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CARBON STOCK ASSESSMENT OF SELECTED AGROFORESTRY SYSTEMS IN BENGUET

[1]Marissa R. Parao, [1]Kenneth A. Laruan, [2]Mendil T. Palista

[1]College of Forestry, Benguet State University
[2]Research Assistant, HERRC, Benguet State University

ABSTRACT

Agroforestry is a sustainable land use management system and has great role in adapting to expected changes in climate by small holder farmers. The provision of permanent cover such as trees served as important carbon stocks and the practice can reduce carbon emission. Nevertheless, very few studies investigated the potential of Agroforestry to sequester carbon. The objective of this study is to evaluate and compare the carbon stocks of the different components of agroforestry systems that are commonly practiced in Benguet and to identify practices that can help improve carbon sequestrations of agroforestry farms. Representative farms of the most commonly practiced agroforestry systems from Atok, Tuba, La Trinidad and Sablan were surveyed for their carbon stocks in 2014. Results indicate that the most commonly practiced agroforestry systems were chayote and coffee-based agroforestry systems. In all the agroforestry farms evaluated, the bulk of the carbon stock comes from their tree and soil components and the carbon density and CO_2 sequestered are highest among chayote-based farm (208.2 t ha^{-1}), anthurium-based agroforestry (171.45 t ha^{-1}) and the vegetable-based agroforestry with coffee(156.16 t ha^{-1}). Further, practices that increase tree components and vertical layering in crops as well soil and water conservation measures can help improve Carbon sequestration in an agroforestry farm.

Keywords: *agroforestry systems, carbon stock and assessment*

INTRODUCTION

Awareness on the effects of climate change had been significant in the recent years. This is because the impacts of this phenomenon are extensive, affecting nations and individuals regardless of development level, socioeconomic status, gender and profession.

In Benguet, manifestations of climate change are apparent. Calora *et al.*, (2012) revealed that an increase in the average daily temperature of about 0.4 °C in the last four decades as compared to the recent decade occurred. Accordingly, a 1 °C increase in temperature can decrease crop yield by 5%-10%. This is further compounded by a wide range of maximum daily temperature which sometimes resulted in crop failure. Moreover, the range in daily temperatures has increased during the cold months, reaching to as high as 8.1 °C difference between the minimum and the maximum temperatures in a day. This indicates that the minimum daily temperatures dropped while the maximum daily temperatures increased. This climate variability may result in crop yield reduction. Decrease in crop yield and increase pest and disease occurrences due to higher temperature, rainfall and frost are but some of the commonly observed impacts that the agricultural sector is facing in Benguet for the past years (Calora *et al.*, 2012).

Agriculture is one of the high priority sectors where the impacts of climate change can exceed the tolerance limits (Rao *et al.*, 2013). This has implications on the livelihoods and well-being of farmers as well as global food security.Human activities such as conversion of forest to agricultural lands, poor land management practices are reported to contribute in an increased concentration of greenhouse gases, including CO_2, methane, nitrous oxide and chlorofluorocarbons in the atmosphere (Lambrou and Piana, 2006). Thus, farmers need to be informed as to what should constitute a climate-sensitive farming practice.

Agroforestry (AF) is "a dynamic, ecologically based, natural resources management system that, through the integration of trees in farms and in the landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels" (Leakey, 1996). The practice of agroforestry is considered as a viable option to agriculture and a sustainable land use management system (Nair and Garrity, 2012). Agroforestry interventions, because of their economic and environmental benefits are considered to be the best "no-regrets" measures in making communities adapt and resilient to impacts of climate change (Rao *et al*., 2013). Further, agroforestry has potential role in the adaptation to expected changes in climate by small holder agroforestry farmers. Its provision of permanent cover such as trees serving as important C stocks diversifies the system which makes it stable and efficient in its use of resources, such as soil, water and other local resources. It also contributes to soil fertility, reduces C emissions and sequesters C.

Carbon pool, stocks and sequestrations are important gauge in the mitigation measures adopted by a country to arrest climate change. Enhancing C sequestration and continued protection of the C pools is the best option that we can do to help arrest climate change.

At present, limited studies were conducted to identify and assess the agroforestry systems in Benguet. More researches are needed in assessing the potential of this land use system in addressing the concerns on C sequestration and adaptation to climate change.

It is the objective of this research to measure and compare the C stock of the different components of agroforestry systems and to determine the CO_2 sequestration potential of the most dominant agroforestry systems employed in Benguet. Specifically the study aimed to:

a. determine the most commonly practiced agroforestry systems practiced in Benguet;

b. measure and compare the C stocks in tree, understory, litter and soil components of the different agroforestry systems;

c. compare the C density and CO_2 sequestration of the different agroforestry systems; and

d. identify practices in agroforestry that can help improve C sequestration in AF farms.

The result of the study can serve as baseline information on the most practiced AF system in Benguet, the distribution of C pools in AF farms and the C sequestration of the different AF systems can also provide basis in making recommendations on how to improve the C sequestration of the agroforestry farms in Benguet.

MATERIALS AND METHODS

Selection of Barangays for the determination of the different agroforestry systems in Benguet

The project covered all the 13 municipalities of Benguet. The activity was coordinated with the concerned local government units, farmers groups and the municipal agriculture officers (MAOs) of each municipality in order to identify barangays that practices agroforestry. In each municipality, three barangays were selected as study sites to represent the different cropping systems practiced to provide a cross sectional representation of AF practices in the municipality. The barangays with the highest volume of crop production and the different ethnicity of the municipality were the additional criteria used in determining the representation of the cropping systems practiced in the province.

Identification of the agroforestry farms for the study

In order to further screen the barangay for the study sites, a set of criteria were used to define an acceptable agroforestry system and identify the

farms to be surveyed. The following criteria were used in determining whether the farming system is an agroforestry system or not:

a. the farm involves two or more species of plants (and or animals);
b. at least one is woody perennial present;
c. perennials (including trees) and agricultural crops are produced in the same unit of land;
d. the tree cover is at least 10%; and
e. it has at least two or more outputs.

Those AF farms that met the criteria were further classified based on the dominant crops and nature of the components. The dominant and perennial crops and main cash crops of the cropping system were clustered. Sample areas of the top five AF systems practiced in Benguet were selected as study sites. Representative farms for the different agroforestry systems in Benguet were studied for C sequestration potential. A fix area of 10m x 20m plot size was used for evaluating C sequestration of each farm. Based on the classification made, nine agroforestry farms that represent seven AF systems were surveyed. The location of the AF farms surveyed is presented in Table 1.

Data gathered

The top five AF farms which represents about 87% of the AF systems were chosen for this study but considering that majority of those surveyed had chayote as a major component; three sample farms that represent the years of chayote farming were chosen instead. Further, a small fraction of agroforestry systems practiced in the lower elevations of Benguet was included.

Other than the type of AF systems practiced in Benguet, the other field data gathered consisted of the number and diameter of trees, biomass weight of the understory (including cash crop) vegetation and litters and bulk density and organic matter content of the soil.

1. Measurement of biomass in tree, understory and litter components

Details on how biomass and C content for each plant components was measured or verified is given in the succeeding section.

a. Tree component

Since cutting and uprooting of trees were not feasible due to legal prohibition, a non-destructive approach was employed for this component which utilized allometric equations to determine the tree biomass. These equations were taken from various studies (Table 2).

In order to estimate the above the ground biomass, trees with a diameter at breast height (DBH) of 10 cm and above were gathered on the sample farms. For the above ground biomass, species-specific equation is used if available, otherwise the above ground biomass (AGB) computation by Kahawara *et al*. (1981) as cited by Banaticla *et al*. (2005) was used in case there is no other allometric equation that is specific for the species. DBH of trees was measured using a diameter tape. The allometric equation or formula used for the study is shown in Table 2. The formula used by Brown (1997) as cited by Lasco (2002), Kahawara *et al*. (1981) as cited by Lasco and Pulhin (2003) and Banaticla *et al*. (2005) and other authors were compared prior to adoption of any formula. Priority was given to formula generated locally and for species-specific equation and C density.

The formula for mix species (y = 0.342D2.073) was used in the calculation of AGB if no formula is specified for the species in Table 2 and a default C content of 45% was used in the absence of studies that specifies the C content of the plant surveyed. For below ground biomass, the allometric equation of Brown (1997) as cited by and Lasco (2002) was applied.

b. Understory

The understory which included the crop and the grass components including other low lying vegetation were sampled from three sample plots (1 m^2 each) established within the AF farm which were identified as representative for the understory.

Owing to the bulkiness of litter and the understory plant materials gathered, only samples from the total collections were brought to the laboratory. The samples were weighed in the field and considered as representative fraction of the total collections.

In order to determine the biomass content of

Table 1. The Agroforestry systems measured for the study and their locations

Agroforestry System	Location of site surveyed for C stock assessment
Chayote-based AF	1 farm in Caliking, Atok and 1 farm in Shilan, La Trinidad,
Chayote-coffee-based AF	1 farm in Caliking, Atok
Anthurium-based AF	1 farm in Poblacion, Tuba
Banana-based AF	1 farm in Bayabas, Sablan
Coffee-based AF/fruit plantation AF	1 farm in Wangal, La Trinidad
Pineapple-based AF	2 farms in Bayabas, Sablan
Tiger grass-based AF	1 farm in Banangan, Sablan

Table 2. Formula used for AGB and species-specific C content

Species	Above Ground Biomass Formula	C Content (%)	Source
Mix species	y = aDb; where a = 0.342; b = 2.073	45.0	Kahawara *et al.* (1981) as cited by Banaticla *et al.* (2005)
Alnus	*	50.0	Paran, 2013
Calliandra	*	43.1	Racelis (2000) and Kahawara *et al.* (1981) as cited by Lasco and Pulhin (2003) and as cited by Banaticla *et al.* (2005); Lasco and Pulhin (1998)
Dapdap	*	43.1	
Gmelina	y = aDb, where a =0.153; b =2.217	45.0	
Ipil-ipil	y = aDb, where a =0.132; b =2.316	40.0	
Kakauate	*	43.1	
Mahogany	y = aDb, where a =0.022; b =2.920	41.6	
Benguet pine	*	48.5	Lasco & Pulhin (2003)
Coffee	*	44.0	Zamora (1999) as cited by Lasco and Pulhin, (2003)

* The formula for mix species (y = 0.342 D2.073) was used in the calculation of AGB if no formula is specified for the species

the understory, 100g samples was brought to the College of Forestry laboratory for oven drying. The samples were first air-dried before oven-drying. All plant samples were placed in paper containers and dried in the oven at 70 °C for at least two weeks or until the oven dry weight became constant. The constant weight of the oven dried samples was recorded as biomass.

c. Litter component

Litters were taken from the same plot measured for the understory component. After grasses were removed from the subplot, the litters consisting mostly of leaves were collected. In determining the biomass weight of litter, the procedure for measuring biomass of understory was adopted.

2. Determination of C content in tree, understory and litter components

The C content was calculated using the biomass of each tree as derived from the different allometric equations (Table 2). The dry matter weight (biomass) of litter and understory was multiplied by 45% which represents the fraction of organic C in the biomass. Furthermore, the CO_2 content was computed using the conversion ratio of one kg of C equal to 3.67 kg of CO_2. Results of C stored are presented in ton per hectare (t ha^{-1}). The percent C

of the different components was calculated based on the C provided by the component divided by the total C stored for the farm multiplied by 100.

3. Determination of soil organic Carbon (SOC)

Two sets of soil samples were collected in the field. From the same plots utilized for the understory, soil samples from the first 10cm layer was obtained using a core sampler of 8cm x 5cm diameter. The soil taken using the core sampler was completely removed, weighed and oven-dried at 100 °C for about two weeks or until its weight became constant. These values were used to calculate the bulk density of the soil from each farm. Bulk density was computed as the oven-dry weight of the soil collected divided by the volume of the soil as contained in the core sampler.

A composite soil sample was also collected in each farm for the determination of organic matter content of the farm. These samples were air dried, pulverized and sieved using 2mm mesh, and was sent to the Soils Laboratory in Pacdal, Baguio City.

The OM content of the soil was used to determine the SOC. SOC is equal to the percent organic matter divided by 1.724 (Moura-Costa, 1996 as cited by Lasco and Pulhin 1998). This relationship was used in determining the amount of CO_2 sequestered by soil. Results of C stored are presented in ton per hectare (t ha^{-1}). The percent C stock for soil was calculated as the fraction between C stored and the total C stock of the agroforestry farm multiplied by 100.

RESULTS AND DISCUSSION

Agroforestry Systems in Benguet

Out of the 1,117 farms representing different cropping systems practiced in Benguet, only 95 farms passed the criteria as agroforestry. Some farms integrate 10% perennial crops such as banana, tiger grass and bamboos but since these are not trees, these are not included. This show that Benguet have a low adoption of agroforestry despite the fact that it is often quoted to be a sustainable technology as it increases food and cash availability while rehabilitating the environment. It was looked upon as a possible solution to put an end to forest denudation, a farming system that can yield wood and food while at the same time rehabilitating, conserving and maintaining the productivity of the upland or forest ecosystem. Specifically, many experts dubbed agroforestry as a vehicle for rural development, a tool for upland development or as an approach to watershed management.

The different AF systems were further classified based on dominant crops and nature of the components. The dominant and perennial crops and main cash crops of the cropping system were clustered. The AF systems surveyed in all municipalities are presented in Table 3 and Figures 1 to 8.

Based on the survey made, majority of the agroforestry systems employed in Benguet involves two or more vertical layers consisting of crops at the lower strata and fruit trees and multi-purpose trees in the upper strata. In most of the areas visited, the integration of chayote, coffee and fruit trees are most commonly observed.

Carbon Pools in Agroforestry Systems in Benguet

The C source, C density and CO_2 sequestration of the surveyed AF systems is presented in Table 4.

Majority of the C pool of all the AF systems surveyed are stored in the soil and tree components of the agroforestry farms. Carbon from soil forms the bulk of C pool which ranged from 34-75% of the total C, followed by C from trees, 22-58%. Least C contents were measured from litters (0.9-5.5%) and the shrub, vegetable and grasses which are mostly herbaceous plants (0.4-2%). This is consistent with the findings in a Pine forest study showed that much of the bulk of C is stored in trees and soil (Bantas *et al.*, 2011).

The highest SOC was measured in the Anthurium-based AF; the vegetable AF with chayote and the coffee and chayote-based AF. These AF have high organic matter content (5%-7%) and thick soil. In contrast, most of the AF found to have lower SOC were those from high steep areas and old chayote-farms.

Table 3. Agroforestry systems practiced in Benguet

Agroforestry System	No. of Adopters	Percent Adoption
Chayote-based	36	37.89
Chayote-coffee-based	9	9.47
Chayote-anthurium-based	4	4.21
Anthurium-based	7	7.37
Banana-based	1	1.05
Coffee-based AF/fruit plantation-based	24	25.26
Pineapple based	2	2.11
Rice-based	2	2.11
Tiger grass-based	4	4.21
Tiger grass-pineapple based	3	3.16
Sweet potato-based	2	2.11
Cassava-based	1	1.05
Total	95	100%

Fig. 1. Coffee based AF under alnus trees in Caliking, Atok

Fig. 2 . Chayote+ alnus based AF in Caliking, Atok

Fig. 3. Chayote + coffee AF in Caliking, Atok

Fig. 4. Chayote based AF with pine trees in Ampucao, Itogon

Fig. 5. Banana based AF in Bayabas, Sablan

Fig. 6. Pineapple based AF in Bayabas, Sablan

Fig. 7. Banana + tiger grass in Pappa, Sablan

Fig. 8. Anthurium based AF in Poblacion, Tuba

The C stored from the tree components contribute significant amount to the C pool. Most of the AF that have higher amount of tree C were those dominated by medium to large sized pine trees in chayote-based AF; large leaf Mahogany in anthurium-based AF; and *Gmelina arborea*, *Lepting* and *Calliandra* in coffee-based and banana-based AF.

In some areas, small diameter trees are densely stocked which account for the higher tree C content in coffee-based, banana-based and anthurium-based AF.

The highest undergrowth and litter contribution to the C pool was surveyed in chayote-coffee-based AF. High C pool is due to the fact that coffee is woody as compared to the herbaceous vegetable crops. The chayote-coffee based AF also had the highest litter content which could be due to greater deposition of plant matters specifically leaves.

Of all the AF systems surveyed the contribution of the undergrowth such as vegetables, grasses and other herbaceous plants were very small to negligible.

Carbon Density and CO_2 Sequestration of the Different AF Systems in Benguet

1. Carbon density of the AF systems in Benguet

Among the different agroforestry systems in Benguet, the highest C density and potential CO_2 sequestered was recorded under the newly opened (<5 years) chayote-based AF farm, followed by

Table 4. Carbon source, Carbon stock and CO_2 sequestration potential of the AF systems in Benguet

AF System	C Source	C(%)	C Stock Per Farm (t)	C Stock (t ha^{-1})	CO_2 Sequestered Per Farm (t)	CO_2 Sequestered (t ha^{-1})
Banana-Pineapple withPigeon pea (Kardis)	Tree	26.51	0.39	19.75	1.45	72.47
	Shrub, vegetable and grasses	1.50	0.02	1.12	0.08	4.11
	Litters	4.63	0.07	3.45	0.25	12.67
	Soil	67.35	1.00	50.16	3.68	184.09
	Total	100.00	1.49	74.48	5.47	273.34
Pineapple with Taro	Tree	36.63	0.46	23.18	1.70	85.06
	Shrub, vegetable and grasses	1.99	0.03	1.26	0.09	4.62
	Litters	3.58	0.05	2.26	0.17	8.31
	Soil	57.80	0.73	36.57	2.68	134.23
	Total	100.00	1.27	63.28	4.64	232.22
Banana with Gmelina based	Tree	43.41	0.95	47.41	3.48	173.98
	Shrub, vegetable and grasses	1.34	0.03	1.46	0.11	5.37
	Litters	4.41	0.10	4.81	0.35	17.65
	Soil	50.84	1.11	55.52	4.08	203.75
	Total	100.00	2.18	109.20	8.02	400.76
Vegetable based with coffee	Tree	35.48	1.11	55.40	4.07	203.31
	Shrub, vegetable and grasses	0.91	0.03	1.43	0.10	5.24
	Litters	2.24	0.07	3.50	0.26	12.83
	Soil	61.37	1.92	95.84	7.03	351.74
	Total	100.00	3.12	156.16	11.46	573.12
Chayote-coffee based	Tree	58.44	1.59	79.52	5.84	291.82
	Shrub, vegetable and grasses	2.03	0.06	2.76	0.20	10.12
	Litters	5.47	0.15	7.44	0.55	27.32
	Soil	34.07	0.93	46.35	3.40	170.12
	Total	100.00	2.72	136.07	9.99	499.38
Chayote-based	Tree	37.22	1.55	77.49	5.69	284.38
	Shrub, vegetable and grasses	1.50	0.06	3.13	0.23	11.49
	Litters	0.92	0.04	1.92	0.14	7.05
	Soil	60.36	2.51	125.66	9.22	461.18
	Total	100.00	4.16	208.20	15.28	764.11

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AF System	C Source	C (%)	C Stock Per Farm (t)	C Stock (t ha^{-1})	Tons CO_2 Sequestered Per Farm (t)	CO_2 Sequestered (t ha^{-1})
Tiger grass based	Tree	57.37	0.67	33.58	2.46	123.24
	Shrub, vegetable and grasses	1.88	0.02	1.10	0.08	4.05
	Litters	3.02	0.04	1.77	0.13	6.49
	Soil	37.72	0.44	22.08	1.62	81.03
	Total	100.00	1.17	58.53	4.30	214.80
Anthurium-based	Tree	28.14	0.96	48.25	3.54	177.06
	Shrub, vegetable and grasses	0.35	0.01	0.60	0.04	2.20
	Litters	0.85	0.03	1.46	0.11	5.35
	Soil	70.66	2.42	121.15	8.89	444.63
	Total	100.00	3.43	171.45	12.58	629.24
Chayote-based	Tree	37.22	1.55	77.49	5.69	284.38
	Shrub, vegetable and grasses	1.50	0.06	3.13	0.23	11.49
	Litters	0.92	0.04	1.92	0.14	7.05
	Soil	60.36	2.51	125.66	9.22	461.18
	Total	100.00	4.16	208.20	15.28	764.11
Vegetable with chayote and coffee	Tree	21.63	0.51	25.32	1.86	92.94
	Shrub, vegetable and grasses	1.78	0.04	2.08	0.15	7.63
	Litters	1.70	0.04	1.98	0.15	7.28
	Soil	74.90	1.75	87.68	6.44	321.78
	Total	100.0	2.34	117.07	8.59	429.64
Average	Tree	37.45	0.91	45.54	3.34	167.14
	Shrub, vegetable and grasses	1.37	0.03	1.66	0.12	6.09
	Litters	2.61	0.06	3.18	0.23	11.66
	Soil	58.57	1.42	71.22	5.23	261.39
	Total	100.00	2.43	121.60	8.93	446.29

the anthurium-based AF and the coffee-vegetable based AF (Table 4, and Figures 9 and 10).

The highest C density among the different AF systems were observed in chayote-based farm (208.2 t ha^{-1}), anthurium-based AF (171.45 t ha^{-1}) and the vegetable-based AF with coffee (156.16 t ha^{-1}). Low C density was recorded from tiger grass-based AF having C density of 58.53 t ha^{-1},followed by pineapple with taro AF system (63.28 C t ha^{-1}) and banana with pineapple and pigeon pea (74.58 t ha^{-1}). Low C density could be attributed to sparse and small diameter trees integrated between tiger grass and pineapple which need more open space for maximum sunlight interception.

As much as 208.2 t ha^{-1} of C (Table 4) is contained in the best AF system documented. This value is almost similar to that of a natural forest with 254 t ha^{-1} C (Banaticla *et al*., 2005). It has even surpassed the C density of young pine forest at 90.1 t ha^{-1} and other agroforestry systems in other area such as rubber agroforest in Indonesia of only about 104-116 t ha^{-1} (Lasco, 2002). Other studies conducted in Benguet reported C density of 123.76 of an 8-year old Alnus stand (Paran, 2013) and 73.2 t ha^{-1} in Burnham park mix stand dominated by pine trees (Lumbres, 2009). This shows that C stock of AF farms in Benguet are better than other AF farms except for some AF such as Narra-cacao and Gmelina-cacao based in Makiling Forest having 191.6 t ha^{-1} and 257.7 t ha^{-1}, respectively (Banaticla *et al*., 2005).

The overall mean C density in Benguet AF is also high at 121.6 t ha^{-1} as compared with other AF systems in the Philippines such as fallow system, coconut+coffee, alley cropping and home garden, with a C densities of 32, 99.2, 3.8, 32.7 t ha-1, respectively. On the average, agroforestry farms in the country have 102.8 t ha^{-1} C (Banaticla *et al*., 2005) which is lower when compared to AF systems practiced in Benguet. The high C densities of AF systems in Benguet could be due to the continued integration and or maintenance of trees such as pine, *dapdap* and *Alnus*. Trees are retained after shifting cultivation or planted to enhance tree cover and various soil and water conservation measures are practiced to promote better soil quality resulting to higher C densities.

2. <u>CO_2 sequestration of an average AF systems in Benguet</u>

In terms of potential CO_2 sequestered by the AF system (Figure 11), the amount of CO_2 can be as high as 764.11 t ha^{-1} in chayote-based AF and as low as 214.80 t ha^{-1} in tiger grass-based AF system (Table 4). From highest to lowest order of CO_2 sequestration potential of the various AF systems in Benguet, chayote-based AF is greater than (>) anthurium-based AF>vegetable with coffee AF>chayote-coffee AF>vegetable-chayote and coffee AF>banana-based AF>banana with pineapple and pigeon pea AF>pineapple with Taro AF>tiger grass based AF.

In all the farms visited, the importance of tree component in terms of CO_2 sequestration cannot be discounted. Although all these AF systems have at least 10% tree cover, yet, its CO_2 sequestration were still variable depending on the number of trees, the species of trees planted as well as its age and condition. Employing bigger and greater number of trees through the practice of multi-layering increases the amount of C sequestered by an AF system. If trees will be maintained or integrated in farms, in the future it is estimated that agroforestry systems in the tropics can sequester an average of 22.68 kg CO_2 per year, hence the more trees planted the better the sequestration potential of the AF system.

Likewise, the soil organic C has significant contribution in CO_2 sequestration. Among the different AF systems, the chayote-based, anthurium based and the vegetable-based AF systems provided the highest soil C sequestration potential. This can be attributed to the better soil condition in these areas and the practice of soil and water conservation measures such as riprapping and stone walling, use of diversion canals and composting.

<u>The chayote-based agroforestry.</u> Chayote-based AF is the most dominant agroforestry system practiced in Benguet. Chayote (*Sechium edule*) is one of the main crops of the mountainous areas of Benguet. Based on the survey, 52% of the AF farms surveyed have chayote as its major or one of the major components. Variations of this AF system included integration of coffee, citrus, vegetable crops and bees.

The AF in Benguet usually use existing pine trees or other native trees as live post or as trellises where wires are tied for chayote. Trees are maintained by pruning and branches are used as additional brace. This practice is feasible in areas where pine trees are tall and widely spaced. In areas that are not previously forested or have few native trees, *Alnus* and *dapdap* are planted and serve as trellises. *Alnus* had been proven by farmers to enhance fruiting of Chayote since it can fix N and its litter is a good compost material. The litter contribution of the tree and the more broken type of crown favor the growth of the crop underneath. The higher C pool of this AF system is attributed to the tree component.

As vegetable production progress, the AF system incorporates more vegetable crops, thus, more trees are removed, more nutrients are extracted and the

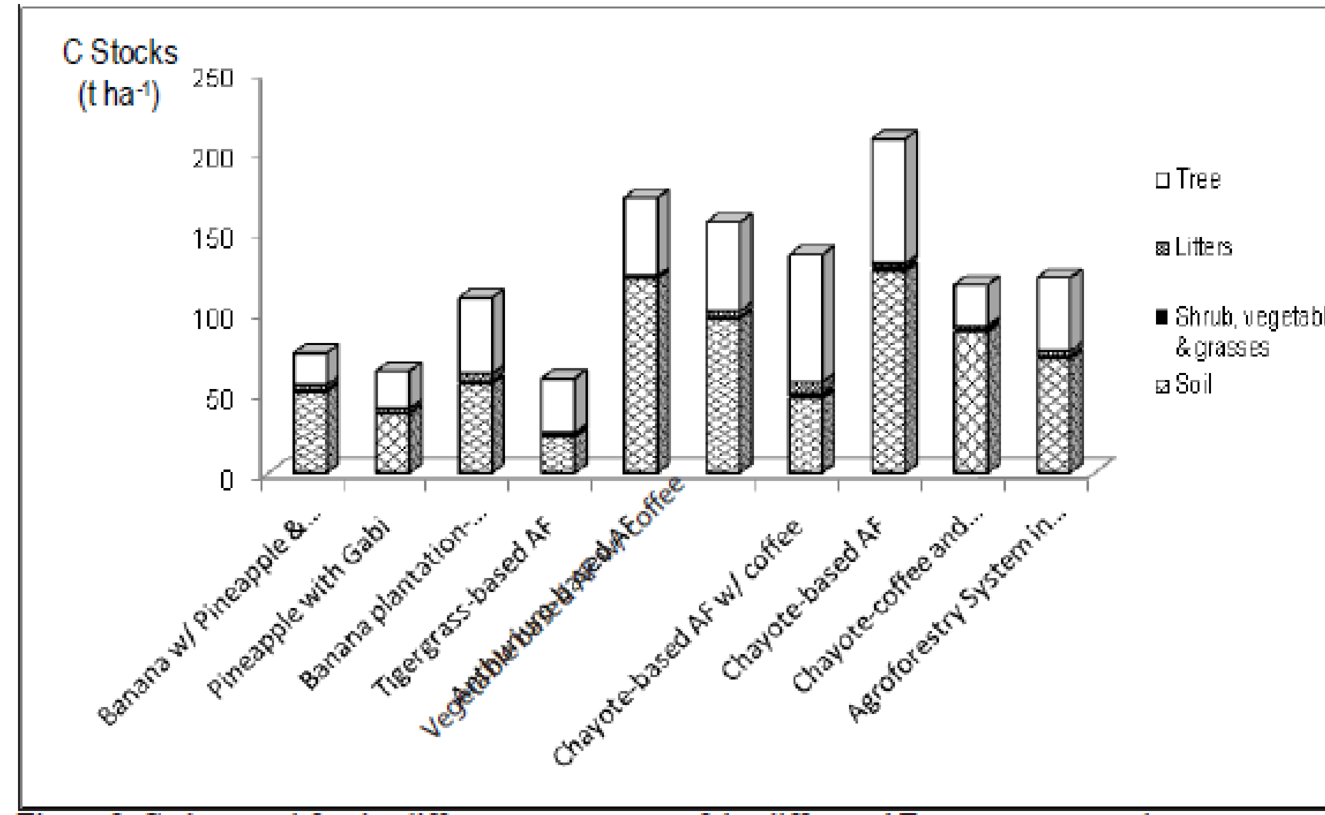

Figure 9. Carbon pool for the different components of the different AF systems surveyed

soil becomes more prone to erosion reducing the sustainability of the system. Further, the wood needs of the farmer (for lumber and post) require cutting of trees in their AF farms. Farmers address this by replanting. Thus, some areas have smaller diameter trees. Since chayote is a vine and wide spreading, the ground has minimal or clear understory vegetation. Further, due to poor penetration of sunlight, the area becomes more prone to erosion.

<u>The coffee-based agroforestry.</u> Next to chayote, the most integrated crop documented in agroforestry farms in Benguet is coffee. Benguet is known for its Arabica coffee that has excellent aroma and taste and is best grown under shade and cool climate. Other species/varieties also exist and are used in coffee mixes. Many coffee farmer cooperatives exist in the province considering this had been continuously promoted for planting under the high value crop of "AgriPinoy". Arabica is commonly grown in areas with high elevation, thus, it was mostly adopted by farmers in the Cordillera. Coffee, however also requires sufficient amount of light penetration.

Maintenance is a key factor in coffee-based AF system. In order to promote tree-coffee integration, regular pruning of trees, fertilization and at times rejuvenation of coffee trees are practiced by farmers to make it profitable.

Farmers should be encouraged to incorporate coffee in their AF farms since it can last for centuries though fruiting may decline. Further, woody component enhances the expansion of C pool for AF system. The coffee based AF had the highest C pool for understory because of this woody component.

<u>The anthurium-based agroforestry.</u> Anthurium based-AF is an evolving AF system. Since Benguet is also a cut flower capital, its promotion in agroforestry farm is a good opportunity to increase income. Anthurium is a shade loving plant. Shading promotes vigorous growth and flowering in anthurium. Since anthuriums are often contained in pots, it can be placed underneath multilayered-AF system as documented in Shilan, La Trinidad, Benguet. The AF system in the area does not only incorporates anthurium, but also other crops such as chayote, coffee, Spanish tomato, passion fruit, oranges, lemons, large leaf mahogany, Alnus, Palosanto, lychee and other fruit trees. Multi-layering allows more C storage in AF farms per unit area. In the evaluation of C stock in this area,

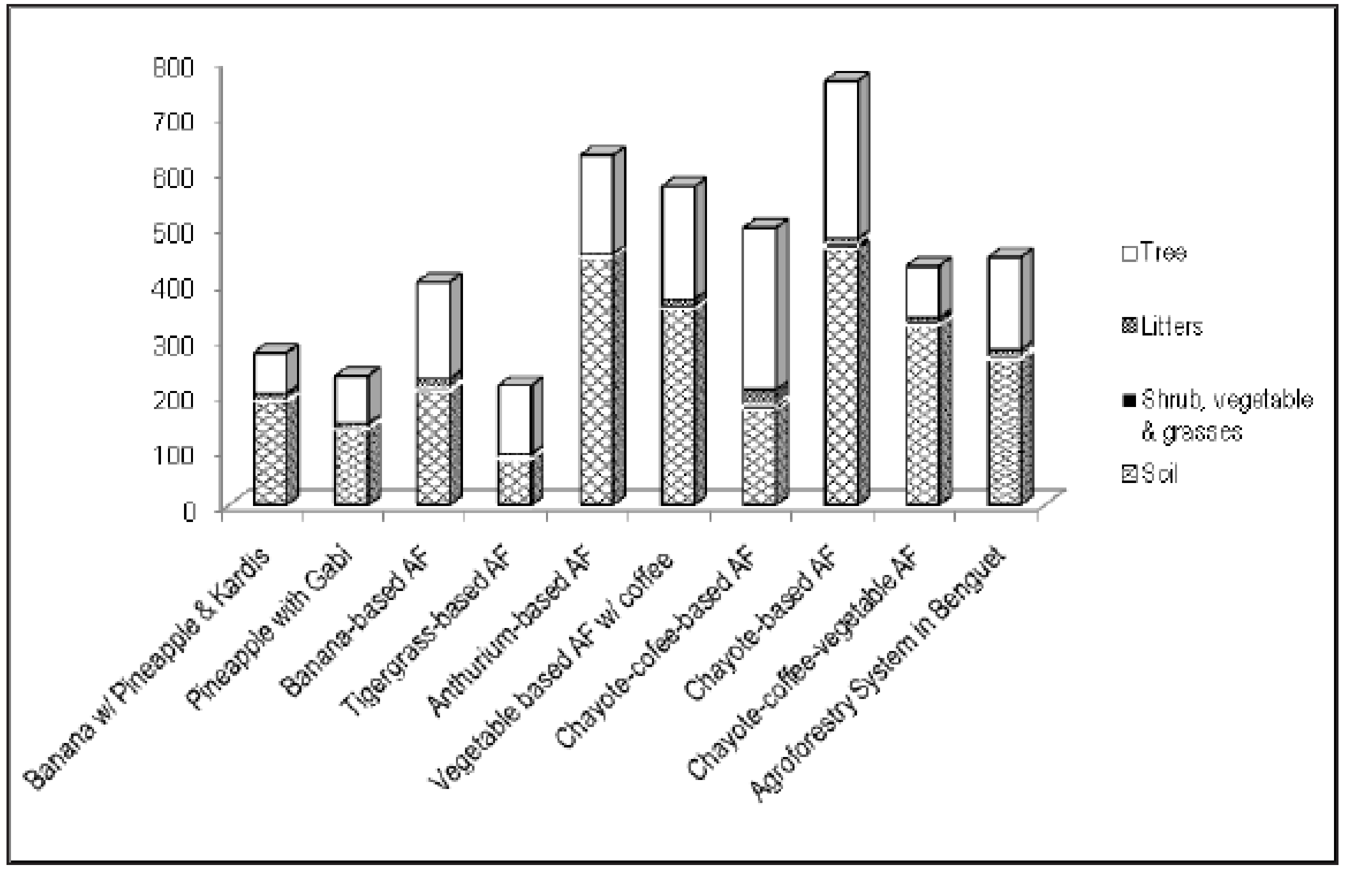

Figure 10. CO_2 sequestration potential of the different AF systems surveyed

trees in the AF farms are mostly of small diameter trees but many trees (21 trees/200 m^2) and crops are incorporated in the system.

AF systems practiced in lower elevations. In contrast to the first three AF system, the AF system of the low elevation areas of Benguet mostly used crops that are sun-loving such as tiger grass, rice and pineapple. Only trees that are of broken-type crown such as *Gmelina, Kakawate* (*Glericidia sepium*), *Ipil-ipil* (*Leucaena leucocephala*), breadfruit, guava, and *Akleng parang* (*Albizia procera*) are effectively incorporated in this AF system. Some shade tolerant crops such as yam and taro, banana, cassava, palms (Betel nut) and bamboos, spice plants like ginger, red chili, black pepper and betel leaves are documented and promoted for integration to increase income and C sequestration of the AF system. Unless trees are effectively incorporated just like in the banana-*Gmelina* AF system, C sequestration in this system is lower.

Least C stock was measured in rice farms as most of the tree crops integrated in this AF system are border perennial plants such as papaya, betel nut, Horseradish tree (*Moringa oleifera*) and Agati (*Sesbania grandiflora*). Only in the system that integrates upland rice can narrow crown trees are effectively incorporated such as bread fruit, coconut and Horseradish tree.

Practices in agroforestry that improves C sequestration in AF farms

Several practices were documented that improves the C sequestration of AF farms. Among these were: (1) the continued integration of trees, whether naturally existing in the area or planted, (2) employment of soil and water conservation measures and (3) the practice of multi-layering.

Efforts are being made by the farmers to maintain trees in their AF farms. Trees are utilized as living post, trellis and nurse trees. Based on the results, AF farms that undertake active planting, replanting, pruning, caring and protecting of these trees had more productive AF system in terms of CO_2 sequestration.

The practice of soil and water conservation

measures also helps improve C sequestration of the AF farms. Establishment of ripraps, contour canals, planting of trees and hedges of shrubs and grasses does not only help the farmer to maintain the productivity of the soil but help form better C sink.

Other than the agroforestry's potential to sequester CO_2, it allows multiple benefits such as provisions of income, food security, biodiversity resource conservation and maintenance of ecological structure and functionalities, the practice of agroforestry should continually be promoted in the province. Thus, AF systems in Benguet such as chayote, anthurium and coffee based AF systems which employed main crops that are shade tolerant and effectively integrate trees should continually be promoted in the province for greater C sequestration.

CONCLUSIONS AND RECOMMENDATIONS

Majority of the C pool of all the AF systems documented are stored in the soil and tree components of the agroforestry farms. Carbon from the soil forms the bulk of C pool followed by the tree component. Least C contents are found from the litter and understory vegetation. Soil organic C is highest in areas where fertility of the land particularly its organic matter is maintained.

The AF systems that has the high tree C sequestration consist of areas having tall or densely stocked trees, characterized by multi-layering and utilize fast growing trees species having broken type crown.

In terms of potential CO_2 sequestered by the AF system, the amount of CO_2 is as high as 764.11 t ha^{-1} in chayote-based AF and as low as 214.80 t ha^{-1} in tiger grass-based AF system. The CO_2 sequestration potential of the various AF systems in Benguet is in the following order:chayote-based AF>anthurium-based AF>vegetable with coffee AF>chayote-coffee AF>vegetable-chayote and coffee AF>banana-based AF>banana with pineapple and pigeon pea AF>pineapple with taro AF>tiger grass based AF. All these AF systems have at least 10% tree cover. CO_2 sequestration depends on the number, species and age and condition of trees. Multi-layering and presence of bigger and more number of trees may increase the amount of C sequestered by an AF farm.

Proper choice of the tree and main crops and its maintenance, the use of soil and water conservation measures, as well as the use of cultural management practices that promote the establishment of diverse and multi-layered AF systems are important in having a climate resilient AF system. These practices help maintain the productivity of the system and allow multiple benefits and maintenance of ecological structure and functionalities.

AF systems in Benguet should be continually promoted in the province for greater C sequestration. The following are further recommended:

1. AF farmers and the MAO's may be made aware of the importance of incorporating sufficient amount of trees in their farms as a response to the climate change impacts.

2. Both the tree and soil components may be protected and maintained in AF farms to improve C sequestration. This can be done by undertaking the following:

a. Encourage planting of more broken type crown trees that can be used as nurse trees and provide wood materials and environmental services such as soil and water conservation and maintenance of biodiversity resource;

b. Encourage cultural management techniques like pruning, multi-layering and training of crops that can help improve the productivity and sustainability of these AF systems.

c. Promote soil and water conservation techniques that maintain soil productivity and increase SOC.

d. Encourage incorporation of woody cash crops in AF farms; in mid elevation areas include cacao, various species of mountain tea, Chinese *malunggay*, Spanish tomato, edible tree ferns, betel nut and other native fruit plants while in low elevation areas, pigeon pea, cassava and woody vines for food can be added in order to enhance the C sequestration of the understory vegetation.

e. Promote planting of woody and shade tolerant trees such as coffee, Chinese *malunggay*, cacao, cassava and bamboos which allow more C storage in AF farms per unit area.

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