and Rizal in Luzon Island, Philippines. The work also aimed to identify activities that will enhance the watershed potential as a carbon sink, including soil organic stock determination as one component. The following land use-based ecosystems in the watershed covered by the assessment were two secondary forest stands, brushland, and grassland.

In both secondary forest stands, Table 1 showed that most of the carbon is held captive in the soils. This situation is perhaps due to the lower aboveground biomass, as compared with other secondary forest (300-500 Mg/ha). This also suggests that the soils can accumulate carbon. If the area is cleared, burned or cleared, the consequence is the release of carbon in considerable amounts.

Table 1. Carbon density in biomass and soil in the secondary forest.

Sink/carbon pool	Carbon Density (Mg/ha)	
	General Nakar	Tanay
Trees > 10 cm dbh	64.04 (42%)	34.12 (37%)
Understorey/liter	1.58 (1%)	3.74 (4%)
Soil	84.72 (57%)	53.22 (59%)
Total	150.34 (100%)	91.08 (100%)

Source: Lasco et al., 2007.

Brushland and Grassland

Though on a much relatively smaller scale, the same observation applies to the brushland and grassland (Table 2) in which carbon density is higher in the soil pool. Practices that would reverse the process of declining productivity in the brushland and grassland can potentially lead to increased soil organic carbon.

The carbon status of the secondary forests, brushland and grassland reflects the high potential of these ecosystems as a long-live storage for soil organic carbon. This potential, according to Lasco et al. (2007), can be “enhanced through several protective and rehabilitative activities, including the provision of alternative livelihood to the local communities to reduce pressure in the forest resources and lessen the practice of shifting cultivation in the area”.

Table 2. Carbon density of the different land use types.

Sink/carbon pool	Carbon density (Mg/ha)	
	Brushland	Grassland
Brush	14.73 (20%)	
Grass	2.49 (3%)	2.57 (4%)
Soil	57.05 (77%)	55.00 (96%)
Total	74.27 (100%)	57.57 (100%)

Source: Lasco et al., 2007.

Mangrove

The mangrove ecosystem plays a dual role and provides two important environmental services: as carbon sink and as buffer to protect the terrestrial ecosystem from adverse effects of climate change such as sea level rise and salt water intrusion. Aiming to assess the potential of mangrove ecosystems for carbon sequestration, several researchers (Gevana and Pampolina, 2009) determined the carbon density of the biomass and soils of two mangrove stands in Verde Island Passage and Barangay Catmon in the province of Batangas, Philippines.

The data (Table 3) revealed that most of the carbon is held by the biomass while soil organic carbon comprises only 10 – 11 percent of the total carbon pool. While the potential of the whole ecosystem is high, management efforts should be focused on biomass production rather than developing mangrove soils to serve as carbon sink.

Table 3. Carbon pool status, biomass and carbon density distribution in mangrove ecosystem.

Sink/carbon pool	Carbon Density (Mg/ha)	
	Verde Passage	Brgy Catmon
Biomass	103.50 (90%)	125.79 (89%)
Soil	11.95 (10%)	15.92 (11%)
Total	115.45 (100%)	141.71 (100%)

Sources: Gevaña and Pampolina, 2009; Gevaña, Pulhin and Pampolina, 2008.

Degraded Pasture Land

The degraded pastureland has the potential to serve as carbon sink of a degraded by stocking it with fast-growing tree species. However, the species differed in their sequestrating ability and in increasing soil organic matter (Table 4), as revealed by a study of dela Cruz (2008) of three stands in a degraded pasture area (yemane, mahogany, and kakawate) in Mount Makiling in Laguna Province, Philippines. Yemane held the most carbon in its biomass but the kakawate stand with the least biomass has kept a large proportion of the carbon in the soil. Dela Cruz explained that kakawate, being a nitrogen-fixing tree species, stimulated the incorporation of the carbon through litterfall compared with non-fixing tree species.

Table 4. Degraded pasture land with kakawate, mahogany, and yemane stands.

Sink/carbon Pool	Carbon Density (Mg/ha)		
	Kakawate	Mahogany	Yemane
Tree Biomass	16.41 (21.04%)	29.35 (35.82%)	101.16 (66.96%)
Understorey	1.33 (1.7 %)	0.75 (0.92%)	0.91 (0.63%)
Litter	0.48 (0.62 %)	0.01 (0.01%)	1.71 (1.18%)
Soil (SOC)	58.81 (76.35 %)	51.84 (63.27%)	41.42 (28.53%)
Total	77.03 (100%)	81.94 (100%)	145.21 (100%)

Sources: dela Cruz, 2008.

Agroforestry

Agroforestry ecosystems can serve as sink for atmospheric carbon but the types of agrorestry schemes differ in their sequestrating ability. Carbon density of the multi-storey agroforestry system is twice as that of the alley cropping and the total. However, soil has sequestered more carbon under alley cropping condition. The aboveground biomass contributed much to the total carbon. Mostly in alley cropping system, kakawate leaves are incorporated in the soil, hence, increasing the soil organic carbon.

Table 5. Carbon status in degraded pasture land planted to fast-growing tree species.

Sink/carbon pool	Carbon Density (Mg/ha)	
	Gmelina-cacao multistorey	Alley cropping system
Gmelina arborea	106.62	
Theobroma cacao	8.33	
Understorey	0.28	
Necromass	0.99	
Roots	0.24	
Gliricidia sepium		
Biomass total	116.46	1.69
Soil	68.12	91.96
Total	184.58	93.25

Source: dela Cruz, 2010.

SOIL CARBON SEQUESTRATION IN AGRICULTURAL ECOSYSTEMS IN SOUTHERN PHILIPPINES

The recent work of Salang (2010) evaluated the soil carbon sequestration under different tillage and cropping systems and types of vegetation in two selected soil series (Faraon and Adtuyon) of Zamboanga Peninsula, and used the soil organic level as indicator for soil carbon stock, amount of CO_2 sequestered, and for carbon trading potentials and sustainable crop production. The selection of soil types was based on the parent materials believed to sequester high carbon once associated with conservation practices. Estimates of carbon sequestration potentials of soils were evaluated through chemical and physical properties by quantitative analysis.

Conceptual Framework

This pioneering study in the Zamboanga Peninsula was anchored on the concept that soil is the largest sink of carbon. However, the carbon pool is dynamic and the releases of carbon through tillage, swidden farming, land use change, traditional agriculture practices, quantity, depth and intensity of stubble incorporation, type of vegetation, and oxidation of soil organic matter through microbial respiration are accelerated by anthropogenic activities. This pool is the biomass and its by-products in soils may account for a fairly substantial amount of carbon. An increase in the stock of sequestered carbon stored in these pools represents a net removal of carbon from the atmosphere. Carbon sequestered in the form of soil organic carbon can be used for potential carbon trading and for sustainable crop production. Direct soil sequestration occurs through inorganic chemical reactions that converts CO_2 into soil inorganic carbon compounds such as calcium and magnesium carbonates. The weathering of feldspar mineral kaolin is one way CO_2 from the atmosphere is directly sequestered by soil. Moreover, certain bacteria also use CO_2 from the atmosphere in chemosynthesis.

The Soil Series

The Faraon series, derived from the weathering of coralline limestone, includes soils with rolling topography to hilly area. External drainage is good under forest but becomes excessive in the open fields. Internal drainage is fair. Faraon soils in Zamboanga Peninsula are found in the municipalities of Olutanga, Mabuhay, Manucan, and Zamboanga City. Its native vegetation has been completely replaced by the cultivated crops. Usually, Faraon clay has the landscape of a rolling to undulating topography with slopes normally not exceeding 30 percent. The surface soil is very plastic and sticky when wet and ranging from 10-15 cm. in depth. When dry, it remains black and seldom hardens or cracks. It has poor coarse granular structure when wet, but becomes fine granular upon drying. The subsoil is bluish black to grayish black clay, plastic and sticky when wet which slightly hardens upon drying (BSWM, 2004). Faraon series are found both in lowland and upland areas with an elevation ranging from 125 m to 540 m, lying usually from undulating to rolling areas with relief of convex creep.

The Adtuyon soils are developed from weathered rocks that originated from volcanic lava (lahars) chiefly composed of andesites and basalts. It is characterized by light brown (7.5YR 4/4), brown to dark brown (7.5YR 4/2 to 3/2), clay to clay loam surface soil with granular to sub-angular structure. This soil series is found in plateau and on strongly rolling relief. The external drainage is good to excessive and the internal drainage is fair to good. Some Adtuyon soils are considered problem soils because of high erodibility and low nutrient content but still have potential for agricultural production. Adtuyon series are usually found in upland areas with in elevation from 620 m to 750 m, lying on plateau to strongly rolling relief mostly in seepage slope.

The Tillage Systems

No-tillage. This system is practised in the Zamboanga Peninsula by cutting the weeds close to the ground using bolos called *"lampisa"* and *"hilamon". Lampisa* is used to clear the area by scraping the soil surface to cut grasses, while *hilamon* is used to cut grasses by thrusting it into the soil surface. It is also used for planting the seeds and/or seedling materials by making a small hole about five cm deep and five cm wide, placing the planting materials on it and covered with fine soil.

Usually, no-tillage is practiced in sloping lands where farm implements are difficult to use. It is actually an option in situations when farmers have no other choice to prepare the fields, due to lack of capital for crop production, rather than that of aiming for soil conservation. The residues were left at the surface and allowed to decompose as the crops are grown in the fields.

Conservation tillage. Tillage is accomplished by one plowing and one harrowing using carabao to draw the farm implements, returning the residues on the field for decomposition. During harrowing, farm residues were returned to the field by lifting the harrow periodically to remove the weeds that are being stacked on the spikes, rather than dragging the residues to the side of the farm. Occasional fertilization was also done depending on the need of crop and availability of funds for fertilizers.

Conventional tillage. In this system, tillage is done by plowing two times and harrowing two times. It has similarity with conservation tillage but the main difference, other than the number of soil surface disturbances, is the manner of harrowing. Unlike conservation tillage, farm residues during harrowing were dragged to the sides of the farm, and leaving the field clear from any debris, and no stubble incorporation. The piles of residues at the sides of the farms were sometimes burned or just allowed to decompose.

The Cropping Systems

The cropping systems used in Zamboanga Peninsula depend on many agronomic, environmental, and social factors as farmers have different levels of education, culture, religion, and economic status. The areas commonly used for production, covercrops, pastures, and fruit crops are in between coconut palms aging at least 25 years old and above; however, some are just had replanted with the young coconut. It is on this land where different tillage and cropping systems were practiced. Likewise, soil and crop management varieties (spacing and population density, pest control, tillage, and fertilization) that affect crop yield levels on annual cropping were also practiced.

<u>Com cropping.</u> In Zamboanga Peninsula, this is the planting of com year after year in the same piece of land, either in no-tillage, conservation tillage or conventional tillage system, throughout the arable period of five to seven years. After the arable period, the area is fallowed for five to seven years. Typically, the local corn cultivar is the variety used in the production.

<u>Corn-legumes rotation.</u> One of the reasons for including legumes in the rotation is to harvest the crop early within 50 to 65 days after corn harvest. Legumes are usually planted right after the harvest of corn with less labor and capital inputs. The most common legumes planted are mungbeans, pole sitao, and winged beans. Some farmers are aware that planting legume after corn in rotation reduces nitrogen requirement of the succeeding crop; however, others are not attracted to the beneficial effects of planting legumes after corn.

<u>Vegetables.</u> Vegetables are planted in areas where transportation and irrigation are accessible. Vegetables are produced using both inorganic and organic fertilizers. Normally, an area ranging from half to one hectare is planted with many kinds of vegetables in rotation, which is quite manageable and attended only by family of three

or four members for labor. The most common vegetables planted are eggplant, tomato, bell pepper, pechay, mustard, cabbage, raddish, white gourd (kondol), bottle gourd (upo), bitter gourd (ampalaya), okra, patola, cucumber, and watermelon. Commonly, conservation tillage is practiced in raising vegetable production.

Root crops. These crops are cultivated primarily for its edible roots, a storage organ enlarged to store energy in the form of carbohydrates. Root crops are used as staple food for some tribes in Zamboanga Peninsula. The most common root crops planted in small areas (0.25 to 1.00 ha) are cassava and sweet potato. Cassava is planted in no-tilled soil and sweet potato is usually planted in cultivated soils either in conventional or conservation tillage systems.

Cover crops. These are grown to protect and improve the soil, not for harvest. Cover crops have the potential to improve soil tilt, control erosion and weeds, and maintain soil organic matter. The most common cover crops grown in the study area were calopogonium, kudzu, and centrosema. Grown as companion crops or living mulch, they cover the surface soil between the rows of the coconut palms, and sometimes banana.

Pasture/grassland. This refers to land with vegetation cover used for grazing of livestock as part of a farm. Pasture is the primary source of food for grazing animals such as carabao (water buffalo), cattle, goats and horses, which is extensively used particularly in areas where the land is not suited to any other agricultural production. Pasture growth in the study area was composed of grasses, legumes, or shrubs or a mixture of such vegetation. In general, no-tillage system is practiced in establishing pasture/grassland by just allowing any vegetation that grows at the surface of the soil. Only a few of the vegetation is not palatable to the animals.

Banana. A common and widely grown fruit crop in the Zamboanga Peninsula is banana. It is grown by farmers in subsistence. Usually, no fertilization was done throughout the production and banana trunks after harvest were just left in the area for decomposition. Plants depend only on the native source of nutrients from soil.

Fruit Crops**.** Production is a profitable enterprise and a promising way of raising the incomes of upland and sloping land farmers in the peninsula. Existing food production and environment conservation programs in the region tend to integrate fruit trees into the existing cropping system. The most common fruit crops raised are mango, lanzones, rambutan, jackfruit, and marang.

Soil Carbon and Selected Soil Properties

Table 6 below shows the values for selected soil properties and the sequestered CO_2. The high concentration of sequestered carbon in Adtuyon soils is due to the high organic matter at 30-cm depth. Its accumulation in soils was probably brought by conservation of existing stock, and the increase in carbon stock. The conservation of existing carbon stock could be attributed to the increased bonding between organic carbon compound and clay minerals having a low pH in Adtuyon soils.

Faraon soils are calcareous soils that have $CaCO_3$ in abundance, and have pH greater than 7. Calcareous soils tend to be low in organic matter and available nitrogen (FAO, 2007). High pH or excessive application of lime can accelerate the decomposition process of humus; however, the low pH in acid Adtuyon soils can inhibit the activities of the bacteria.

Table 6. Sequestered carbon and soil properties of Adtuyon and Faraon series.

SOIL SERIES	SOIL PARAMETERS			
	Soil pH	BD, Mg/m^3	SOC, %	Sequestered CO_2, Mg/ha
Adtuyon	5.31	1.13	3.14	390
Faraon	7.18	1.16	1.92	246

The greater amount of sequestered carbon in Adtuyon soils compared to that in Faraon soils suggested that the bonding of fulvic acids (the fraction of humic substances that is soluble in water under all pH conditions) to the polyvalent cations of soil clays such as Fe^{3+} and $A1^{3+}$ were greater than Ca^{2+}. The divalent Ca^{2+} ion doesn't form strong coordination complexes with organic molecules. In contrast Fe^{3+} and $A1^{3+}$ form strong coordination complexes with organic compounds. These polyvalent cations act as a bridge between two charged sites.

Moreover, the environmental conditions for microbial decomposition are not ideal in Adtuyon soils since the soils are strongly acidic. Although both soils are clayey, Adtuyon clay can also assist in more stabilization of humus. The clay-humus complexes formed in the soil can further inhibit bacteria decomposition and increase the lifespan of humus to over a thousand years, thus sequestering SOC longer (SSSA, 1987).

Tillage Systems Effects on Sequestered SOC. Soil organic carbon (SOC) and sequestered CO2 equivalent were significantly higher under no-tillage and conservation tillage than those in conventional tillage (Table 7) in Faraon soils while only no-tillage was significantly different from other two tillage systems in Adtuyon soils.

Generally, conventional tillage had decreased the SOC levels in soils as this tillage favored the decay of any organic materials trapped in soils, eventually leading to the release of carbon in soils as carbon is dynamic once environmental conditions become favorable.

No-tillage has conserved the carbon stock in both soils. Tillage favors diffusion of gases from atmosphere to soil air thereby favoring oxidation of organic materials by biochemical processes. Tillage with more soil disturbance may reduce spatial variability of the bulk densities. Soil aggregates store and protect additional organic carbon until the aggregates break down. Thus, greater stability of aggregates leads to larger amounts of protected organic carbon in terrestrial ecosystems (Wright et al., 1998).

Table 7. Effects of tillage systems on carbon of soils.

TILLAGE SYSTEMS	SOC, %	SEQUESTERED CO_2 EQUIVALENT
Faraon		
No Tillage	2.01	256
Conservation Tillage	2.04	261
Conventional Tillage	1.75	227
Adtuyon		
No Tillage	3.14	393
Conservation Tillage	3.10	382
Conventional Tillage	3.09	383

The high SOC in no-tillage means that more sequestered carbon are conserved due to non-disturbance of the soil structure and pore arrangement, and the residues are left on the surface and allowed to decompose as the crops are grown in the fields. However, in tilled-soil particularly the conventional tillage, the sequestered carbon in soil is low due to removal of crop residues and more disturbances of soil structures and soil pore arrangement. Tillage tends to hasten the loss of organic stabilizers. Aeration from plowing is probably the most significant factor in the depletion of soil organic carbon levels of cultivated topsoil. That, coupled with mono-cultural practices and poor soil, had caused a greater decline in SOC.

Notwithstanding, the increase in carbon stock in soil is brought about by the depth and intensity of residue incorporation, and less disturbance of soil matrix that led to low oxidation of soil organic matter in conservation tillage system.

Vegetation Types and Soil Organic Carbon

Cropping systems have an effect on the SOC (Table 8). The SOC under covercrop, forage, and perennial cropping systems were significantly higher than those of soils under annual cropping systems. The high sequestration of SOC in covercrop, forage, and perennial cropping systems was due to the increase of carbon stock that was contributed to continuous supply of raw material for humus accumulation. In addition, no-tillage in these types of cropping systems led to conserve the existing SOC. The resistance to decay and the non disturbance of soils were the factors that contributed to the preservation and increase of the carbon stock.

Table 8. Effect of cropping systems on carbon of soils.

CROPPING SYSTEMS	**SOC, %**		**SEQUESTERED CO_2 EQUIVALENT,** Mg/ ha	
	Adtuyon	**Faraon**	**Adtuyon**	**Faraon**
Annual Cropping Systems				
Corn	3.0	1.88	352	241
Corn-Legume	3.12	1.90	368	244
Vegetables	3.0	1.86	371	249
Rootcrops	2.98	1.85	361	243
Covercrop and Forage Cropping Systems				
Covercrop (Calopogonium)	3.29	2.59	394	328
Pastures	3.26	2.28	398	326
Perennial Cropping System				
Banana	3.27	2.58	389	325
Fruit crops	3.13	1.85	387	321

In summary, Salang's pioneering work resulted in the elaboration of factors in soil carbon sequestration and revealed that the capacity of soil to sequester SOC is dependent on soil type, pH, tillage systems, and type of vegetation. No-tillage and conservation tillage systems are better alternatives to conventional tillage for conserving sequestered SOC. The data and information generated from this research can find application in managing agricultural ecosystems for SOC sequestration. When carbon is sequestered in the agricultural ecosystem, it opens opportunities under the carbon trading scheme. Sequestered carbon can be sold as carbon credits and the land user can be rewarded for building up carbon levels in the farm.

ASSESSMENT AND VALUATION OF GHG MITIGATION IN LOWLAND RICE AGROECOSYSTEMS

In the agricultural sector, rice is the most important and dominant commodity in the Philippines. It is the staple food of over 80 percent of Filipinos, and about 70 percent of the total population depends on rice cultivation and marketing for their livelihood. However, rice production in the Philippines contributes a total of 566.61 Gg of methane emission per year and 89 percent of the total emissions are coming from continuously flooded rice fields (ALGAS-ADB, 1998).

The recent work of Floresca provided information on the current GHGs emitted from rice cropping in lowland rice agroecosystems in Isabela Province in northern Philippines. The emissions are affected by the different farm management practices employed by farmers based on their knowledge, perceptions, resources constraints, and the amounts and economic values of GHG reduction of changing to a more climate-friendly farm management practices. Climate-friendly farm management practices in lowland rice agroecosystems include those that have less emission of GHGs by avoiding anaerobic decomposition such as reducing the amounts and duration of irrigation, and use of aerobically composted rice straw.

Study Area

The study area located in Isabela province in northern Luzon covers District 2 of National Irrigation Authority – Magat River Integrated Irrigation System (NIA-MRIIS). It services an area of 22,676.68 ha with a total of 104 Irrigators' Associations or IAs. A total of 30 IAs evenly distributed among major canals (4-8 IAs/canal) were randomly selected.

The climate in the area is Type III (relatively dry from November to April and wet for the rest of the year). Soil type is dominated by Bago sandy clay loam.

Table 9. Existing farming practices in the study site.

No. of crops/year	2
Land preparation	Land soaking
Variety	Assorted (hybrid/inbred); more hybrids in San Mateo
Seedling preparation	Transplanted
Water management	Continuously flooded (based on NIA irrigation delivery schedule)
Fertilizers applied	Dominantly commercial inorganic (urea and complete)
Harvesting method	Cutting of upper straw containing palay using scythe then threshed immediately
Rice straw utilization	Dominantly left in the field (only few farmers burn)

Estimated Annual GHG Emissions

As shown in the summary table, the existing farming practices (continuous flooding and incorporation of 4-5 tons/ha rice straw) emit 5,882.93 tons CH_4/year. Mid-season drainage results in 2,823.81 tons CH_4/year or 48% emission reduction; aerobic composting results in 3,756.44 tons CH_4/year or 64% emission reduction; and simultaneous drainage and composting result in 4,777.16 tons CH_4/year or 81% emission reduction (Table 10).

Table 10. Summary of annual CH_4 emissions by farming practice, CY 2008.

FARMING PRACTICE	ANNUAL CH4 EMISSION tons/yr	REDUCTION tons CH4	%	tons CO2e
EXISTING PRACTICE	5,882.93	0	0	-
MID-SEASON DRAINAGE	3,059.12	2,823.81	48.00	59,300.01
COMPOSTING	2,126.49	3,756.44	63.85	78,885.24
DRAINAGE + COMPOSTING	1,105.77	4,777.16	81.20	100,320.36

Economic Value of GHG Mitigation

Values of CH_4 emission reductions based on 2009 World Bank price of US$12/CO2e using P48/$ exchange rate are PhP34.16, PhP45.44, and PhP57.78 for mid-season drainage, aerobic composting and simultaneous drainage and composting, respectively (Table11).

Table 11. Values of CH_4 emission reduction based on 2009 World Bank Carbon Price.

FARMING PRACTICE	ANNUAL CH4 EMISSION tons/yr	REDUCTION			VALUE *	
		tons CH4	%	tons CO2e	US$/yr	P Million/yr
EXISTING PRACTICE	5,882.93	0	0	-	-	
MID-SEASON DRAINAGE	3,059.12	2,823.81	48.00	59,300.01	711,600.12	34.16
COMPOSTING	2,126.49	3,756.44	63.85	78,885.24	946,622.88	45.44
DRAINAGE + COMPOSTING	1,105.77	4,777.16	81.20	100,320.36	1,203,844.32	57.78

** WB PRICE = US$ 12/ton CO2e; P48/US$*

Simulated GHG Emissions Over Time

Simulation of GHG emission within 50 years showed the following scenario when shifting from existing farmers practices to climate-friendly farming practices:

1. Keeping the existing farming practice results in a linear pattern of accumulation (increase) of CH_4 at the rate of 5,882.93 tons/year.
2. Shifting from continuous drainage to mid-season drainage stabilizes (no more increase) the annual CH_4 emission at 13,000 tons within the period 0-12 years.
3. Shifting from rice straw incorporation to aerobic composting stabilizes the annual CH_4 emission at 10,000 tons within the period 0-12 years.
4. Total shifting of the existing practices to both mid-season drainage and aerobic composting stabilizes the annual CH_4 emission to 8,000 tons/year within the period 0-12 years.

In summary, the data and information generated by this study are:

1. Mid-season drainage rather than continuous flooding will have 2,823.81 tons/year or 48% methane reduction in the 7,789.34 ha service area of 30 selected IAs in NIA-MRIIS District 2 with a tradable CO_2 equivalent of P34.16 million/year.

2. Application of rice straws composted aerobically rather than incorporated in flooded rice fields will have 3,756.44 tons/year or 64% methane reduction in the 7,789.34 ha service area of 30 selected IAs in NIA-MRIIS District 2 with a tradable CO_2 equivalent of PhP45.44 million/year.
3. Simultaneous mid-season drainage and application of aerobic rice straw compost rather than the existing farming practices (continuous flooding and rice straw incorporation in flooded fields) will have 4,777.16 tons/year or 81% methane reduction in the 7,789.34 ha service area of 30 selected IAs in NIA-MRIIS District 2 with a tradable CO_2 equivalent of PhP57.78 million/year.
4. The incremental benefits of shifting from existing farming practices (continuous flooding and rice straw incorporation) to climate-friendly farming practices (mid-season drainage and rice straw compost application) will be PhP138.95 million/year.

Recommendations for Mitigating Lowland Rice Production

1. This scientific information should be shared with farmers, Irrigators Associations, the NIA-MRIIS and the Local Government Units (LGUs) through the production of IEC materials such as posters, flyers, brochures and conduct of awareness-raising seminars, fora and other on-farm trials and policy advocacy activities.
2. In addition, the following future research topics are suggested:
    - Design and testing of rice straw balers that facilitate gathering of rice straws for aerobic composting.
    - Comparative testing of the effectiveness of vermicomposting of rice straw, use of compost fungus activator (Trichoderma), EM or other rapid composting technologies.
3. Pursue research and advocacy that will include the following:
    - Prohibit rice straw incorporation under flooded rice field, considering the high GWP of methane produced.
    - Adoption of balanced fertilization strategy (BFS) to maximize the utilization of aerobically composted rice straws and minimize the use of inorganic fertilizers.

SUGGESTIONS AND RECOMMENDATIONS

Based on review of the works undertaken on carbon stock assessment in various ecosystems, the following recommendations are forwarded:

1. Development of cost-effective methodological tools and techniques in analyzing and determining soil organic carbon. This will allow quantification of carbon stocks and sequestration rates of carbon in the various ecosystems. For instance, data aggregation from a plot scale to national scale is a big barrier to overcome in carbon stock assessment.
2. Conduct of valuation studies for carbon trading purposes. Determining the actual value of SOC will bring appreciation at its importance to policymakers.
3. Promoting activities that will enhance the potentials of various ecosystems to serve as carbon sinks rather than sources.

   While soil carbon storage plays a crucial role in GHG mitigation, strategies to reduce carbon emission must be carried out with the full understanding that there should be a balance between the environmental benefits and the need for food and fiber.

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