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How much soil organic carbon is there in agricultural lands? A case study of a prime agricultural province in Southern Philippines

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Abstract. This paper is a synthesis of the study on the estimation of the actual contribution of major agricultural land use types in Bukidnon, an agricultural province in Southern Philippines, as soil carbon sink. Soil organic carbon sampling was done in plantations of corn, rice, sugarcane, pineapple, banana, rubber, cassava, coconut, coffee, and mango. Carbon saturation deficit of soils in these plantations was also determined. Among the 10 land use types examined, rubber and coconut plantations showed significantly the highest soil organic carbon sequestered amounting to 37.1 MgC ha^{-1} and 30.3 MgC ha^{-1}, respectively while pineapple plantation had the least at 14.7 MgC ha^{-1}. Overall, soil organic carbon sequestration in these agricultural land use types goes in the following order: rubber plantation (37.1 MgC ha^{-1}) > coconut plantation (30.3 MgC ha^{-1}) > rice plantation (22.7 MgC ha^{-1}) > cassava plantation (22.3 MgC ha^{-1}) > coffee plantation (20.0 MgC ha^{-1}) > sugarcane plantation (19.8 MgC ha^{-1}) > mango plantation (19.3 MgC ha^{-1}) > banana plantation (18.3 MgC ha^{-1}) > corn plantation (17.5 MgCha^{-1}) > pineapple plantation (14.7 MgC ha^{-1}). Land use devoted for rubber plantation is basically soil carbon saturated with mean C_{org}/C_{ref} ratio of 0.99 which is comparable to that of a natural forest while those areas utilized for pineapple, corn and sugarcane production had the greatest carbon saturation deficit. Results of this study need to be effectively communicated to various stakeholders especially policymakers to institutionalize interventions that are vital to maintain, if not further increase existing soil carbon stocks in such agricultural lands.

Key Words: agricultural lands, Bukidnon, climate change, policy interventions, SOC.

Introduction. The Intergovernmental Panel on Climate Change (IPCC) in its latest assessment report declared that “warming of the climate system is unequivocal” (IPCC 2007). Specifically, global mean temperature has increased by 0.74^{o}C from 1906-2005. This 100-year trend is higher compared to the 0.6^{o}C correspondingly taken from 1901-2000 (IPCC 2001). Similarly, the annual mean temperature of the Philippines has increased by 0.57^{o}C for the last 59 years (1951-2009). This temperature increase is expected to continue as a result of unabated land use conversions and industrial emissions of greenhouse gases foremost of which is carbon dioxide (CO_2). Annual fossil CO_2 emissions increased from an average of 6.4 GtC per year in the 1990s, to 7.2 GtC per year in 2000-2005 (IPCC 2007).

Global warming and climate change have been attributed to the continuous increase in the amount of carbon dioxide and other greenhouse gases in the atmosphere. Recently, soils and soil organic carbon (SOC) have received attention in terms of the role they can play in mitigating the effects of elevated atmospheric CO_2 and associated global warming. The carbon associated with soil organic matter, SOC is the largest component of the terrestrial carbon pools, approximately twice the amount of carbon in the atmosphere and in vegetation (Chan 2008). If more carbon is stored in the soil as organic carbon, it will reduce the amount present in the atmosphere, and therefore helps to alleviate the problem of global warming and climate change. This process of storing carbon in soil is called soil carbon sequestration. Lal (undated as cited in Milne 2008), estimated that with appropriate use and management soils have the potential to sequester about 0.9 Pg C per year. This is roughly equal to 13% of the anthropogenic CO_2-C produced annually.

Increasing SOC does not only help mitigate climate change but it can as well improve soil health. One of the factors that affect the amount of SOC is land use and management (Milne et al 2008). There is growing evidence that changes in land use patterns and agricultural practices can affect the amount of carbon released into the atmosphere from soil organic matter. Management practices that increase soil carbon include conservation farming and use of organic amendments. In conservation farming, cultivation is either reduced (reduced tillage) or completely eliminated (no tillage) and stubble (crop residue) is retained (Chan 2008). In contrast, organic amendments include the use of manure, plant debris, composts, and biosolids from sewage which are applied to agricultural soils.

This study was undertaken to estimate the actual contribution of agricultural soils of varying land uses as carbon sink since the existing or available studies related on this concern were mostly based on assumed values. This study hoped therefore to provide more data and better information on the amount of carbon sequestered in various agricultural land use soils in Bukidnon. The research data obtained in this study could be useful in directing farming practice and policy making process for SOC sequestration. The challenge therefore is to find the right land use and appropriate farm management practices that can enhance a farm's potential as carbon sink. This study becomes even more relevant especially for Bukidnon, a province whose "bread and butter" is agriculture but at the same time predicted to be a major recipient of negative impacts of climate change.

This study was conducted therefore to assess the soil carbon sequestration potential of major agricultural land uses in Bukidnon, Southern Philippines in mitigating climate change. Specifically, it aimed to: a) describe briefly soil management and conservation practices adopted in these agricultural farms; b) determine the quantity of carbon stored in agricultural soils under different land uses; c) find out the carbon saturation deficit in the soils of these agricultural land use types; d) describe the influence of soil depth and organic matter on carbon sequestration potential of soils in these land use types; and e) propose measures useful in directing farming practice and policy making process for SOC sequestration.

Material and Method

Locale of the study. Study sites were chosen based on the extent of land area devoted in cultivating identified agricultural crops. The Bureau of Agricultural Statistics (nd) and the PPDO (2011) reported that the top 10 agricultural land uses in Bukidnon in terms of land area included that of corn (*Zea mays*), rice (*Oryza sativa*), sugarcane (*Saccharum officinarum*), pineapple (*Ananas comosus*), banana (*Musa sapientum*), rubber (*Hevea brasiliensis*), cassava (*Manihot esculenta*), coconut (*Cocos nucifera*), coffee (*Coffea arabica*), and mango (*Mangifera indica*). Hence, this study covered these 10 major land use types. As shown in Table 1 and Figure 1, specific study sites for each land use were purposively determined through desk study and field reconnaissance of agricultural land areas in Bukidnon.

Situated in a landlocked plateau in North Central Mindanao, Bukidnon is a prime agricultural province located in Southern Philippines. It lies between parallels 7°25' and 8°38' north latitude and meridians 124°03' and 125°16' east longitude (www.bukidnon.gov.ph). Bukidnon is an agricultural economy. It is a major producer of rice, maize, sugar, coffee, rubber, pineapple, banana, tomato, flowers, cassava, and other fruits and vegetables. In fact, it is the second largest producer of corn in the country having reached a total production of 481,370 metric tons in 2010 (http://en.wikipedia.org/wiki/Bukidnon).

Table 1

Major agricultural land uses and corresponding study sites in Bukidnon, Philippines

Land use	*Study site*	*Total area in the province, ha*
Corn plantation	Bayabason, Maramag & Kibawe	186,004
Rice plantation	CMU, Musuan & Dagat-kidavao, Valencia City	87,435
Sugarcane plantation	Butong, Quezon & Bayabason, Maramag	82,700
Pineapple plantation	Don Carlos & Impasug-ong	20,500
Banana plantation	Dangcagan & Impasug-ong	20, 392
Cassava plantation	Impasug-ong & Maramag	13,700
Coconut plantation	CMU, Musuan & Butong, Quezon	9,500
Coffee plantation	CMU, Musuan & San Roque, Sumilao	9,022
Rubber plantation	Maramag & Don Carlos	6,639
Abaca plantation	*Not covered in the study*	3,100
Mango plantation	CMU, Musuan & San Roque, Sumilao	2,345

Source: PPDO (2011).

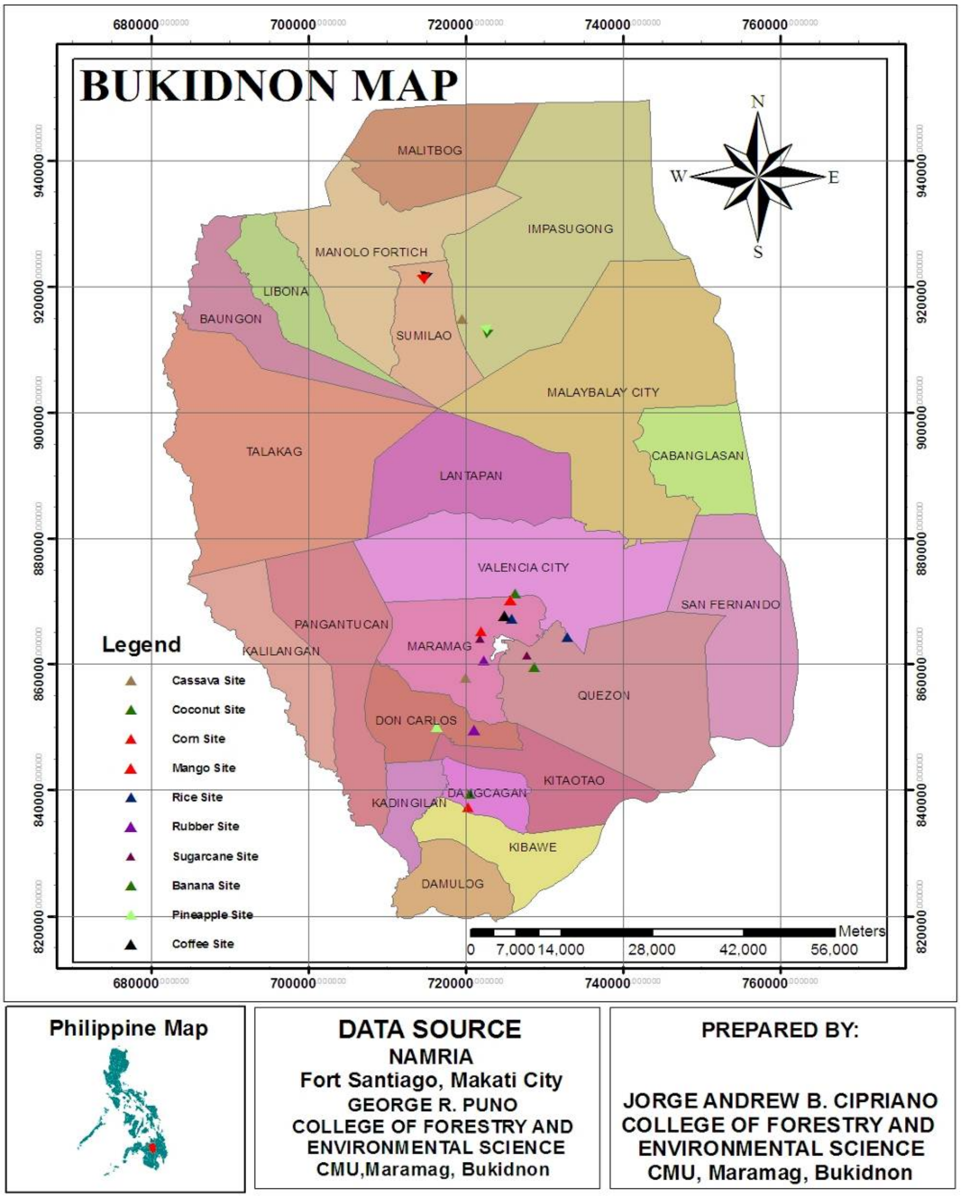

Figure 1. Bukidnon map showing the various sampling sites of the study
Source: NAMRIA (http://www.namria.gov.ph/).

Having an average elevation of 915 m above sea level (masl), the province has two types of climate prevailing between its northern and southern sections. The northern part which includes the study sites in Impasugong, Sumilao and Patulangan is classified as belonging to Type III, that is, there is no pronounced rain period but relatively dry during the months of November to May. In the southern portion of the province which includes the other study sites such as Maramag, Valencia City, Don Carlos, Quezon, and Dangcagan, the climate is classified as Type IV with no very pronounced maximum rain period and no dry season.

The climate in Bukidnon is relatively cool and humid throughout the year. The average annual rainfall is 2,800 mm which is more pronounced from June to October (www.wikipedia.com). Temperature and relative humidity (RH) vary with elevation. In areas lower than 500 masl, the recorded temperature and RH range is between 20°C to 34°C and 65-70%, respectively. On the other hand, those with elevations greater than 500 masl would have temperatures ranging from 18°C to 28°C and RH of about 80%.

Description of soil management and conservation practices*.* A semi-structured interview was conducted involving landowners or caretakers of the sampled farm areas. The following information were solicited: 1) the kind of crops grown during the preceding 3 to 5 years, 2) crop to be grown next, 3) the kind and amount of fertilizers which have been used in the past, 4) the slope and extent of erosion, and 5) types of farm management practices adopted. These pieces of information were utilized to reinforce interpretation of the data on SOC potential of the sampled agricultural land areas.

Field measurement of SOC stock*.* Soil samples were taken from the 10 major land use types identified in this study. In each identified land use, two separately located sites were considered for a total of 20 sampling sites. The sampling protocol as described by Hairiah et al (2001) was adopted with modification. In each sampling site, two types of soil samples were gathered, that is, 1) soil samples for chemical analysis, and 2) soil samples for physical analysis especially for bulk density determination.

Soils for chemical analysis. In each sampling site, soil samples were separately taken from each of the 5-10 cm, 10-20 cm, and 20-30 cm soil depth. To gather representative soil sample from each soil depth, 5 to 10 pits were randomly dug and spot soil sample was then collected from each pit. A composite soil sample of about ½ kg was taken for carbon content analysis at the Soil and Plant Tissue Testing Laboratory (SPPTL) in Central Mindanao University in Musuan, Bukidnon. The concentration of SOC was determined using the Walkley-Black method (PCARR 1980).

Soils for physical analysis (bulk density). Using the same sampling site, bulk density was determined by collecting undisturbed soil cores from each soil depth (5-10 cm, 10-20 cm, and 20-30 cm) using a sampling metal tube with a diameter of 5.3 cm and length of 10 cm. Samples were wrapped with aluminum foil to avoid any loss of soil from the cores. The soil samples were initially air-dried and brought to SPPTL for oven drying to constant weight for 40 hours at ±102°C. Soil texture of samples was also determined in the laboratory.

Bulk density was computed using the formula: $BD = W_2/V$ where: BD = bulk density of the soil sample; W_2 = oven dry weight of the sample; and V = volume of the cylinder/tube. SOC was computed by multiplying SOC concentration (%), soil bulk density ($Mg\ m^{3\ -1}$), and sampling depth (cm) expressed as $MgC\ ha^{-1}$.

Determination of carbon saturation deficit*.* The difference between current and potential carbon storage can be expressed as a carbon saturation deficit (van Noordwijk et al 1997). Carbon saturation deficit can be calculated on the basis of the difference between the actual soil carbon content and amount that would be expected for a forest soil with a long history of large litter inputs for the same type of soil. It is computed as follows:

$$C_{satDeficit} = (C_{ref} - C_{org})/(C_{ref}) = 1 - (C_{org}/C_{ref})$$

where:

C_{org}/C_{ref} = SOC content relative to that for forest soils of the same texture and pH;
C_{ref} = a reference soil carbon level representative of forest soil
$= \exp(1.333 + 0.00994 \times \%\ clay + 0.00699 \times \%\ silt - 0.156 \times pH_{KCl})$.

If the value of the C_{org}/C_{ref} ratio is 1, this means the soil is similar to that of a forest and basically carbon saturated, and values less than 1 indicate a carbon deficit relative to the forest soil.

Statistical analysis. Soil data obtained in this study were analyzed using SPSS statistical package for analysis of variance (ANOVA) to compare differences in SOC stock among sampled agricultural land use types. Differences between SOC means were further analyzed using post hoc analysis. Correlation coefficient *r* was also computed to determine degree of association between SOC, and soil depth and organic matter content. On the other hand, soil management and conservation practices adopted by landowners/farmers were determined in support of analysis made on variation in SOC sequestered by various land use types.

Results and Discussion. Soils serve as the largest terrestrial reservoir of carbon. This is made possible through a natural process called soil carbon sequestration which involves the transfer of 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 (Sundermeier et al n.d.). Scientists widely agree that agricultural soils have the ability to sequester carbon in much the same way that trees can. 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. In this study, 10 major agricultural land use types in Bukidnon were determined in terms of carbon sequestration potential of these land uses.

Basic soil properties and farm management practices of the study sites. Table 2 presents some of the basic properties of soils in various agricultural land uses considered in this study. pH level of these plantations is generally acidic especially the mango, pineapple, and corn plantations located in CMU, Don Carlos and Maramag, respectively which have pH values below 5.0. Cassava and coffee plantations in Impasug-ong and Sumilao, respectively, seem to have ideal pH owing probably to lime application in these farms.

Meanwhile, organic matter (OM) content in the sampled soils is generally low particularly in banana, corn and pineapple plantations which only have about 2% OM. Most of the productive agricultural soils have between 3-6% OM (CUCE 2008). In contrast, coconut and rubber plantations contained the highest OM which reached to about 7%. However, these OM levels are still way below to that of organic soils which could contain as much as 20-30% OM (wikipedia.org). In terms of texture, the soils sampled are all categorized as clayey except for the one taken from a lowland rice plantation in Dagat-kidavao in Valencia City which was categorized as clay loam.

In terms of cropping system, only rubber, coconut, mango and coffee plantations are considered as perennial while the rest are said to be annual crops. In addition, except for the rubber plantation in Musuan which is intercropped with coffee, all the other land use types are devoted purely for monocropping system. Rubber and coconut plantations covered in this study also practiced the no or reduced tillage management system. The results of the interview conducted likewise showed that all owners of these farms have been planting the same crop year round for the past 3-5 years and that the same crop would be grown in the next growing season. Most of these farms were continuously subjected to application of inorganic fertilizers and conventional tillage particularly sugarcane and pineapple plantations. Owners of sugarcane and lowland rice plantations also adopt crop residue burning in their farms which is a common practice in Bukidnon. In terms of slope, the plantations are situated generally from level (0-3%) to gently sloping (3-8%) areas.

Table 2

Basic properties of soil and farm management practices in the study area

Land use	*Location*	*pH*	*OM (%)*	*Texture (%)*			*Textural type*	*Farm management practices*
				Sand	*Clay*	*Silt*		
Rice pltn	CMU, Musuan	5.5	3.0	16.7	57.0	26.4	Clay	Lowland rice, with irrigation, continuous inorganic fertilizer application, crop residue burning
	Dagat-kidavao, Valencia City	5.4	4.1	29.6	37.3	33.2	Clay Loam	Lowland rice, with irrigation, continuous inorganic fertilizer application, crop residue burning
Sugarcane pltn	Butong, Quezon	5.3	3.7	6.9	73.3	19.8	Clay	Continuous tillage, crop residue burning
	Bayabason, Maramag	5.1	2.3	16.0	71.0	13.0	Clay	Continuous tillage, crop residue burning
Corn pltn	Bayabason, Maramag	4.6	2.4	7.0	80.8	12.2	Clay	Reduced tillage
	Kibawe	5.0	3.1	27.6	63.3	9.1	Clay	Continuous tillage
Cassava pltn	Impasug-ong	6.3	4.4	38.1	52.7	9.2	Clay	Continuous tillage, with chicken dung and lime application
	Maramag	5.0	3.1	14.9	60.5	24.5	Clay	Continuous tillage
Rubber pltn	Maramag	5.8	6.6	5.4	76.2	18.3	Clay	No tillage
	Don Carlos	5.6	5.9	12.6	80.3	7.0	Clay	No tillage
Coconut pltn	CMU, Musuan	5.3	7.1	9.5	80.3	10.2	Clay	Coconut-coffee combination, no tillage
	Butong, Quezon	5.2	2.4	25.0	63.3	11.7	Clay	Reduced tillage
Mango pltn	CMU, Musuan	4.0	2.9	14.7	65.3	20.0	Clay	Reduced tillage
	San Roque, Sumilao	5.9	3.6	9.8	85.3	4.9	Clay	Contour farming
Coffee pltn	CMU, Musuan	5.1	3.0	20.0	56.7	23.3	Clay	Reduced tillage
	San Roque, Sumilao	6.1	4.5	12.0	76.0	12.0	Clay	Reduced tillage
Pineapple pltn	Don Carlos	4.1	2.3	5.0	89.8	5.2	Clay	Continuous tillage, inorganic fertilizer application
	Patulangan, Impasug-ong	5.0	3.1	3.3	94.6	2.2	Clay	Continuous tillage, inorganic fertilizer application
Banana pltn	Dangcagan	5.1	2.0	9.0	83.5	7.5	Clay	No tillage, inorganic fertilizer application
	Impasug-ong	5.8	4.3	23.2	70.8	6.0	Clay	No tillage, inorganic fertilizer application

SOC sequestration of the study sites. As shown in Table 3, there is a significant difference at 0.001 level among certain types of agricultural land uses in Bukidnon in terms of SOC sequestered. The results showed that rubber plantations situated in the municipalities of Maramag and Don Carlos significantly contained the highest amount of mean SOC amounting to 42 MgC ha^{-1}, 37 MgC ha^{-1}, and 31 MgC ha^{-1} at 10 cm, 20 cm and 30 cm soil depth, respectively with a mean of around 37.1 MgC ha^{-1} as presented in Table 4 and Figure 2. These values pale in comparison to the amount of soil carbon sequestered in natural forest which is 191 MgC ha^{-1} (Lasco & Pulhin 2009). These are also much lower to soil carbon sequestered in three types of agroforestry systems in Bukidnon, Philippines which ranged between 84.69 to 160.42 MgC ha^{-1} (Labata et al 2012). However, carbon sequestration ability of rubber plantations in this study is comparable to a 5-year old rubber plantation in Thailand which sequesters SOC at the rate of 37.36 MgC ha^{-1} (Saengruksawong et al 2012). The relatively high amount of SOC stored in this land use type may be attributed to the adoption of reduced or no tillage system of farming. Such system enhances sequestration of soil carbon due to less disturbance of the soil structure, and the residues (mostly litterfall) are left at the surface and allowed to decompose as rubber is grown in the fields. In contrast, tillage exposes the organic matter to air and will result in the lowering of stable organic matter due to increased mineralization rates and erosion losses (CUCE 2008). A literature review on studies related to SOC accumulation in agriculture revealed that conservation agriculture provides higher rates of soil carbon sequestration compared to tillage agriculture (Corsi et al 2012). The review further showed that zero carbon sequestration or loss of carbon in agricultural systems is attributed to any one or combination of soil disturbance, monocropping, specific crop rotations, poor management of crop residues, and soil sampling beyond 30 cm down the soil profile.

Table 3

ANOVA results for SOC (MgC ha^{-1}) per type of agricultural land use

Source of variation	*Sum of squares*	*df*	*Mean square*	*F-value*
Between land use type	2399.555	9	266.617	4.897***
Within land use type	2722.105	50	54.442	
Total	5121.660	59		

*** Significant at 0.001.

Table 4

Post hoc analysis for ANOVA of SOC (MgC ha^{-1}) per type of agricultural land use

Land use	*Mean SOC*	*Significant SOC difference*
Rice plantation	22.7000	Rubber***
Sugarcane plantation	19.7850	Rubber***, Coconut**
Corn plantation	17.4750	Rubber***, Coconut**
Cassava plantation	22.2917	Rubber***
Rubber plantation	37.0717	All Except Coconut***
Coconut plantation	30.3017	Sugarcane**, Corn**, Mango**, Coffee**, Pineapple***, Banana**
Mango plantation	19.3167	Rubber***, Coconut**
Coffee plantation	19.9550	Rubber***, Coconut**
Pineapple plantation	14.7167	Rubber***, Coconut***
Banana plantation	18.2817	Rubber***, Coconut**

** Significant at 0.05; *** Significant at 0.001.

Meanwhile, soils of coconut plantations in the CMU Coconut Farm Project and in Quezon, Bukidnon sequestered the second highest organic carbon at an average of 34 MgC ha^{-1}, 28 MgC ha^{-1} and 29 MgC ha^{-1} at 10 cm, 20 cm and 30 cm soil depth, respectively. Statistically, this SOC value is significantly different at 0.05 level when compared to that of mango, corn, coffee, pineapple and banana plantations (Table 4). These SOC values are relatively higher when compared to the one studied in Southern Mindanao (Magat 2011). The author reported that a coconut-*lanzones* fruit tree agroecosystem had stored SOC amounting to 10 t C ha^{-1} and 20 t C ha^{-1}, at 15 cm and 30 cm soil depth, respectively. Note that one (1) ton of C is equivalent also to one (1) Mg of C. However, Lasco et al (1999) as cited in Lasco & Pulhin (2009) reported that a coconut plantation has SOC that is only about 50% lower than the SOC density of a natural forest. Results of the study undertaken showed that coconut plantation has SOC density of 111 MgC ha^{-1} while natural forest has SOC density of 191 MgC ha^{-1}.

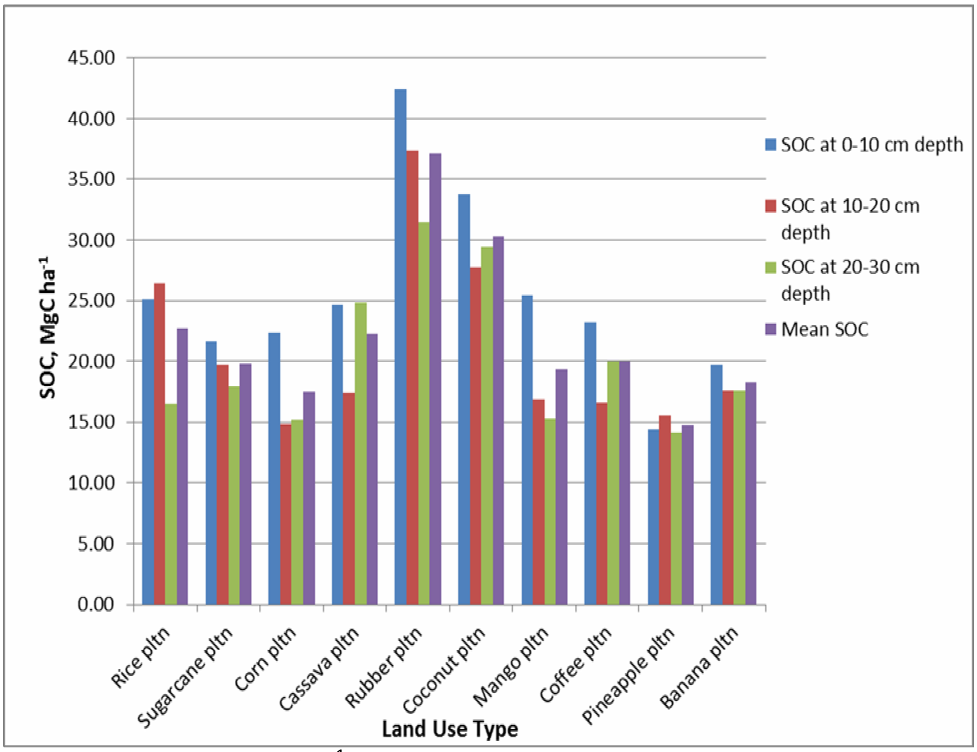

Figure 2. Mean SOC (MgC ha^{-1}) at different soil depths in various agricultural land use types in Bukidnon.

At any rate, Lales et al (2001) as cited in Magat (2011) found coconut 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 other agricultural crops such as rice and sugarcane. Like rubber plantations, coconut farms are considered to be perennial cropping systems. According to Ilao et al (2010), SOC under cover crop, forage, and perennial cropping systems were significantly higher than those of soils under annual cropping systems. This is attributed to the depth and intensity of residue incorporation, and less disturbance of soil matrix that led to low oxidation of soil organic matter. In effect, zero or reduced tillage in these types of cropping systems led to conserve the existing SOC.

In this study, rice and cassava plantations have practically the same soil carbon sequestration potential at about 22 MgC ha^{-1} at an average soil depth of 10 cm, which is significantly different to that of rubber plantation but not to other agricultural land uses covered in this study at 0.001 probability level (Table 4). Both sites of rice plantations in Musuan and Dagat-kidavao, Valencia City are lowland in nature and are continuously irrigated. The relatively high SOC in rice may be due to the continuous application of inorganic fertilizers in rice paddies. As more productive croplands, rice paddies generally have higher SOC storage (Pan et al 2004, as cited in Liu et al 2011) and sequestration capacity under fertilization (Wang et al 2010, as cited in Liu et al 2011) when compared to drier croplands. Gou & Lin (2001) also reported that the amount of organic carbon in paddy soils is greater than upland soils because of different biochemical processes and mechanisms mainly caused by the presence of flooded water in paddy soils. In fact, Yu (1994) suggested rice cropping irrigation as a measure to improve soil conditions.

Meanwhile, SOC in sugarcane land use type is around 20 MgC ha^{-1} which is statistically comparable to those of other land uses except the ones for rubber and coconut. In Bukidnon, burning is a common farming practice in sugarcane farms. This is done prior to harvest to eliminate leafy non-sucrose containing material to reduce transport and labor costs and to facilitate land preparation and other cultural practices. However, burning is detrimental to soil structure and nutrient availability due to the loss of soil organic matter (Ball-Coelho et al 1993). During burning, large amounts of C, N and S present in the plant residues are lost via volatilization (Hemwong et al 2009). Razafimbelo et al (2006) also reported that sugarcane cultivation with residue mulching returns great amounts of carbon to the soils, which are otherwise lost when residues are burned. In fact, Noble (2003) as cited in Naquin (2005) observed an increase of four tons per hectare of organic carbon in soils under a green trash blanket as compared to fields which residue was burned. On the other hand, Yoneyama et al (2004) reported that conversion of forest areas to field for sugarcane cultivation in Central Luzon and Negros Island, Philippines had been associated with a rapid decrease of the soil organic C content.

Among land use types covered in this study, pineapple plantations showed statistically the least stored SOC in the average amount of 14 MgC ha^{-1}, 16 MgC ha^{-1}, and 14 MgC ha^{-1} at 10 cm, 20 cm, and 30 cm soil depth, respectively. The comparatively low SOC in this land use type can be attributed to continuous tillage adopted in pineapple farming. Lal (2001) reported that most soils under the managed ecosystems contain a lower SOC pool than their counterparts under natural ecosystems owing to the depletion of the SOC pool in cultivated soils. The most rapid loss of the SOC pool occurs in the first 5-10 years of conversion from natural to agricultural ecosystems in the tropics. In general, cultivated soils normally contain 50-75% of the original SOC pool. The depletion of the SOC pool is caused by oxidation or mineralization, leaching and erosion. Sundermeier et al (2005) similarly concluded that when soils are tilled, organic matter previously protected from microbial action is decomposed rapidly because of changes in water, air, and temperature conditions, and the breakdown of soil aggregates accelerates erosion.

Drinkwater et al (1998) and Buyanoski & Wagner (1998) as cited in Lal (2001) further noted that soils under diverse cropping systems generally have more SOC than those under monoculture such as pineapple plantations. High rates are obtained with no-till farming, retention of crop residue as mulch, growing cover crops in the rotation cycle and adopting complex farming systems including agroforestry, integrated nutrient management including manuring and restoration of degraded soils by afforestation. Similarly, the use of plant residues, mulching and animal manure, combined with conservation practices such as zero tillage (Christensen et al 1994; Salinas-Garcia et al 1997; Dao 1998; Potter et al 1998; Allmaras et al 2000; Feller et al 2001 as cited in Albrecht & Kandji 2003), have been shown to increase soil C.

Overall, the results showed that soil organic carbon sequestration in major agricultural land use types in Bukidnon goes in the following order: rubber plantation (37.1 MgC ha^{-1}) > coconut plantation (30.3 MgC ha^{-1}) > rice plantation (22.7 MgC ha^{-1}) > cassava plantation (22.3 MgC ha^{-1}) > coffee plantation (20.0 MgC ha^{-1}) > sugarcane plantation (19.8 MgC ha^{-1}) > mango plantation (19.3 MgC ha^{-1}) > banana plantation (18.3 MgCha^{-1}) > corn plantation (17.5 MgCha^{-1}) > pineapple plantation (14.7 MgC ha^{-1}).

Carbon saturation deficit of soils in the study sites. It is difficult to interpret absolute soil carbon levels considering their variation between soils of different texture and mineralogy under the same land cover types. Van Noordwijk et al (1997) as cited in Hairiah et al (2001) suggested for the determination of carbon saturation deficit which is defined as "the difference between the current organic carbon (C_{org}) content and a reference content, C_{ref}, which is supposed to indicate the undisturbed forest condition". The ratio of the measured C_{org} and a reference C_{org} value for forest (top) soils of the same texture and pH serves as a sustainability indicator.

In this study, pineapple plantation which exemplifies pure monocropping system has the lowest C_{org}/C_{ref} ratio which is 0.33 which further indicates that it has the highest average carbon saturation deficit (Table 5). This value suggests that soil organic matter content and probably soil fertility have declined in such land use type. In contrast, land use devoted for rubber plantation especially the one located in CMU is found to be carbon saturated with C_{org}/C_{ref} ratio of almost 1. This is an indication that this land use system is comparable to a natural ecosystem such as forest in terms of soil carbon sequestration.

Table 5

Carbon saturation deficit values of soils in the study sites

Land use type	*Mean pH*	*Texture (%)*			*Mean* C_{org}	*Mean* C_{org}/C_{ref}	*Mean* C_{satdef}
		Sand	*Clay*	*Silt*			
Rice pltn	5.42	23.10	47.13	29.77	2.05	0.65	0.35
Sugarcane pltn	5.23	11.45	72.16	16.39	1.75	0.45	0.55
Corn pltn	4.78	17.32	72.01	10.67	1.58	0.41	0.59
Cassava pltn	5.63	26.51	56.61	16.88	2.17	0.74	0.26
Rubber pltn	5.66	9.03	78.29	12.68	3.63	0.99	0.01
Coconut pltn	5.25	17.25	71.82	10.93	2.74	0.72	0.28
Mango pltn	4.93	12.24	75.33	12.43	1.88	0.48	0.52
Coffee pltn	5.64	16.00	66.33	17.67	2.19	0.64	0.36
Pineapple pltn	4.56	4.12	92.17	3.71	1.55	0.33	0.67
Banana pltn	5.44	16.09	77.16	6.76	1.83	0.53	0.47

SOC variation with depth and organic matter of soils in the study sites. As shown in Figure 3, mean SOC at 10 cm soil depth appears to be the highest while SOC at 30 cm soil depth is the least in almost all land use types covered in this study. Theoretically, SOC decreases with soil depth. Usually, the surface layer has the highest level of SOC which decreases with depth down the soil profile (Chan 2008). However, in this study, the difference in SOC means among the three soil depth categories is not statistically significant as indicated in Tables 6 and 7 (r = -0.216 and p = 0.097). This is probably due to the clayey type of soil texture which is common regardless of soil depth in almost all land use types covered in this study as shown earlier in Table 2.

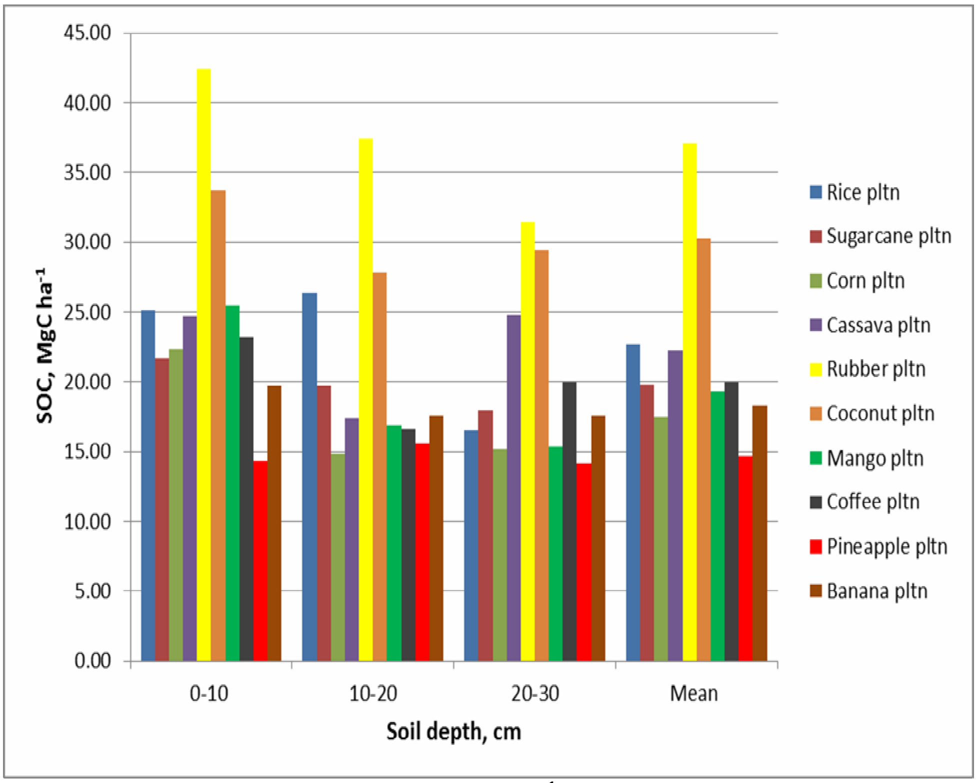

Figure 3. Variation of SOC (MgC ha^{-1}) with soil depth for major agricultural land use types in Bukidnon.

Paul et al (1997) and Trumbore (2000) as cited in Jobaggy & Jackson (2000) reported that although precipitation and climate were the best predictors of total SOC in the top 20 cm of soil, clay content was the best predictor in deeper layers. This result may be due to the increased proportion of slower cycling SOC pools at depth in which such C pools are strongly associated with clay particles and noncrystalline minerals that stabilize and protect organic matter (Paul 1984; Torn et al 1997 as cited in Jobaggy & Jackson 2000). In addition, Von Lutzow et al (2006) reported that organic matter binds to minerals, particularly clay particles, a process that further protects carbon. Organic matter also provides cohesive strength to soil and improves soil fertility, water movement, and resistance to erosion.

Table 6

ANOVA results for SOC (MgC ha^{-1}) per soil depth

Source of variation	*Sum of squares*	*df*	*Mean square*	*F-value*
Between layers	268.189	2	134.095	1.575^{ns}
Within layers	4853.471	57	85.149	
Total	5121.660	59		

ns - not significant.

Table 7

Correlation matrix between SOC (MgC ha^{-1}) with soil depth (cm) and organic matter (%)

Variables	*r*	*P-value*
Depth	-0.216	0.097^{ns}
Organic matter	0.957	0.000^{***}

ns - not significant; *** - significant at 0.001.

On the other hand, expectedly, SOC is strongly positively correlated with organic matter (r = 0.957 and p = 0.000) as shown in Table 7. Soil organic matter is the organic fraction of the soil that is made up of decomposed plant and animal materials as well as microbial organisms, but does not include fresh and un-decomposed plant materials, such as straw and litter, lying on the soil surface. In this study, SOC increases by 5.65 MgC ha^{-1} for every one percent increase in soil organic matter as shown in Table 8. This result highlights the importance of conserving organic materials in the soil. Some management practices, such as fallowing, cultivation, stubble burning or removal, and overgrazing can reduce SOC by reducing inputs to the soil, increasing the decomposition of soil organic materials, or both (Chan 2008). Cultivation operations can expose SOC and increase losses by decomposition and erosion while fallowing results to increased decomposition of organic matter due to the cultivation operations as well as the higher soil moisture conditions prevailing in the fallowed soils. For instance, no-tillage helped to save 169 kg C ha^{-1} yr^{-1} compared to traditional tillage, whereas stubble retention helped to save 108 kg C ha^{-1} yr^{-1} compared to stubble burnt in a study conducted by Chan (2008).

Table 8

SOC (MgC ha^{-1}) regression model with organic matter (%) as predictor

Independent variables	*B*	*P-value*
Constant	1.403	0.122
Organic matter	5.651	0.000

Conclusions. Based on the results of the study, the following conclusions are made: First, among the 10 land use types examined, rubber and coconut plantations showed significantly the highest soil organic carbon sequestered amounting to 37.1 MgC ha^{-1} and 30.3 MgC ha^{-1}, respectively while pineapple plantation had the least at 14.7 MgC ha^{-1}; second, land use devoted for rubber plantation particularly the one located in CMU is basically soil carbon saturated with mean C_{org}/C_{ref} ratio of 0.99 which is comparable to that of a natural forest while those areas utilized for pineapple, corn and sugarcane production had the greatest carbon saturation deficit; third, although theoretically, SOC decreases with soil depth, there is no significant variation among soil depths at 10 cm, 20 cm and 30 cm in terms of their ability to store organic carbon in this study; and fourth, soil organic carbon storage capacity of agricultural land uses was significantly ($p<0.0001$) affected by organic matter concentration wherein SOC increases by 5.65 MgC ha^{-1} for every one percent increase in soil organic matter.

Knowing the great potential of agricultural soils to sequester carbon, there is a need to communicate to policymakers of the Province of Bukidnon, agency heads of the Philippine Department of Environment and Natural Resources and the Department of Agriculture, and owners of farms/plantations data and information generated in this study in a manner that is relevant and simple to make them interested in soil carbon sequestration as a policy option of addressing impacts of climate change. Specifically, agricultural and environmental policy interventions should be directed towards identification and implementation of programs that would promote the use of sustainable management practices that enhance soil carbon sequestration in the agriculture sector such as crop management, conservation tillage, pasture management and utilization of organic amendments. It is also necessary that relevant environmental laws and policies are fully implemented such as the prohibition of common farm management practice of crop residue burning in sugarcane and rice plantations, which can lead to the reduction in SOC. Large scale agricultural plantations such as pineapple and banana must likewise be required to monitor and evaluate environmental impacts of their operations such as the effect of large scale monocropping on carbon sequestration ability of soils in their farms. Finally, new enabling policies, strategies and mechanisms should be put in place to pay farmers for ecosystem services such as that created through carbon sequestration in agricultural soils.

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