International Journal of Agricultural Technology 2020 Vol. 16(2): 457-474
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Accounting the net carbon sequestered of various agroforestry systems (AFSs) in Zamboanga City, Philippines

Tabal, E. P.[1*] and Mendoza, T. C.[2]

[1]Western Mindanao State University, Zamboanga City, Philippines; [2]University of the Philippines, Los Banos, Laguna, Philippines.

Tabal, E. P. and Mendoza, T. C. (2020). Accounting the net carbon sequestered of various agroforestry systems (AFSs) in Zamboanga City, Philippines. International Journal of Agricultural Technology 16(2): 457-474.

Abstract The importance of agroforestry as a land-use system for carbon (C) sequestration had been recognized. The various levels of C stocks expressed into CO_2 sequestered by major agroforestry systems (AFSs) across the 16 community-based forest management (CBFM) sites in Zamboanga City, Philippines was investigated. The major AFSs were compared to pure forest stand (PFS). Among the AFSs, the rubber-based had the highest C stocks at 68.93 tC ha^{-1} compared to lanzones-based (60.33 tC ha^{-1}), marang-based (60.23 tC ha^{-1}) and mango-based (60.01 tC ha^{-1}). Some other types had below 60.0 tC ha^{-1} C stocks. In terms of net carbon dioxide equivalent (net CO_{2e}) sequestered, the PFS had the highest at 1,098.62 tCO_{2e} ha^{-1} compared to the top four AFSs with the highest net tCO_{2e} sequestered such as the rubber+3-based, lanzones, marang and mango-based AFSs where each had about 248.66, 217.70, 218.17 and 217.41 tCO_{2e} ha^{-1}, respectively. The PFS had 5-7 times higher CO_2e sequestered compared with the top four AFSs. Results provided data that none of the AFSs can replace the real pristine forest in terms of C sequestration (5.0 ha AFS is equal to 1.0 ha pristine forest) and its watershed role as a net concerver of water. Further, it was observed that no water was available in the 16 CBFM sites and community residents had to fetch water for their household use. Also, Zamboanga City, Philippines had insufficient water for domestic use during extended rainless or El Nino months.

Keywords: Energy inputs, agroforestry systems, pure forest stand, net carbon emission, net carbon sequestered

Introduction

Before the Industrial Revolution in the 19th century, global average of atmospheric CO_2 concentration was about 280 ppm (Ewald, 2013). In 2017, greenhouse gas (GHG) concentration reached new highs, with global averaged mole fractions of CO_2 at 405.5 ± 0.1 parts per million (ppm), while methane (CH_4) at $1,859 \pm 2$ parts per billion (ppb) and nitrous oxide (N_2O) at 329.9 ± 0.1 ppm. These values constitute, 146, 257 and 122% relative to pre-industrial levels, respectively. Global average indicate that levels of CO_2, CH_4 and N_2O

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[*] **Corresponding Author**: Tabal, E. P.; **Email:** rico_cya2000@yahoo.com

continued to increase (Sharma *et al.*, 2016) attributed largely to energy usage and industry including land-use change (LUC) and this constitutes a record high of 53.5 $GtCO_{2e}$ in 2017, an increase of 0.7 $GtCO_{2e}$ compared with 2016 (IPCC, 2017). The uphill scale continued as of the current year, in fact, the last four years were the hottest on record and winter temperatures in the Arctic have risen by 3 ℃ since 1990 (UNCAS, 2019). This implication strongly points out that climate changes forced by GHGs depend primarily on cumulative emissions, making it progressively more and more difficult to avoid further substantial climate change (IPCC, 2017). The current analysis showed that if we act now, C emissions can be reduced within 12 years and hold the increase in the global average temperature to well below 2 ℃ and even to 1.5 ℃ (UNCAS, 2019), and this is approximately 25 and 55%, respectively lower than in 2017 to put the world on a least-cost pathway to limiting global warming (IPCC, 2017).

The impacts of global warming are being felt everywhere and are having very real consequences on agriculture, fisheries and humans. The evidence is conclusive that the strong growth of global CO_2 emissions from the burning of coal, oil, and natural gas is driving the acceleration (Ewald, 2013), this was why the United Nation Framework on Climate Change Convention (UNFCCC) through the Paris Agreement in 2015 had envisioned a viable policy framework that sets out exactly what needs to be done to stop climate disruption and reverse its impact but the agreement itself is meaningless without concrete action (UNCAS, 2019). This has led to a deepening international and domestic concerns for the development of viable methods to help slowdown the addition of GHGs to the atmosphere. One way to enhance the rate of C sequestration is to utilize a practically feasible and much affordable alternative method (Abalus, 2017) of which agroforestry systems (AFSs) could play important roles (Garrity, 2012; Malayao and Mendoza, 2013).

However, growing agricultural crops as food sources integrated in AFSs require enormous energy inputs to produce in the form of fuel, farm machineries and implements, irrigation pumps, equipment, agricultural inputs like seeds, fertilizers and chemical pesticides, motorized vehicles used for hauling and transport to markets and labor - the entire process is fossil fuel intensive. Before reaching our plates, our food is produced, stored, processed, packaged, transported, prepared, and served. At every stage, there is considerable amount of accumulated energy footprints expressed as direct energy inputs (DEI) and indirect energy inputs (IEI) which implicate that our food production systems has been increasingly dependent on energy derived from fossil fuels (Pimentel, 1980; Egle and Mendoza, 2013; Mendoza, 2016) and with the increase in energy footprints (EF) comes the increase in levels of carbon emission (CE) equivalents expressed in tCO_{2e} ha^{-1} which contribute significantly to global warming that drives climate change.

In this study we tried to account the net carbon emissions (NCE) derived from the energy inputs and net carbon sequestered (NCS) expressed in tCO_{2e} ha^{-1} of various agroforestry systems (AFSs) in Zamboanga City, Philippines.

Materials and Methods

Site selection and time of study

Zamboanga City is located at a latitude of 6°55'17.19”N and a longitude of 122°4'44.5”E. There were 16 Community Based Forest Management (CBFM) sites with nine identified Agroforestry Systems (AFSs) covered for this study, namely: 1) coconut+1-based, 2) coconut+2-based, 3) coconut+3-based, 4) rubber+1-based, 5) rubber+2-based, 6) rubber+3-based, 7) lanzones-based, 8) mango-based, and 9) marang-based. The study was carried out from July-December 2018.

Calculating the energy inputs and carbon emissions

The ‘direct energy input (DEI)’ included the use of diesel/gasoline to run the machines for farm operations and transport of farm products, while the ‘indirect energy input (IEI)’ were seeds used, NPK fertilizers, agrochemicals and labor inputs. Lastly, the ‘embedded energy input (EEI)’ was accounted from the utilization of machines, farm equipment and implements, motorized vehicles and draft animal. Hence, the total energy input (TEI) is the sum of DEI, IEI and EEI.

The energy accounting procedures and energy coefficients were based from the work of Pimentel (1980), Yaldiz *et al.* (1993), Wells (2001), Shresta (2002), Singh *et al.* (2002), Mendoza and Samson (2002); Ozkan *et al.* (2004), Yilmaz *et al.* (2005), Taghavi and Mendoza (2011), Thu and Mendoza (2011), Mohammadshirazi *et al.* (2012), Egle and Mendoza (2013), Karimi *et al.* (2008), Gliessman (2014), Mendoza (2016) and Savuth (2018). All energy units in Mcal ha^{-1} were converted into Liter Diesel Oil Equivalent (LDOE), where 1.0 LDOE = 11.414 Mcal (Pimentel, 1980).

The net carbon emission (N_{CE}) was computed using the equation:

N_{CE} = TEI x 3.96 Eq. 1

Where:

3.96 kg CO_{2e} $LDOE^{-1}$ (Pimentel, 1980) = C emission coefficient

Calculating the biomass and C stocks

The nested plot sampling method was modified to obtain biomass measurements of perennial woody trees, coconut, banana and other understorey vegetation present within the 2,000 m^2 sampling frame (Figure 1). The circumference of woody trees was measured at 4.5 ft (Waskiewicz *et al.*, 2015) from the ground using a measuring tape and later converted to its diameter at breast height (dbh) equivalent using the equation:

$$\text{Diameter (cm)} = C/\pi \qquad \text{Eq. 2}$$

Where: C = circumference of tree (cm) and $\pi = 3.1416$

Destructive sampling was not applied to larger trees with >5.0 cm in dbh. The use of allometric and regression models typically relating tree dbh to biomass or the aboveground biomass (AGB) developed by Unruh *et al.* (1993), Brown (1997), Ketterings *et al.* (2001) and Banaticla *et al.* (2007) were used and the C content were assumed at 45% (Lasco and Pulhin, 2003; Labata *et al.*, 2012). The resulting mean of AGB was used as basis to compute for the C stocks on biomass yield (C_{BY}) expressed in tC ha^{-1} using the formula:

$$C_{BY}\ (\text{tC ha}^{-1}) = \text{Biomass} * 0.45 \qquad \text{Eq. 3}$$

And the CO_2 equivalent (CO_{2e}) was computed using the equation:

$$\text{t}CO_{2e}\ \text{ha}^{-1}\ \text{(trees)} = C_{BY} * 3.6667 \qquad \text{Eq. 4}$$

Where: 3.6667 = constant factor, CO_2 to C ratio (Romm, 2008)

The biomass of coconut palms were computed using the three (3) allometric/regression equations developed by Frangi and Lugo (1985), and Goodman *et al*. (2013) and the resulting mean was used to compute for the C and CO_{2e} stocks ha^{-1} using equations 3 and 4.

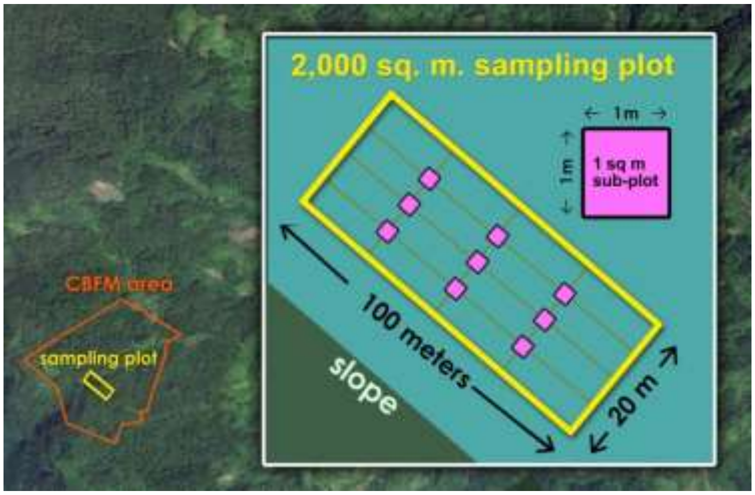

Figure 1. Modified nested plot sampling method

Collection of samples and computations

Trees and other woody vegetation. Due to practical concerns, destructive sampling is not recommended for large trees. Instead, the biomass is estimated through the use of allometric equations typically relating tree diameter to biomass. The biomass value is then used to calculate the carbon in trees. All trees with a circumference or diameter at breast height at 1.3 meters (dbh) > 5cm that fall within the plot were measured using measuring tape and later converted to its diameter equivalent using the equation: Diameter (cm) = circumference (cm)/π. Species name was recorded. Tree biomass was calculated using the allometric equation from Brown (1997):

$Y \text{ (kg)} = \exp\{-2.134 + 2.53 * \ln * D\}$
Where: exp {...} = “raised to the power of”
ln = “natural log of (...)”
Y = biomass per tree in kg
D = diameter at breast height (1.3m) in cm

While the allometric/regression biomass models for banana were adopted from Armecin and Gabon (2008), Arifin (2001) and Moore (2012). The resulting mean was used to estimate the C and CO_{2e} stocks following equations 3 and 4.

For the belowground biomass yield (BG_{BY}) or root biomass (RB) of trees, palms and banana, the average of 22.0% was used from the studies of Moura-Costa (1996), Santantonio *et al*. (1997), Cairns *et al*. (1997), Green *et al.* (2007), Moore (2012). The equation for C stocks is shown as:

$$BG_{BY} \text{ (tC ha}^{-1}\text{)} = \text{Biomass} \bullet 0.22 \bullet 0.45 \qquad \text{Eq. 5}$$

Where: Biomass = AGB of trees, coconuts and banana

Carbon yield of understorey biomass (USB), floor litter (FL) and soil organic carbon (SOC)

Samples were gathered in three different locations within the sample frame in three replicates represented by the three quadrats (sub-plots) with 1.0 m^2 area that were set up in the top, middle and bottom (Figure 1). These sub-plots were used for the collection of USB and FL employing destructive sampling method (Zaragoza *et al*., 2016).

Fresh USB and FL samples were weighed in the field. Representative sample of 1.0 kg each were brought to the College of Agriculture, Western Mindanao State University (CA-WMSU) for the oven drying activity. All samples were oven-dried at 65-70^{o}C for 48 hours or until constant weight was attained and were brought to the College of Agriculture and Food Sciences (CAFS), University of the Philippines Los Banos (UPLB), Laguna for the organic carbon (OC) analysis.

Soil samples were mixed and 1.0 kg representative sample was secured, air-dried and pulvurized and brought to the Bureau of Soil and Water Management (DA-BSWM) regional laboratory center for soil pH, N, P, K and % OM analysis. While, the bulk density (BD) was computed using the equation of Salang (2010).

The C yield of USB, FL and SOC were computed using Eq. 6, 7 and 8:

CY_{USB} (tC ha^{-1}) = (ODW•CF•10,000)/1,000 Eq. 6

Where ODW = oven dry wt. in kg, CF = C fraction = 41%, default value (Lasco and Pulhin, 2003), 10,000 = 10,000 sqm = 1.0 ha area, 1,000 = conversion factor, 1.0 ton = 1,000 kg

CY_{FL} (tC ha^{-1}) = (ODW•%C•10,000)/1,000 Eq. 7

Where:

%C = percent carbon from the laboratory analysis

SOC (t ha^{-1}) = (A) • (SD) • (BD) • (%OC) Eq. 8

Where: A (Area) = 10,000 m^2 = 1 ha, SD (Soil depth) = 0.30 m

%OC = %organic carbon (OM) = %OM/1.72

BD (g/cm^3) = bulk density, %OM = soil laboratory result, 1.72 = conversion factor (constant value)

Carbon yield on biomass

The carbon yield on biomass (C_{YB}) expressed in tC ha^{-1} is the sum total of AGB, CY_{USB}, and CY_{FL} as shown in the equation:

C_{YB} (tC ha^{-1}) = AGB + CY_{USB} + CY_{FL} Eq. 9

Gross carbon yield. The gross carbon yield (G_{CY}) is the sum total of C_{YB} and SOC as shown in the equation:

G_{CY} (tC ha^{-1}) = C_{YB} + SOC Eq. 10

Gross CO_{2e} on biomass. The gross CO_2 equivalent (G_{CE}) on biomass expressed in tCO_{2e} ha^{-1} was computed using the equation:

G_{CE} (tCO_{2e} ha^{-1}) = (G_{CY} • 3.6667) Eq. 11

Where:

3.6667 = CO_2 to C ratio, constant factor (Romm, 2008)

Net CO_{2e} Emission:- the net CO_{2e} emission (N_{CE}) in CO_{2e} ha^{-1} was computed using equation 12:

N_{CE} = (TEI/CF • 3.96)/1,000 Eq. 12

Where:
TEI = total energy input in Mcal
CF = 11.414 Mcal $LDOE^{-1}$ (Pimentel, 1980)
3.96 = constant factor = 3.96 kg CO_{2e} $LDOE^{-1}$ (Pimentel, 1980)

Net CO_{2e} ha^{-1} sequestered. Finally, the Net CO_{2e} Sequestered (N_{CS}) in CO_{2e} ha^{-1} is the difference of G_{CE} and N_{CE} as shown in equation 13:

$$N_{CS} = G_{CE} - N_{CE} \qquad \text{Eq. 13}$$

The G_{CE} and N_{CE} of pure stand upland rice and yellow corn, pure stand coconut, pure stand mango, pure stand rubber, and pure forest stand (PFS) were computed. The relationships of predictors (biomass and carbon) per system were analyzed using descriptive statistics. Means, percentages and sums were compared.

Results

Gross carbon stocks

The gross carbon stocks yield expressed in tC ha^{-1} and tCO_{2e} ha^{-1} of various agroforest types and monocrop systems are shown in Table 1. Among the AFSs, the rubber+3-based stored the highest gross C stocks at 68.93 tC ha^{-1}, or an equivalent of 252.75 tCO_{2e} ha^{-1}, followed by lanzones-based at 60.33 tC ha^{-1} (221.21 tCO_{2e} ha^{-1}), marang-based at 60.23 tC ha^{-1} (220.85 tCO_{2e} ha^{-1}), and mango-based at 60.01 tC ha^{-1} (220.04 tCO_{2e} ha^{-1}) and rubber+2 based at 52.90 tC ha^{-1} (193.97 tCO_{2e} ha^{-1}), respectively, while all coconut-based AFSs (coconut+1, coconut+2 and coconut+3) yielded a gross average of 40.74, 48.77 and 45.83 tC ha^{-1}, or these are equal to 149.38, 178.82 and 168.04 tCO_{2e} ha^{-1}, respectively. The result further showed that the tree-based AFSs mainly composed of rubber, forest and fruit trees yielded the highest C stocks as compared to coconut-based AFSs. On the other hand, the pure upland rice and yellow corn systems obtained a gross yield of 16.26 and 15.39 tC ha^{-1}, while the pure mango stand, coconut and rubber yielded 33.49, 44.59 and 50.56 tC ha^{-1}, respectively, but when compared to pure forest stand (PFS) which had a gross C stocks of 299.62 tC ha^{-1} or equal to 1,098.62 tCO_{2e} ha^{-1} was significantly higher than any of the agroforest types and monocrop systems. Of this gross amount, the C yield on biomass was 266.95 tC ha^{-1} and this was 89.1% of its gross C stocks, while RB and FLB contributed at 17.8 and 0.4 percent, respectively. Of the total C yield on biomass of PFS (266.95 tC ha^{-1}), the AGB contributed 81.8% as compared with 43.0 to 70.5 percent (17.49 to 42.56 tC ha^{-1}) yield levels of various systems across the 16 CBFM sites.

Beside the C stocks on biomass yield, SOC contributed about 30-57 percent of the gross C stocks across all agroforest types and monocrop systems (Table 1). Results showed that the coconut+1-based (coconut+banana) had a total SOC of 23.25 tC ha^{-1}, coconut+2-based (coconut+rubber+banana) at 25.53 tC ha^{-1}, coconut+3-based (coconut+rubber+banana+mahogany) at 22.49 tC ha^{-1}, mango-based (mango+coconut+banana+mahogany) at 28.06 tC ha^{-1}, marang-based (marang+coconut+banana) at 28.96 tC ha^{-1}, rubber+2-based (rubber+coconut+ banana) at 25.23 tC ha^{-1}, rubber+3-based (rubber+coconut+banana+marang) at 27.02 tC ha^{-1} and lanzones-based (lanzones+coconut+banana+Spanishcedar) at 17.77 tC ha^{-1}, respectively. Almost comparable to this amount were the pure coconut and pure rubber stands where each had a total SOC stocks at 25.04 tC ha^{-1} and 21.7 tC ha^{-1}, respectively as compared to pure stand mango (14.23 tC ha^{-1}), upland rice (14.74 tC ha^{-1}) and yellow corn (13.79 tC ha^{-1}), respectively. The results further revealed that the PFS had the highest SOC stocks at 32.67 tC ha^{-1}.

Net carbon emissions and net carbon sequester

There was a considerable amount of C footprint derived from energy inputs of each analyzed systems. Results on net C emissions of agroforestry and monocrop systems expressed in tCO$_{2e}$ ha^{-1} are shown in Table 1. Across the agroforest types, the net C emissions ranged from 2.17 (coconut+1-based) to 4.10 tCO$_{2e}$ ha^{-1} (rubber+3-based), while the other AFSs obtained less than the 4.0 tCO$_{2e}$ ha^{-1} level such as the coconut+2-based (3.90 tCO$_{2e}$), coconut+3-based (3.87 tCO$_{2e}$), mango-based (2.62 tCO$_{2e}$), marang-based (2.68 tCO$_{2e}$), rubber+2-based (3.90 tCO$_{2e}$) and lanzones-based (3.51 tCO$_{2e}$), respectively. Among the monocrop systems, pure mango stand, pure coconut stand and upland rice system yielded the lowest at 0.22, 0.73 and 0.96 tCO$_{2e}$ ha^{-1} lower than yellow corn and pure stand rubber systems at 1.47 and 4.39 tCO$_{2e}$ ha^{-1}, respectively. The result further showed that PFS had zero emission attributed to zero energy footprint.

The respective emissions were deducted from the total gross C stocks to obtain the net C sequestration, results are shown in Table 1. The highest net C sequestered was found in rubber+3-based AFS at 246.65 tCO$_{2e}$ ha^{-1}, followed by marang-based (218.17 tCO$_{2e}$ ha^{-1}), mango-based (217.42 tCO$_{2e}$ ha^{-1}) and lanzones-based (217.70 tCO$_{2e}$ ha^{-1}) AFSs, while the rest obtained significantly lower than the 200.0 tCO$_{2e}$ level especially in upland rice (58.66 tCO$_{2e}$ ha^{-1}) and yellow corn (54.96 CO$_{2e}$ ha^{-1}) systems, respectively. Results further showed that combining the net C stocks of mango-based, marang-based, rubber+3-based and lanzones-based (considered as best systems) still it cannot reach the net sequestered C of PFS at 1,098.62 tCO$_{2e}$ ha^{-1}.

Table 1. Gross carbon stocks (tC ha^{-1}), Gross CO_2 Equivalent (tCO_{2e} ha^{-1}), net C emissions (tCO_{2e} ha^{-1}), Net C stocks (tC ha^{-1}) and Net CO_{2e} sequestered (tCO_{2e} ha^{-1}) of the selected agroforestry and monocrop systems across the 16 CBFM sites in ZC, Philippines

	CARBON YIELD ON BIOMASS, tC ha^{-1}					**CY on Biomass**		**SOC**		**TOTAL**		**Net C**	**Net C**	**Net CO_2**
TYPE OF SYSTEMS	**AGB**			**RB**	**FLB**	**Total**	**%**	**Total**	**%**	**Gross Carbon Stocks**	**Gross CO_2 Stocks**	**Emission**	**Stocks**	**Sequestered**
	UPS	**UDS**	**Total AGB**			**tC ha^{-1}**		**tC ha^{-1}**		**tC ha^{-1}**	**tCO_{2e} ha^{-1}**	**tCO_{2e} ha^{-1}**	**tC ha^{-1}**	**tCO_{2e} ha^{-1}**
Coconut + 1 based AFS	11.92	1.52	13.43	2.62	1.44	17.49	42.9	23.25	57.1	**40.74**	**149.38**	2.17	40.15	**147.21**
Coconut + 2 based AFS	17.06	1.39	18.45	3.75	1.04	23.24	47.7	25.53	52.3	**48.77**	**178.82**	3.90	47.70	**174.92**
Coconut + 3 based AFS	15.88	1.68	17.56	4.14	1.64	23.34	50.9	22.49	49.1	**45.83**	**168.04**	3.87	44.77	**164.17**
Mango based AFS	23.93	1.51	25.44	5.26	1.25	31.95	53.2	28.06	46.8	**60.01**	**220.04**	2.62	59.30	**217.42**
Marang based AFS	23.57	1.41	24.98	5.25	1.04	31.27	51.9	28.96	48.1	**60.23**	**220.85**	2.68	59.50	**218.17**
Rubber + 2 based AFS	20.54	1.45	22.00	4.52	1.15	27.67	52.3	25.23	47.7	**52.90**	**193.97**	3.90	51.84	**190.07**
Rubber + 3 based AFS	31.96	1.23	33.19	7.03	1.69	41.91	60.8	27.02	39.2	**68.93**	**252.75**	4.10	67.27	**246.65**
Lanzones based	32.45	1.25	33.70	7.14	1.72	42.56	70.5	17.77	29.5	**60.33**	**221.21**	3.51	59.37	**217.70**
Pure stand forest trees	215.03	2.59	217.62	47.31	2.02	266.95	89.1	32.67	10.9	**299.62**	**1,098.62**	-	299.62	**1,098.62**
Pure stand upland rice	1.52		1.52	-	-	1.52	9.4	14.74	90.6	**16.26**	**59.62**	0.96	16.00	**58.66**
Pure stand yellow corn	1.60		1.60	-	-	1.60	10.4	13.79	89.6	**15.39**	**56.43**	1.47	15.00	**54.96**
Pure stand coconut	13.37	1.43	14.80	2.94	1.81	19.55	43.8	25.04	56.2	**44.59**	**163.49**	0.73	44.39	**162.76**
Pure stand mango	14.03	1.03	15.06	3.09	1.11	19.26	57.5	14.23	42.5	**33.49**	**122.80**	0.22	33.43	**122.58**
Pure stand rubber	21.61	1.37	22.99	4.76	1.11	28.86	57.1	21.70	42.9	**50.56**	**185.39**	4.39	49.36	**181.00**

Rubber+1-based (rubber+upland rice), mean C yield on biomass = 8.54 tC ha^{-1}, lower due to young age of rubber (5.5 yrs), excluded in the table.

UPS, UDS, RB, FLB and SOC: upperstorey, understorey, root biomass, floor litter biomass and soil organic carbon, respectively.

CY on biomass total, total carbon yield on biomass is the sum of AGB + RB + FLB (tC ha^{-1}).

Gross carbon stocks or GCS (tC ha^{-1}) is the sum of CY biomass total and SOC.

Gross CO_2 (tCO_{2e} ha^{-1}) calculated from the Gross C stocks (tC ha^{-1}) multiplied by 3.6667 CO_{2e} (CO_2 to carbon ratio) (Romm, 2008)

Net emissions (tCO_{2e} ha^{-1}) was derived from the TEI in Mcal, where 11.414 Mcal = 1.0 LDOE = 3.96 kg CO_{2e} emission (Pimentel, 1980)

Net CO_2 sequestered is the difference of the Gross C stocks (tCO_{2e} ha^{-1}) less the net emission (tCO_{2e} ha^{-1}) per AFSs.

Discussion

The lanzones-based, rubber+3-based, marang-based and mango-based AFSs were all considered as the best systems having obtained significantly higher C stocks on biomass and SOC levels as compared with other AFSs and monocrop systems. The high C stocks on biomass were mainly attributed to higher C stocks contributed by AGB, RB and FLB. The varying levels were suggestive of the varying dynamics of the major tree-based components within the system mainly attributed to larger dbh of tree components, type of tree-crops being intercropped and number of plants within a system. It explained the importance of perennial woody components in the upland environment for sequestering carbon. The case of PFS, its gross C stocks on biomass was considered a benchmark value to compare the C stocks of the best tree-based and coconut-based systems including the combined results of pure coconut, pure mango and pure rubber stands. This was a strong indication that none of the AFSs could replace PFS in terms of C sequestration. This is why, PFS ecosystem as C sink is irreplaceable. The higher C stocks in a PFS vegetation means that any of the AFSs and monocrop systems cannot replace the condition of real pristine forest in terms of C sequestration.

Also, any of the AFSs cannot sustain water availability – an inherent function only found in PFS. In one of the CBFM sites, this existing PFS has been maintained by the people’s organization where this site remains as source for domestic and irrigation water with more than 150 households benefiting from it especially during drought. This only mean that AFSs without a forest cannot achieve sustainable water flow significantly, hence AFSs cannot replace forest in terms of its hydrologic role in addition to C sequestration and biodiversity conservation. This means that in areas where there are still forest stands must be identified, preserved and protected for long term and sustainable water source in the community and to address sustainably the water shortage crisis in the entire City of Zamboanga especially during the prolong dry months and El Nino events.

The C stocks on SOC were very varied among all the systems analyzed attributable to the varying amount of OM in the soil. The low SOC resulted in lanzones-based AFS, pure mango and pure rubber stands was attributed to low amount of OM in the upper layer of the soil measured at 30.0 cm depth. These areas were once intensively tilled for growing upland rice and yellow corn. These type of cropping practices involving tillage agriculture in the upland environment has been recognized to enhance loss of OM due to soil erosion. Upland farming practices, management and climate are among the major factors affecting OM and SOC build-up (Perie and Ouimet, 2008; Sakin, 2012).

Temperature, rainfall, land management, soil nutrition and soil type all influence OM and SOC levels (Nair *et al.*, 2010). On the other hand, practices like zero under brushing, no-tilling and weeding were significant activities which had helped in OM and SOC build-ups (Viscarra-Rossel *et al*., 2014).

The low OM result (0.4%) which was best exemplified in pure upland rice and yellow corn production systems was a consequence of frequent cultivation and application of glyphosate (round-up) to replace the costly labor requirement on weeding but this practice had contributed to the slow removal of top soil over time especially during the wet months (May-November). Upland rice and corn production happened in large scale during rainy season employing moderate to heavy cultivation. Such practice had greatly affected SOM and SOC build-ups, thus reduced greatly the soil fertility level due to gradual loss of top soil. This is contrary to OM and SOC storage levels that are mainly controlled by managing the amount and type of organic residues that enters the soil and minimizing the soil carbon losses (FAO, 2015).

The variability of C stocks contributed by AGB, RB, FLB and SOC were the major determinants in the overall C stocks of each systems. This further suggests that the higher the C stocks on biomass and SOC, the higher the rate of CO_{2e} sequestration in the terrestrial ecosystems mainly attributed to various woody tree-crop components. This was significantly demonstrated by the PFS which yielded the highest in terms of C stocks which is 5-7 times higher in terms of C sequestration than the major agroforest types. In fact, it will take about 4.3 hectares of rubber+3-based AFS (highest C stocks) to equalized the rate of total C stocks of PFS (assumed that each having the same age and stands of tree components), and about 6.0, 6.7 and 9.0 hectares of pure rubber, coconut and mango stands (best monocrop systems), respectively, to reach the same C stock levels to that of PFS.

The world’s forests continue to shrink due to human pressure and forest land is converted to agriculture and other uses, but over the past 25 years, the rate of net global deforestation has slowed down. But still some 129.0 million hectares of forest (an area almost equivalent in size to South Africa) have been lost since 1990 (FAO, 2015). In 1934, Philippine forests comprised more than half or about 17.1 M hectares (57%) of the country’s total land area. In 2010, the forest cover has gone down to 23% or about 6.8 M hectares mainly due to increasing agriculture, commercial and illegal logging, and slash-and burn (*kaingin*) among others.

The AFSs across the 16 CBFM sites have demonstrated significant amount of C stocks at various levels. From among these systems, a choice of one or more systems can be established suitably to help restore the estimated 6.3 M hectares deforested lands while at the same time producing food for the looming Philippine population. This can be a significant contribution to world's effort in addressing global warming while achieving Philippine sustainable food system from here on and beyond. Due to the tree components of various AFSs, they sequester more carbon greater than the pure annual crops such as upland rice and yellow corn, but while this is true, they sequestered C significantly lower than the PFS. The study further showed that it will take 5-7 hectares of AFS to equal 1.0 hectare of PFS. This means that 30-42 M hectares of AFS should be established to match the 6.0 M hectares deforested areas, or 50-70 M hectares for the 10.0 M hectares deforested areas since the start of the 19th century. The Philippine has only 30.0 M hectares, this strongly implies that we cannot pin our hopes on AFSs to significantly address climate change and the lost hydrologic role of PFS, more so its role on biodiversity conservation and protection.

The energy footprint (EF) and carbon footprint (CF) are two distinct terms. The EF refers to the total carbon dioxide equivalents (CO_{2e}) emitted from the various energy inputs such as in the production of seeds (upland rice, corn), fertilizers and pesticides (particularly N and round-up), direct fuel, inputs on farm labor and machinery, while the CF refers to the total set of greenhouse gasses (GHGs) such as CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions caused mainly by human. The CF being described in this study is the amount of carbon dioxide (CO_2) emitted derived from the total energy inputs (TEI) or the energy footprint (EF) in the form of liter diesel oil equivalent (LDOE) either directly or indirectly used or consumed on a particular agricultural system. In this case, each of the AFSs with their specific TEI was considered as potential CF expressed in LDOE ha^{-1} where 1.0 LDOE is 3.96 kg CO_{2e} emission (Pimentel, 1980). The total CF derived from TEI were considered as the net CO_{2e} emissions.

The high C emissions (rubber+3-based, coconut+2-based, rubber+2-based, coconut+3-based and lanzones-based) were directly attributed to high energy inputs (TEI) or energy bills (Mendoza, 2016) mostly derived from the indirect use of energy in the form of farm inputs (agrochemicals) and labor, hence increase in CF. On the other hand, the AFSs with low net C emissions (coconut+1-based, mango-based and marang-based) were mainly due to minimal energy usage on coconut, mango and banana components. While upland rice had short gestation period, hence required no further energy inputs on agrochemicals and labor usage. On monocrop systems, majority had low net C emissions except on pure rubber stand mainly attributed to high energy bills on fertilizers, agrochemicals and labor or call these as the 'energy hotspots', while zero emissions were accounted on PFS. This significantly implied that increasing the TEI will not only increase the level of energy inputs (energy footprints) but it also increases the CF or carbon emission equivalents as demonstrated by the majority of the tree-based AFSs which are primarily composed of rubber and coconut.

On the other hand, majority of the AFSs had significant tC ha^{-1} and tCO_{2e} ha^{-1} stocks compared to monocrop systems, this further explained that the multi-tree crops AFSs or the ‘farmer’s choice system’ can sequester more C than the monocrop and tree-less systems. However, the PFS had the most significant net tC ha^{-1} stocks and tCO_{2e} ha^{-1} sequestered as compared to all agroforest types and monocrop systems. Combining the total tC stocks of the best AFSs such as the mango-based, marang-based, rubber+2-based, rubber+3-based and the lanzones-based still it cannot reach the total C yield of PFS in the amount of 299.62 tC ha^{-1} (1,098.62 tCO_{2e} ha^{-1}). Further, the natural PFS (pristine forest) was an excellent land use model in a terrestrial ecosystem in the uplands of Zamboanga City compared to manmade AFSs.

The net tCO_{2e} sequestered were derived after deducting the computed C emission equivalent derived from the TEI of each agroforestry and monocrop systems. The current study has successfully accounted the different levels of C emissions expressed in tCO_{2e} ha^{-1}. With this development, this posed a major concern on the earlier work of Zamora, 1999; Albrecht and Kandji, 2003; Garrity, 2006; Nair *et al*., 2009; Pandey, 2002; Sales *et al*., 2005; Pulhin *et al*., 2007; Nair *et al.*, 2010; Kumar and Nair, 2011; Labata *et al.*, 2012; Nair, 2012; Parao *et al*., 2015; Sharma *et al*., 2016; Sarangle *et al.*, 2018, and various others because the potential CO_{2e} emission that comes from each agricultural crop components involved within the system has not been accounted. This further implies that the earlier data on C sequestration of various AFSs calculated by previous authors tend to be higher. The findings suggest that the earlier data were over reported. None of nine (9) AFSs could approximate the real pristine forest in terms of C sequestration (5.0 ha AFS is equal to 1.0 ha pristine forest) and its watershed role as a net conserver of water. It was observed that no water is available in the 16 CBFM sites and community residents had to fetch water for their household use. Also, Zamboanga City, Philippines had insufficient water for domestic use during extended rainless or El Nino months.

Planting of multipurpose tree species in the CBFM sites serves a dual purpose primarily to promote C sequestration and increase the income of farming households. The net C stocks of various agroforest types and monoculture systems yielded varying results. These variations were attributed to important factors such as age of trees, diameter at breast height (dbh), stocking rate (plant density), amount of soil organic matter (SOM), climate, amount of rainfall and soil moisture, cropping management and nutrition. However, there is a need to validate the much claimed potential impacts of

AFSs as climate change mitigating strategy through C sequestration. The development of appropriate management plans can better promote fairness and equality among the upland communities and to the environment where they live. If upland farmers are given the opportunity to fully benefit from managing their tree-based systems, in return, these systems could evolve into a technological option for reducing the vulnerability of cropping systems to climate variability and from the impact of changing climate.

Among the AFSs, the rubber-based had the highest C stocks at 68.93 tC ha^{-1} compared to lanzones-based (60.33 tC ha^{-1}), marang-based (60.23 tC ha^{-1}) and mango-based (60.01 tC ha^{-1}). Some other types had below 60.0 tC ha^{-1} C stocks. In terms of net carbon dioxide equivalent (net CO_{2e}) sequestered, the PFS had the highest at 1,098.62 tCO_{2e} ha^{-1} compared to the top four AFSs with the highest net tCO_{2e} sequestered such as the rubber+3-based, lanzones, marang and mango-based AFSs where each had about 248.66, 217.70, 218.17 and 217.41 tCO_{2e} ha^{-1}, respectively. The PFS had 5-7 times higher CO_2e sequestered compared with the top four AFSs. Results provided data that none of the AFSs can replace the real pristine forest in terms of C sequestration (5.0 ha AFS is equal to 1.0 ha pristine forest) and its watershed role as a net user of water.

Acknowledgement

The authors wish to acknowledge the Commission on Higher Education (CHED), Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development (PCAARRD) and Yamang Bukid Healthy Products Inc. (YBHPI) for the funding support.

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(Received: 30 August 2019, accepted: 28 February 2020)