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Sustainability assessment of soil properties in *Coffea arabica* - based agroforestry systems of Atok, Benguet, Philippines

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Abstract

This study was undertaken in response to the little evidence and detailed analysis in literature to support claims that coffee-based agro forestry systems are sustainable. It studied the status of soil properties as affected by the farm elevation, species of shade trees and coffee ages in the Arabica coffee–based agro forestry systems in Atok, Benguet, Philippines. The split-split design was used. A total of thirty six (36) experimental plots were established where soil samples were obtained and subsequently analyzed in the soils laboratory of UPLB. Results show that, of the studied soil properties (NPK and OM contents, pH and Bulk Densities), only N is significantly affected by the species of shade trees, and only N and OM are significantly affected by the ages of coffee trees and the interactions of shade trees and coffee ages; all said soil properties are not significantly affected by the elevation of the farms. In addition, the status or level of NPK and OM contents, and soil pH are moderately sustainable, while soil BD is assessed to be highly sustainable. The average initial soil N is significantly higher in the following: 1) Plots with coffee-fruit trees combination, but significantly decreased at the end of the study and become comparable with that of the plots with coffee-Alnus combinations; 2) Plots with old coffee trees but decreased (together with that of the middle-aged) and become significantly lower than that of the younger (3-10 years) coffee trees where it increased;3) Plots with old coffee–Alnus combination which decreased but remain significantly higher at the end of the study; and4) Plots with young coffee–fruit trees combinations which even increased at the end of the study while the rest remained or decreased.

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Introduction

Sustainable agroforestry is a key tool identified by planners and upland community developers to mitigate deforestation and sustain development. In deforested countries where most remaining forests are protected and expansion areas are limited, growing coffee under the crown and among the trees are among the practical strategies (Mendez and Lovell, 2017). Arabica coffee grows well under partial shades (Bilag, 1985).

Upland areas like Benguet province and the rest of the Cordilleras are among the fragile areas where population pressure has inflicted so much environmental damage mainly through forest conversion into agricultural use. The high population growth causes an increasing demand for goods and services from our receding forests. Being the watershed cradle of Northern Luzon, deforestation in Benguet and other Cordillera provinces adversely affects its neighboring lowlands.As per DENR report, there were 771,616 hectares of forest in the Cordillera in 1997 but were reduced to 632,893 hectares in 2004,giving an average annual deforestation rate of 19,817.57 hectares within that period (Tacloy, 2012). Promoting sustainable agroforestry in the region as well as in other similarly vulnerable areas will restore environmental soundness and provide a sustainable livelihood. Agroforestry systems control soil erosion and maintain soil fertility while addressing other more pertinent livelihood concern of the rural dwellers (Chimphamba, 2010 and Syampungani, *et al.*2010).

A common agroforestry practice in the highlands of Benguet and other parts of Cordillera Administrative Region (CAR) is the growing of Arabica coffee (*Coffeaarabica*) under trees, usually Alnus or various fruit trees. The usual practice is planting of few to several coffee plants in the backyard integrated with agricultural crops and other fruit trees (The Agriculture Business Week, 2011). This coffee-based agroforestry system provides coffee for home consumption, generates significant income for the farmers, and promotes environmental soundness and biodiversity. Thus, it is widely being promoted as alternative source of income for the declining vegetable industry of Benguet (Macanes, 2006). However, there is a need to determine the sustainability of such agroforestry system. According to Torquebiau (1992), there is little evidence and detailed analysis in literature to support claims that multi-strata home gardens like coffee-based agroforestry are sustainable land-use system. This study aimed to augment the limited information as to the sustainability of soil properties under the Arabica coffee-based agro frestry systems. It specifically aimed to determine the effects of two elevation ranges, two types of shade trees and three coffee age groups to selected soil properties within one year duration, and the overall soil sustainability status.

Materials and methods

Study Site

Atok, the study site, is the number one Arabica coffee producer among the 13 municipalities of Benguet, Philippines (Benguet Provincial Agriculturist, 2016). Almost all coffee products of the municipality are harvested from Arabica coffee-based agroforestry systems. Atok is located in the heart of the province of Benguet. It is bounded by the municipalities of Kibungan and Buguias on the north, Kabayan and Bokod on the east, Kapangan on the west and Tublay on the south. It has a total land area of 22,385 hectares or 223.85 square kilometers.The terrain is generally mountainous which is occasionally affected by frost causing damages to agricultural crops.

The peak elevation is 2,400 meters above sea level (masl), located at barangays Paoay and Cattubo and the lowest elevation is 600 masl, located at Naguey proper. The municipality is characterized by two distinct seasons: wet from May to October and dry during the rest of the year. Heavy rainfall usually occurs from August to mid-September. Three of the main coffee producer barangays of the municipality were selectedas the study site, namely: Abiang, Todpac and Caliking (Fig. 1).

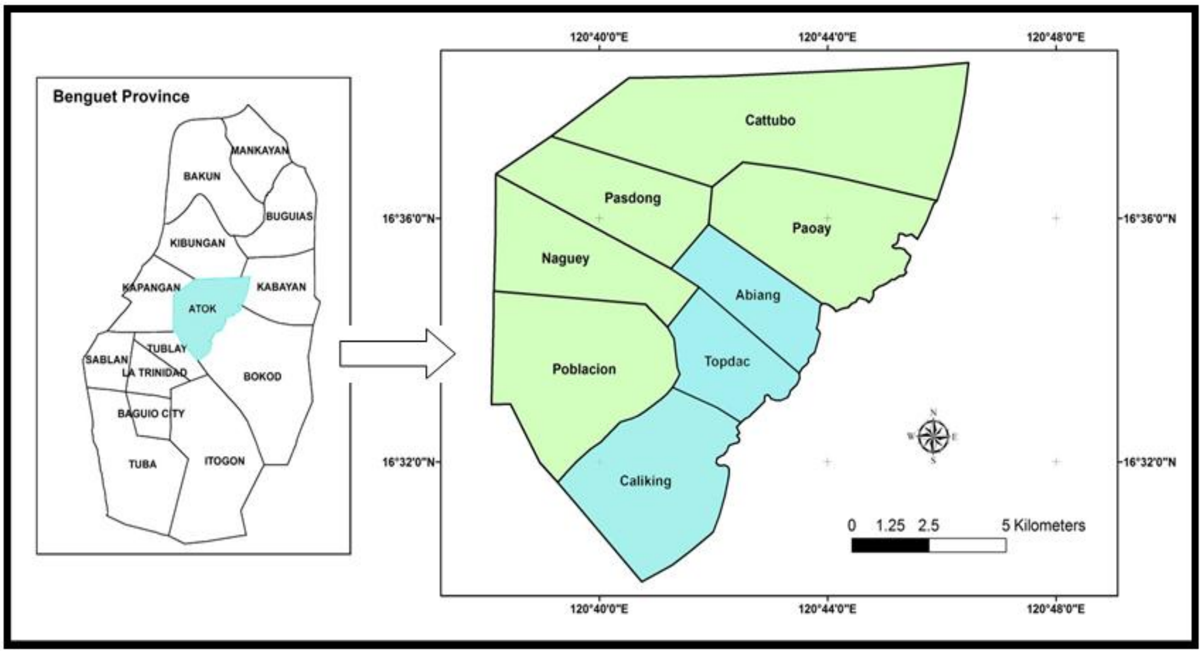

Fig. 1. Location map of the study area, colored blue.

Layout of the Study and Data Gathering

The split-split plot experimental design was used with three replications. The two elevation ranges (≤1,500 masl and >1,500 masl) are the main plot factors, the two types of nurse/shade trees of coffee (Alnus and fruit trees) are the subplot factors, and three coffee ages (3 to 10 years, 11 to 20 years and above 20 years old) served as the sub-subplot factors. A total of 36 10m x20m sub-subplots were established within the 3barangays (Table 1). Composite soil samples were obtained at the start and at the end of the study to determine any changes in total N, available P and exchangeable K,amount of OM, pH and soil BD. To determine the chemical properties of the soil, a soil sample within 0 – 30cm depth were collected using soil auger from three randomly selected areas within each sub-subplot. The samples were taken after scraping away the organic matter of the soil. The collected soil samples were air-dried, pulverized, sieved and mixed. From the resultant soil mixture, a kilogram sample for each representative agro forestry system were obtained and subjected to analyses at the soils laboratory of the University of the Philippines Los Baños (UPLB) at Los Baños, Laguna for the determination of N, P, K and OM contents and pH. The data obtained from the analysis of the soil samples.

Factor 1= Elevation; Factor 2= shade/nurse tree; Factor 3= Coffee agegathered at the beginning of the study were compared with those obtained from soil samples taken at the end of the study to determine the differences. The bulk densities were determined by core method. The fresh weights of soil samples weredetermined on site and the oven dryweights of the same samples were taken after oven drying them.

Statistical Analysis

To determine the effects of the different factors on selected soil properties, analysis of variance for split plot design was applied using SAS software. Tukey's test was used to test the level of significance between the treatment means and a likert scale was applied to evaluate the sustainability levels of the selected soil properties (Table 2). The statistical ranges for the descriptive ratings are the following: highly sustainable (2.50 – 3.00), moderately sustainable (1.50 – 2.49) and low or unsustainable (1.00 – 1.49). The average sustainability ratings of the soil properties were determined for each of the 36 experimental sub-subplots. Their grand means were consequently computed for each soil property as their final sustainability ratings.

Results and discussion

Soil Properties

The average initial soil N contents of the different plots range from 0.24% to 0.47% with a grand mean of 0.3508%; it slightly declined to a range of 0.22% to 0.47% and grand mean of 0.3308% at the end of the study (Table 3). This decline can be mainly attributed to nutrient uptake by crops. As Fisher and Binkley (2000) reported, the decline of N in a forest is most likely attributed to nutrient uptake by the plants.

Table 1. Layout of the experiment.

Replication I				Replication II				Replication III			
Block I		Block II		Block I		Block II		Block I		Block II	
A_1	A_2	A_1	A_2	A_1	A_2	A_1	A_2	A_1	A_2	A_1	A_2
B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1
B_2	B_2	B_2	B_2	B2	B_2	B_2	B_2	B_2	B_2	B_2	B_2
B_3	B_3	B_3	B_3	B3	B_3	B_3	B_3	B_3	B_3	B_3	B_3

Where: Block I = ≤ 1,500 meters asl elevation

Block II = >1,500 meters as l elevation

A_1 = Arabica coffee and Alnus integration

A_2 = Arabica coffee and Fruit trees integration

B_1 = 3 – 10 years old Arabica coffee

B_2 = 11 – 20 years old Arabica coffee

B_3 = above 20 years old Arabica coffee

Table 2. Rating scale used in evaluating the sustainability levels of selected soil properties within the Arabica coffee–based agro forestry system in Atok, Benguet

Soil properties	Highly sustainable (Rating=3)	Moderately sustainable (Rating=2)	Low/un-sustainable (Rating=1)	Reference
1. BD (g/cc)	< 1.05	1.06-1.35*	>1.36	Rachman, 1997
2. OM (%)	> 8.5	3.5 – 8.5*	< 3.5	Legada, 1998 & CSR FAO Staff, 1983
3. N (%)	> 0.75	0.21 – 0.75*	<0.21	CSR/FAO Staff, 1983
4. P (%)	> 35.0	15.0 – 35.0*	< 15.0	Legada, 1998 & CSR FAO Staff, 1983
5. K (%)	> 1.0	0.40 – 1.0*	< 0.40	Legada, 1998 & CSR FAO Staff, 1983
6. pH	5.6 – 6.6*	4.5-5.5 & 6.7-7.5*	<5.2 &>7.5	Sys *et al.*, 1993 & CIARC-DA-CAR, 2001

*Based on values or limits cited/recommended by the authors under the reference column; highly and low/unsustainable ratings were formulated based on these cited ratings.

Elevation did not significantly affect soil N while the types of shade trees,coffee ages and the interaction of both did. However, plots in the upper elevations registered a decrease, while those in the lower elevation registered an increase of soil N at the end of the study. This decrease and increase is most likely due to nutrient movement from higher to lower elevation by gravity and surface run-off. Practices changing vegetation or land use also influence soil pH. Wei, *et al.* (2013) reported that soil nitrogen generally decreases with elevation due to the change of vegetation into coniferous type which develop soil acidity (<6pH) that consequently restrict the growth of nitrogen-fixing organisms. This is not the case in the study area but farmer's practices like application of fertilizers can also change soil pH in their farms.

Table 3. Mean soil N content of the Arabica coffee-based agro forestry system in Atok, Benguet at the start of the study (initial) and after one year (final).

Treatments	Nitrogen (% OF ODW)		
Elevation:	Initial	Final	Difference
≤1,500masl (lower elevation)	0.34 a	0.36 a	-0.02
>1,500masl (upper elevation)	0.36 a	0.30 a	0.06
Arabica coffee-shade tree integration:			
Arabica coffee-Alnus tree integration	0.33 b	0.32 a	0.0067
Arabica coffee-fruit trees integration	0.38 a	0.34 a	0.0333
Arabica coffee age:			
3-10 years old Arabica coffee	0.38 b	0.39 a	-0.0092
11-20 years old Arabica coffee	0.28 c	0.25 c	0.035
>20 years old Arabica coffee	0.39 a	0.36 b	0.035
Arabica coffee-shade tree integration X Coffee age:			
Arabica coffee-Alnus:			
3-10 years old Arabica coffee	0.29 d	0.29 c	-0.005
11-20 years Arabica coffee	0.24 e	0.28 c	-0.04
>20 years Arabica coffee	0.46 b	0.39 b	0.065
Arabica coffee- fruit trees:			
3-10 years old Arabica coffee	0.47 a	0.49 a	-0.015
11-20 years Arabica coffee	0.33 c	0.22 c	0.11
>20 years Arabica coffee	0.33 c	0.33 b	0.005
Grand Mean	0.35^{ns}	0.33^{ns}	0.02

ns = not significant at 5% level

ODW = ovendry weight of soil

Note: Means with same letter in a column are not significantly different at 5% level by Tukey

Negative values means an increase, & no sign or positive means decline in the level of soil N content.

The initial average soil N under the coffee-fruit trees combination is significantly higher than that under the coffee-Alnus combination but at the end of the study, soil N under both types of shade trees did not significantly vary. The initial result could be attributed to the proximity of the coffee-fruit trees combination to the households. Being at the backyard of households, this system receives a steady source of kitchen and other organic wastes. The result at the end of the study could be attributed to the ability of the Alnus trees to add soil N through biological Nitrogen fixation replenishing some N amount utilized or lost.Similarly initial average soil N in plots with>20years old coffee is significantly higher than in plots with younger coffee trees. The significant difference could be due to more litter accumulation over time in the former due to the longer period of existence. Small and McCarthy (2005) found out that a matured (>125 years old) forest stand has significantly higher soil N than 10-year-old stand, and attribute it mainly to the accumulated litter production. However, at the end of the study, soil N in plots with 3–10 years old coffee trees increased and is significantly higher than those in plots with older coffee trees where it significantly decreased.

Soil N also decreased in plots with 11-20 years old coffee trees but not significantly. Furthermore, initial soil N in plots with 3-10 years old Arabica coffee under fruit trees is not only significantly higher but also increased and remained significantly higher than the rest at the end of the study.

Table 4. Mean soil P content of the experimental area at the start of the study and after one year.

Treatments	Phosphorous (ppm)		
Elevation:	Initial	Final	Difference
≤1,500masl (lower elevation)	15.00a	17.37a	-2.37
>1,500masl (upper elevation)	16.17a	15.13a	1.03
Arabica coffee-shade tree integration:			
Arabica coffee-Alnus tree integration	13.33a	14.67a	-1.33
Arabica coffee-fruit trees integration	17.83a	17.83a	0
Arabica coffee age:			
3-10 years old Arabica coffee	15.75a	20.50a	-4.75
11-20 years old Arabica coffee	14.25a	16.75a	-6.75
>20 years old Arabica coffee	16.75a	11.50a	4.13
Arabica coffee-shade tree integration X Coffee age:			
Arabica coffee-Alnus:			
3-10 years old Arabica coffee	14.00a	14.00a	0
11-20 years Arabica coffee	14.50a	24.00a	-9.50
>20 years Arabica coffee	11.50a	6.00a	5.50
Arabica coffee- fruit trees:			
3-10 years old Arabica coffee	17.50a	27.00a	-9.50
11-20 years Arabica coffee	14.00a	9.50a	4.50
>20 years Arabica coffee	22.00a	17.00a	5.00
Grand Mean	15.583^{ns}	16.25^{ns}	-0.67

ns = not significant

ODW = ovendry weight of soil

Note: Means with same letter in a column are not significantly different at 5% level by Tukey

Negative values means an increase in level of the soil Phosphorous property.

On the contrary, it is the initial and final soil N inplots with old (>20 years) coffee trees under Alnus that are significantly higher than the rest. Initial soil Nincreased in plots with 11-20 years old coffee trees under Alnus trees and become comparable with that of the plots with 3-10 years old coffee trees while the initial soil N remained the same at the end of the study in plots with 3-10 years under Alnus and in plots with >20 years old coffee trees under fruit trees. These variable results could be attributed mainly to the care and maintenance practices of the farmers. A number of farmers reported that they usually apply fertilizers during early establishment period of their farms. This practice would account for the higher and/or increase of soil N in plots with young coffee trees. In some farms, total clearing of undergrowth, including most of the litters was observed. This practice would result to the loss of soil N. The removal of litters and clearing of undergrowth would hasten soil erosion. On the other hand, some farmers pile litters or weeds under the trees and/or along contours and put some stakes to keep them in place – a soil conserving practice.

Soil P

Soil P ranges from 11.5ppm to 22ppm with a grand mean of 15.58ppm at the start of the study,and 6ppm to 27ppm with a grand mean of 16.25ppmat the end of the study (Table 4). The soil P increased and could have been contributed by litter production upon decomposition and precipitations. As explained by Fisher and Binkley (2000), the major sources of nutrients are from the atmosphere (e.g. addition through rainfall), decomposition of organic matter and weathering of soil materials and fixation. In addition, farmers usually apply fertilizers (e.g., NPK), especially in the establishment phase of their farms, or in areas with known poor soil condition or previously of low harvests. They apply fertilizers usually before coffee crop starts to flower in order to improve production. This practice can increase soil P level.

Table 5. Mean K content of the soil in the Arabica coffee-based agro forestry system in Atok, Benguetat the start and after one year of the study.

Treatments	Potassium (% OF ODW)		
Elevation:	Initial	Final	Difference
≤1,500masl (lower elevation)	0.54a	0.66a	-0.120
>1,500masl (upper elevation)	0.40a	0.38a	0.138
Arabica coffee-shade tree integration:			
Arabica coffee-Alnus tree integration	0.40a	0.39a	0.007
Arabica coffee-fruit trees integration	0.54a	0.64a	-0.108
Arabica coffee age:			
3-10 years old Arabica coffee	0.45a	0.50a	-0.055
11-20 years old Arabica coffee	0.53a	0.61a	-0.080
>20 years old Arabica coffee	0.43a	0.45a	-0.023
Arabica coffee-shade tree integration X Coffee age:			
Arabica coffee-Alnus:			
3-10 years old Arabica coffee	0.43a	0.46a	-0.030
11-20 years Arabica coffee	0.54a	0.54a	0
>20 years Arabica coffee	0.24a	0.19a	0.050
Arabica coffee- fruit trees:			
3-10 years old Arabica coffee	0.47a	0.54a	-0.070
11-20 years Arabica coffee	0.52a	0.68a	-0.160
>20 years Arabica coffee	0.62a	0.72a	-0.095
Mean	0.47^{ns}	0.52^{ns}	-0.051

ns = not significant

Note: Means followed by same letter in a column are not significantly different by Tukey

Negative values means an increase& positive or no sign means decline in level of the soil Potassium.

The elevation, type of shade trees and coffee ages did not significantly affect soil P. However, as with the soil N, soil P in upper elevation declined while it increased in lower elevation, which is can be attributed to downward nutrient movement caused by gravity and surface runoff. Faster decomposition rate in lower elevation due to higher temperature may be also a contributor to its Pincrease. The soil P under the coffee-Alnus agro forestry system increased at the end of the study.

If not due to fertilizer application by the farmers, this result may indicate that Alnus contributes to soil P build-up. In addition, soil P under the coffee-fruit trees integration system is higher than that under the coffee-Alnus system which could be attributed to the inflow of household organic wastes in the former.

The types of shade trees and coffee ages showed no significant interaction effect to the soil P. However, soil P decreased in plots with >20 years old coffee trees under both type of shade trees, while it either remained, decreased or increased in plots with3–10 and 11–20 years coffee trees.

Table 6. Mean soil OM of the experimental area at the start and after one year of the study.

Treatments	Organic matter (%)		
Elevation:	Initial	Final	Difference
≤1,500masl (lower elevation)	8.21a	8.46a	-0.2484
>1,500masl (upper elevation)	6.87a	6.62a	0.2516
Arabica coffee-shade tree integration:			
Arabica coffee-Alnus tree integration	7.56a	7.34a	0.2217
Arabica coffee-fruit trees integration	7.52a	7.73a	-0.2183
Arabica coffee age:			
3-10 years old Arabica coffee	9.21a	9.01a	0.2000
11-20 years old Arabica coffee	5.73c	7.37b	-0.2900
>20 years old Arabica coffee	7.67b	7.58b	0.0900
Arabica coffee-shade tree integration X Coffee age:			
Arabica coffee-Alnus:			
3-10 years old Arabica coffee	7.01b	6.95b	0.0600
11-20 years Arabica coffee	5.83b	6.91b	-1.0850
>20 years Arabica coffee	9.85a	8.16ab	1.6900
Arabica coffee- fruit trees:			
3-10 years old Arabica coffee	11.42a	11.08a	0.3350
11-20 years Arabica coffee	5.64c	5.13b	0.5150
>20 years Arabica coffee	5.49c	7.00b	-1.5100
Grand Mean	7.54^{ns}	7.54^{ns}	0.0016

ns = not significant

Note: Means followed by same letter in a column are not significantly different by Tukey

Negative values means an increase in level of the soil OM.

The increase in plots with younger coffee trees could be attributed to the generally more vigorous growth of the coffee trees resulting to higher litter production. On the other hand, the decline of soilP in plots with old coffee trees can be attributed to the generally less vigorous growth of old coffee trees and the greater amount of nutrients used by grown trees, significant part of which are used in fruiting that are being harvested and taken away from the agroforestry system.

Soil K

Soil K ranges from 0.24% to 0.62% with a grand mean of 0.47% at the start of the study, and from0.19% - 0.72% with a grand mean of 0.52% at the end of the study (Table 5).

In an Arabica coffee plantation in Papua, New Guinea, the soil K was 0.37% at the age of two, and increased to a range of 0.33% to 0.47% at the age of 30 years old (Clifford and Wilson, 1985). Like in N and P, this increase could be attributed to the accumulation and decomposition of organic matter within the agroforestry systems, together with the farmer's soil improvement and conservation practices. Soil K was not significantly affected by the elevation, type of shade trees, age of coffee crops, and the interaction of type of shade trees and age of coffee trees. However, as in N and P, soil K content decreased in upper elevation while it increased in lower elevation at the end of the study which is attributed mainly to downward movement of nutrients caused by gravity and surface run-off. Further, higher temperatures at lower elevations may result to higher organic matter production and faster decomposition and consequently, the release of more K.

Table 7. Mean soil pH of the experimental area at the start and after one year of the study.

Treatments	Acidity (pH)		
Elevation:	Initial	Final	Difference
≤1,500masl (lower elevation)	4.90a	5.10a	-0.200
>1,500masl (upper elevation)	4.97a	5.10a	-0.133
Arabica coffee-shade tree integration:			
Arabica coffee-Alnus tree integration	4.73a	4.80a	-0.067
Arabica coffee-fruit trees integration	5.13a	5.20a	-0.067
Arabica coffee age:			
3-10 years old coffee	4.90a	5.03a	-0.125
11-20 years old coffee	5.00a	4.93a	0.075
>20 years old coffee	4.90a	5.05a	-0.150
Arabica coffee-shade tree integration X Coffee age:			
Arabica coffee-Alnus:			
3-10 years old Arabica coffee	4.75a	4.80a	-0.050
11-20 years Arabica coffee	4.80a	4.80a	0
>20 years Arabica coffee	4.65a	4.80a	-0.150
Arabica coffee- fruit trees:			
3-10 years old Arabica coffee	5.05a	5.25a	-0.200
11-20 years Arabica coffee	5.20a	5.05a	0.150
>20 years Arabica coffee	5.15a	5.30a	-0.150
Grand Mean	4.93^{ns}	5.10^{ns}	-0.167

ns = not significant

Note: Means followed by same letter in a column are not significantly different by Tukey

Negative values means an increase in level of the soil pH.

Soil K is slightly higher in plots with coffee-fruit trees than those plots under in coffee-Alnus combination which can be attributed to the proximity of the former to households that supply organic wastes such as banana and other fruit peelings. According to Navasero-Gascon (1998), banana fruits contain high amount of K. Bananas are usually integrated with coffee in the backyard, providing the household banana fruits whose peelings are more likely be thrown back.

Soil K is also higher in plots with younger coffee trees than those in plots with older coffee trees (>20 years) which could be due to the greater plant uptake to support larger tree sizes in the later, and more fruits that are finally removed through crop harvests. This result has similarity with the report of Hosseinifard, *et al.* (2010) that the soil exchangeable K in a 40 year old pistachio (*Pistaciavera* L.) orchards is lower than that in the 10–year and 20–year old plantations. Under coffee-fruit tree systems, soil K is higher in plots with older coffee trees and increased under the three coffee age brackets at the end of the study.

The coffee-fruit tree system is commonly established in the backyard. Thus, the sustenance of soil in said system can be attributed to the sustained household wastes disposal. Under the coffee-Alnus tree system, soil K is lowest in plots with >20years old coffee trees and highest in plots with 11-20 years old coffee trees. It decreased in the former, remained the same in the later, while it increased in plots with 3-10 years old coffee trees at the end of the study. These variable results can be attributed mainly to the differences on the care and maintenance practices applied by farmers.

Table 8. Mean soil bulk density in the experimental plots under various treatments at the start (initial) and after one year (final) of the study.

Treatment	Bulk density (g/cc)		
	Initial	Final	Difference
Elevations:			
≤1,500masl (Lower elevation)	1.00a	0.85a	0.156
>1,500masl (Upper elevation)	0.97a	0.86a	0.107
Arabica coffee-shade tree integration:			
Arabica coffee plus Alnus	0.96a	0.84a	0.120
Arabica coffee plus Fruit trees	1.015a	0.87a	0.144
Arabica coffee age:			
3-10 years old Arabica coffee	0.97a	0.82a	0.150
11-20 years old Arabica coffee	0.98a	0.90a	0.086
>20 years old Arabica coffee	1.00a	0.85a	0.155
Arabica coffee-shade tree integration X Coffee age:			
Arabica coffee plus Alnus:			
3-10 years old Arabica coffee	0.96a	0.86a	0.093
11-20 years old Arabica coffee	0.94a	0.87a	0.071
>20 years Arabica coffee	1.04a	0.79a	0.249
Arabica coffee plus Fruit trees :			
3-10 years old Arabica coffee	0.98a	0.78a	0.207
11-20 years Arabica coffee	1.03a	0.93a	0.100
>20 years old Arabica coffee	1.04a	0.92a	0.124
Grand Mean	0.99^{ns}	0.85^{ns}	0.132

ns = not significant

Note: Means followed by the same letter in a column are not significantly different by Tukeys.

Soil OM

The initial average soil OM ranges from 5.49% to 11.42%with a grand mean of 7.54% at the end of the study; it ranged from 5.13% to 11.08% with similar grand mean as that of the initial (Table 6).

Although not significantly different, there is higher OM in plots at lower elevation than those at the higher elevation. Furthermore, OM increased in the former and decreased in the later after 1 year. Similar in N,P and K, this trend is primarily attributed to nutrient movement caused by gravity and surface run-off, and the higher litter production and faster decomposition rate at lower elevation due to warmer temperature. Buckman and Brady (1952) explained that decomposition of OM is accelerated in warm climates and lesser OM loss is the rule in lower regions.Soil OM also did not differ significantly between the two types of shade trees. However, it is higher in plots with coffee-Alnus trees, than that under the coffee fruit trees. It decreased in the former while it increased in the later at the end of the study.

On the other hand, OM significantly varies among coffee ages and as affected by the interaction of type of shades trees and coffee ages. Plots with younger coffee trees

It decreased at the end of the study but remained significantly higher than the rest. It can be construed that there is high OM in these plots prior to coffee farm establishment as the shade trees are already fully established and/or organic fertilizers were applied.

Table 9. Average sustainability rating of soil properties within the coffee-based agro forestry system in Atok, Benguet.

Parameter	Sustainabilityrating	Descriptive equivalent
Soil properties		
a. Nitrogen	1.94	Moderately Sustainable
b. Phosphorous	1.50	Moderately Sustainable
c. Potassium	1.75	Moderately Sustainable
d. Organic Matter	2.08	Moderately Sustainable
e. pH	2.00	Moderately Sustainable
f. Bulk Density	2.90	Highly Sustainable
Average	2.03	Moderately Sustainable

Legend: 2.50 – 3.00 – Highly Sustainable (HS); 1.50 – 2.49 – Moderately Sustainable(MS);1.00 – 1.49 – Low/Unsustainable (L/US).

The least initial OM was recorded in plots with middle aged coffee trees but it significantly increased becoming comparable with that in plots with old coffee trees. This significant increase of OM can be attributed to the soil conserving farmer's practices, pruning conducted and the higher litter production of the coffee trees as they are about to attain or have attained their optimum growth. Being of the lowest initial OM can be due to mismanagement or farmer's neglect.

Initial OM in plots with the old coffee trees was significantly higher than that in plots with middle-aged coffee trees, but declined at the end of the study together with that in plots with young coffee trees. Mineralization, leaching and utilization, as well as farmer's practices such as cleaning and burning could be the causes of the decline.

Under coffee-Alnus combination, plots with younger coffee trees (3-10 and 11-20) have significantly lower OM than in the oldest stand while under the coffee-fruit tree system, plots with young coffee trees (3-10 years old) have significantly higher OM than those with older trees. In the former, OM decreased in plots with young and old coffee trees while it increased in plots with the middle-aged coffee trees, resulting to insignificant differences at the end of the study. In the later, OM decreased in plots with young and middle-age coffee trees while it increased in plots with the old coffee trees, but remained significantly higher in plots with young coffee trees. This undefined pattern of OM differences and changes can be due to various factors and their interactions which are responsible in the inflow and outflow of nutrients in the system. Variations of farmer's practices are considered as a major factor in this case. A practice observed that removes OM is the leaf litter collection (especially Alnus) by farmers for cut-flower production. Farmers learned that Alnu sleaves are rich in N and easily decomposed, thus it is a common practice in the locality to collect these as a growing media for cut-flowers like anthurium.

Soil pH

The initial and final soil pH values in the experimental plots do not significantly vary, but generally increased after one year from 4.93 to 5.1 (Table 7). This soil pH is within the range recommended for Arabica coffee production. Robinson (1964) recommended a pH range of 5.2 to 6.2 while Acl and (1971) recommended a soil pH range of 5.3 to 6.0 for coffee growing. Clifford and Wilson (1985) explained that coffee crops can grow on soils with varying pH ranging from extremely acidic (ph below 4.0) to slightly alkaline (pH up to 8.0) but neither of these extremes is suitable for economically high output production; a slightly acid soil is preferred. The data show that plots with Alnus as shade trees have lower pH (more acidic) than those with fruit trees as shade trees. This can be attributed to the original vegetation of the farm that includes Benguet pine prior to its conversion in to coffee-Alnus agro forestry system. Pine or coniferous forest makes soil acidic. The data also shows that elevation and coffee ages did not significantly affect soil pH.

Soil BD

The initial mean soil BD range from 0.94 g/cc -1.04 g/cc with a grand mean of 0.99g/cc;it decreased to a range of 0.78 g/cc -0.93 g/cc and a grand mean of 0.85 g/c cat the end of study (Table 8).The low soil BD values are indicative of a loose soil in the agro forestry system. In contrast, there is high BD values (1.35 g/cm^3) in rice and rice-corn farms which could be attributed to compaction during tillage and low OM content (Navasero-Gascon, 1998).

The decrease in BD indicates loosening of the soils which could be attributed to the production and decomposition of forest litters and activities of soil organisms. Achutan Nair and Sreedharan (1986) observed that owing to good nutrient cycling and use of organic waste materials in the home gardens in Kerala, India, the soil physical and biological characteristics are improved, and rhizosphere microbial activity is high. Incorporation of OM decreases the BD of soil as its granulation effect Results showed that elevation, type of shade trees and age of coffee trees did not affect significantly the soil BD. However, the initial soil BD in plots with 3–10 years old coffee trees is lower than those with older (11-20 or >20 years old) coffee trees, which could be due to cultivation by farmers done until full establishment of the coffee crops. The spaces in between the coffee and shade trees are usually planted with cash crops while the crown canopies allow enough sunlight. Farmer's practices that affect soil BD include the soil physical alterations by leveling, cultivation, terracing, organic fertilizer application and compaction (due to trampling by both man and domesticated animals or weight of implements/equipment/tools used).Also, plots with coffee under Alnus showed lower initial average BD, including the final average BD in plots with 11-20 years and >20 years old coffee trees than those under the coffee-fruit trees system. This lower BD's can be at tributed to the higher litter production and faster decomposition rate of Alnus.

Sustainability Assessment of Soil Properties in Arabica

Coffee-Based Agroforestry System

The sustainability ratings of soil properties in Arabica coffee-based agro forestry systems of Atok, Benguet are presented in Table 9.The study areas obtained an overall average weighted mean (AWM) of "2.03" or "moderately sustainable". The computed AWM's are 1.94 for N, 1.5 for P,1.75 for K, 2.08 for OM, 2.0 for pH, and 2.89 for BD; all have descriptive equivalent of moderately sustainable, except BD which is highly sustainable. These results imply a good opportunity to further improve the N, P, K and OM contents, and pH of the evaluated coffee-based agroforestry systems to further increase their productivity. Application of appropriate and ample fertilizers and soil conservation measures canim prove the soil fertility and productivity of the farms. As mentioned by Umali-Garcia (2010), theloss nutrients need to be replenished artificially through addition of fertilizers in agricultural cultivation and agro-forestry systems. The soil conservation practices of the farmers can be improved through the introduction of the hedgerows technology as that in Sloping Agricultural Land Technology, witling and fascine.

These measures are not observed in the area.

Conclusions and recommendations

Among the soil proper ties studied, N and OM levels/status are the most significantly changing as affected by the species of shade trees and ages of coffee trees, modified by the farmer's management practices, as well as undetermined environmental factors, and their interactions. Overall, the status of these soil properties made the agroforestry systems productive and sustainable to a level that can be further improved.

Adoption and promotion of the agroforestry systems is highly recommended. The soil conserving practices of the farmers should be identified and promoted. These practices could be further augmented by the introduction of practices not observed in the area such as hedgerow establishment as that in the Sloping Agricultural Land Technology, wattling, fascines, etc. Farmers' seminar-training can help address this need. Further study of the plots to determine the causes of the decline or increase or improvement in the soil properties is desirably undertaken to further understand the dynamics of the system and device a more sustainable and productive Arabica–coffee based agroforestry systems.

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Appendix

Photos above showing the *Coffea arabica*- Fruit trees combination or agroforestry system at the study site in Atok, Benguet, Philippines.

Coffea arabica- Alnus tree agro forestry system with integrated cash crops by the farmers in the study site

Core method used during data gathering to obtain the Bulk Density (BD) of the soil within the Coffee-Based Agro forestry Systems in Atok, Benguet, Philippines