Sustainability Assessment of the Production, Decomposition Rate and NPK Content of Litterfall under the *Coffea arabica*–Based Agroforestry Systems in Atok, Benguet, Philippines

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ABSTRACT

The study assessed the sustainability of coffee-based agroforestry systems in Atok, Benguet based on litterfalls. Data on the litter production, decomposition rate and NPK contents from 36 established experimental plots following the split-split plot design were gathered and analyzed. Sustainability levels were assessed using a Likert scale derived from published threshold levels. Analysis of data showed that average litter production was 10.585.2 t/ha/yr with a range of 4.421 to 17.65 t/ha/yr and was not significantly affected by elevation, type of shade trees and coffee ages. The average monthly litter decomposition rate was 4% and was significantly higher under the coffee-Alnus combination than those under the coffee-fruit trees. The average nutrient contents were 1.75% N, 0.14ppm P and 0.80% K, equivalent to an annual return of nutrients at an average of 185.51 kg/ha N, 28.50 kg/ ha P and 85.39 kg/ha K. Only the N contents of the litters were significantly affected by the type of shade trees. Sustainability levels of litter production, decomposition rate, and NPK contents based on the computed average weighted means (AWM) were moderate to high with an overall AWM of 1.61 or “moderately sustainable”.

Keywords: *litter production & decomposition, NPK content, sustainability*

INTRODUCTION

Sustainable agroforestry systems are key tools identified by planners and upland community developers in mitigating deforestation. Mendez and Lovell (2007) reported that in deforested countries where most remaining forests are protected and expansion areas are limited, it makes sense to promote integration of shade trees and coffee as a conservation strategy. In the eastern part of Ethiopia, most farmers traditionally grow coffee as an important cash crop under shade trees (Teketay and Tegireh, 1991). Thus, farmers are encouraged to plant trees and protect the remaining areas to grow coffee.

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. Being the watershed cradle of Northern Luzon, deforestation in the Cordillera provinces needs to be reversed as this adversely affects the neighboring lowlands. MNR (1983) as cited by Baconguis and Ranes (1993) explained that degradation of upland ecosystems threatens infrastructure development in the lowlands by siltation, flooding and poor water quality resulting from erosion.

As per DENR report, there were 771,616 hectares of forests in the Cordillera in 1997 but has been reduced to 639,893 hectares in 2004. This translates to a deforestation rate of 18,817.57ha/year (Tacloy, n.d.). In 2001, DENR reported that Mt. Data and Balbalasang-Balabalan National Parks were heavily encroached. Their status as a National Park was recommended for cancellation as it no longer served such purpose. The former, which includes a considerable part of Atok, Benguet has only 639 hectares of forest remaining or 11.6% of its total area; 83.6% were converted for use in agriculture and 4.8% were converted as settlement areas (Bayagen, 2005). To help restore the damaged ecosystems and spur economic development, agroforestry land-use systems have to be vigorously promoted.

One agroforestry system in the highlands of Benguet and other parts of the Cordilleras is the growing of Arabica coffee (locally known as "native coffee" or "Benguet coffee") under trees, usually Alnus and various fruit trees. The usual practice is planting a few to several Arabica coffee trees in the backyard, integrated with agricultural crops and other fruit trees. This has made coffee a backyard crop in the Cordillera (The Agriculture Business Week, 2011). About three to ten coffee trees are maintained as backyard crops (Domoguen, 2009). This Coffee-Based Agroforestry System generates income for the farmers when they sell their harvest, and/or enable them to save money when they use their produce for home consumption instead of buying coffee from the market. Tabangcura (2011) reported that an estimated 50% of Arabica coffee produced by farmers in the Cordillera is stored for home consumption and the rest are sold in the market. Furthermore, this agroforestry system promotes environmental soundness and biodiversity, thus is widely advocated by agriculture and forestry experts as an alternative source of income for the vegetable industry of Benguet Province (Macanes, 2006).

With the use of this system, farmers are encouraged to protect their remaining forests and to plant and maintain trees as shade for growing coffee. Shade or nurse trees improve soil fertility and productivity by returning large amounts of litters to the soil, promote biological nitrogen fixation and increase soil and moisture conservation. According to Yadessa *et al.* (2008), all shade trees used for coffee in the agroforestry system contribute to organic matter through litterfall and pruning residues. Related to this, the nutrients released annually from organic matter from shade tree litter can support the production of one ton coffee beans, thus, the higher the nutrient release, the higher the coffee yield (Beer, 1988).

Promoting agroforestry in such areas as well as in other threatened areas likewise contributes in restoring environmental soundness and in providing a sustainable livelihood if vigorously sustained. The use of Agroforestry is a soil erosion control, helps in the maintenance of soil fertility and provides a sustainable livelihood to rural upland dwellers (Chimphamba, 2010 and Syampungani *et al*. 2010).

Tropical multi-strata or tree home gardens are classically said to be sound, efficient and sustainable land-use systems, however, there is little quantitative evidence of detailed analysis of tree home gardens in literature that supports this claim (Torquebiau, 1992). For the Arabica coffee-based agroforestry systems in the Cordillera, data on Arabica coffee-Alnus is wanting as reported by the Cordillera Integrated Agricultural Research Center, Department of Agriculture - Cordillera Administrative Region (DA-CAR) (2001). There is a need to study nutrient production and conservation, among others, towards the development of management strategies to further improve production. This study has been proposed to help respond to data/ information gaps.

Objectives of the Study

The study assessed the sustainability of the Arabica coffee-based agroforestry systems in the municipality of Atok, Benguet based on nutrients returned to the soil via litter production. It specifically aimed to determine the effects of elevation range, types of shade trees, age of Arabica coffee trees and their interactions with the production, decomposition rate and NPK contents of litters; amount of NPK returned to the soil via litterfalls, and decomposition rate and NPK contents of litter; and sustainability levels of litter production, decomposition rate and NPK contents of the Arabica coffee – based agroforestry system in Atok, Benguet.

METHODOLOGY

Locale and Time of the Study

The study was conducted in three barangays of the municipality of Atok, Benguet, namely;

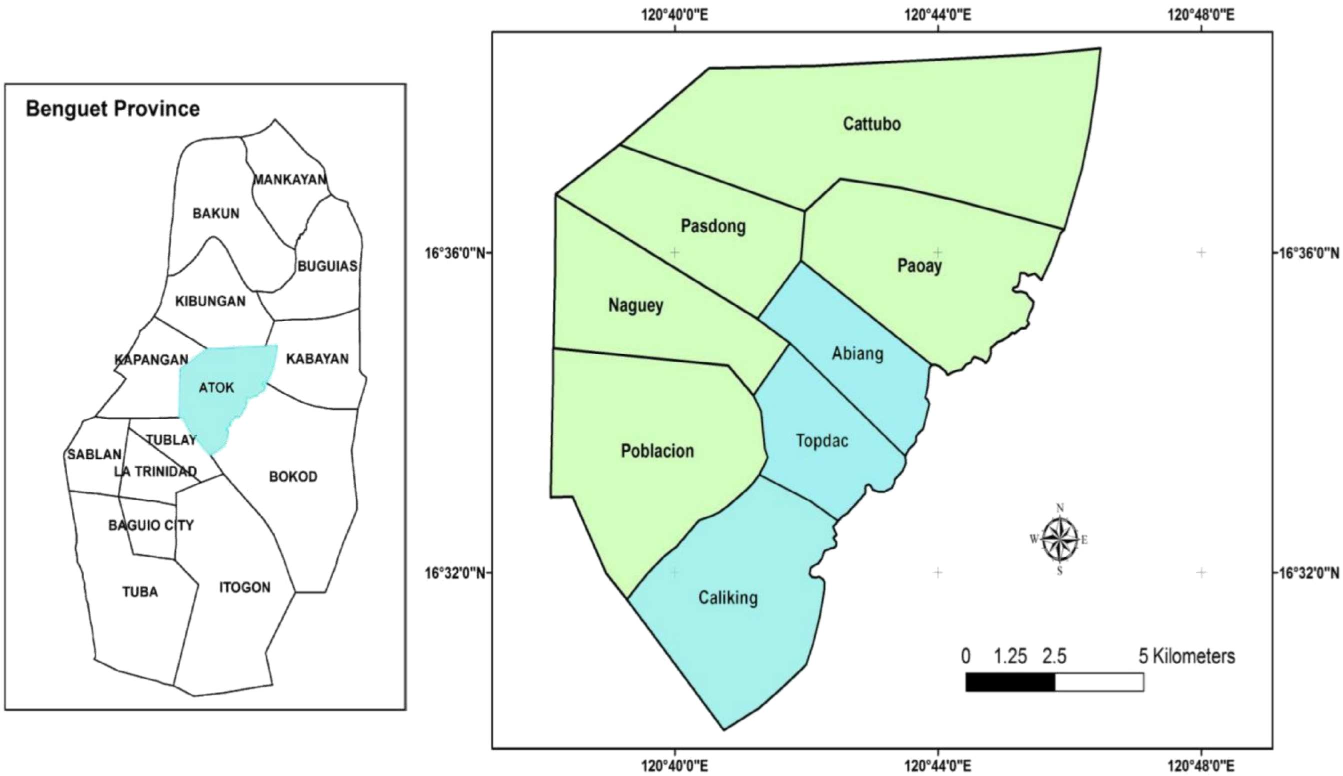

Figure 1: Location map of Atok, Benguet and the barangays covered by the study (colored blue)

Abiang, Caliking and Topdac (Figure 1) from January to December 2013. These three barangays adjoin each other and are considered the major Arabica coffee producers of the municipality.

The Study Site

Atok is considered the number one Arabica coffee producer among the 13 municipalities of the Province of Benguet, Philippines. The Office of the Benguet Provincial Agriculturist (2014) reported that Atok has an annual production of 41,633.99 kg coffee beans, followed by Itogon and Tublay with annual production of 27,960 kg and 24,293 kg, respectively. Atok is centrally located in the province of Benguet, bounded by the municipalities of Kibungan and Buguias on the north, the municipalities of Kabayan and Bokod on the east, the municipality of Kapangan on the west and the municipality of Tublay on the south.

Atok has a total land area of 22,385 hectares or 223.85 square kilometers and a peak elevation of 2,400 meters above sea level located in barangays Paoay and Cattubo. The lowest elevation is 600 meters above sea level, located at Naguey Proper. The terrain is generally mountainous and is occasionally affected by frost in the highly elevated areas.

The municipality falls under climatic type I, 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.

Design and Layout of the Study

The experimental set-up followed the split-split plot design with elevation ranges (≤1,500 masl and >1,500 masl) as main plot factors; two types of shade trees (Arabica coffee plus Alnus and Arabica coffee plus fruit trees) as subplot factors; and three coffee age ranges (3 to 10 years, 11 to 20 years and above 20 years old) as sub-subplot factors (Figure 2). Among the common fruit trees identified within the areas grown with Arabica coffee are fruit tree combinations such as avocado, banana, "suha", citrus, guava, "kaimito", etc. A total of 36 sub-subplots measuring 10m x 20m were established within the covered barangays.

Replication I				Replication II				Replication III			
Block I		**Block II**		**Block I**		**Block II**		**Block I**		**Block II**	
A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2
B1	B1	B1	B1	B1	B1	B1	B1	B1	B1	B1	B1
B2	B2	B2	B2	B2	B2	B2	B2	B2	B2	B2	B2
B3	B3	B3	B3	B3	B3	B3	B3	B3	B3	B3	B3

Figure 2. Layout of the experiment

Where:
- Block I = ≤ 1,500 meters asl in elevation
- Block II = >1,500 meters asl in elevation
- A1 = Arabica coffee and Alnus integration
- A2 = Arabica coffee and fruit trees integration
- B1 = 3 – 10 years old Arabica coffee
- B2 = 11 – 20 years old Arabica coffee
- B3 = above 20 years old Arabica coffee

The parameters used and the methods of measurement were as follows:

PARAMETERS	METHODS OF MEASUREMENT
Litter Production	A litter trap made of fine nylon-mesh measuring 1m x 1m was installed in each experimental sub-subplot (Figure 3). The trapped litters of shade and coffee trees were collected every end of the month from January 2013 to December 2013, segregated by sub-subplot, and oven dried at 70°C. The oven-dried weights were determined using a digital weighing scale.
Litter Decomposition	Fifty (50) grams litter samples from each sub-subplot were placed in a litter bag made of nylon mesh measuring 1ft^2 and then pinned to the forest floor to decompose (Figure 4). The procedure was adopted from that of Cuevas (1978). The changes in weight of the samples were monitored every 15th and 30th day of each month for seven months. Decomposition rates were determined using the formula used by Luna (1998) as follows:

WL = W1 – W2; where: WL= Weight loss (g);
W1= Initial dry weight of sample in the litterbag (50g); and
W2= Final dry weight of sample in the litterbag (g)

Figure 3: Litter trap installed within Arabica coffee-based Agroforestry system

Figure 4: Litter samples (50g) in nylon bags installed under the Coffee-based Agroforestry system for decomposition rate determination

Litter NPK Content

Separate litter samples were oven-dried and pulverized. Fifty grams of pulverized litters were taken from each treatment, placed in cellophane bags and brought to the laboratory for NPK content analysis. The amount of nutrients released was determined using the formula developed by Luna (1998) as follows: ANR = Dw x Nc, where:

ANR = Amount of nutrient released (g)
Dw = Total oven dry weight of litter sample (g)
Nc = Nutrient concentration (%)

Figure 5: Air drying of collected leaf litters for laboratory analysis

Analysis of Data

Statistical Analysis

The data were analyzed using ANOVA for split-split plot design. On the other hand, data on NPK contents were analyzed using split plot design. The levels of significance were determined using the Bonferroni test. The level of sustainability was computed using Average Weighted Means (AWM).

Sustainability Evaluation

To evaluate the sustainability of litter production, decomposition rate and NPK contents, a Likert scale was used (Table 1). The baseline values for the Likert scale were based on the results of previous studies in terms of ecological requirements of coffee.

Table 1. Likert scale for the parameters used to evaluate the sustainability levels of litter production, decomposition rates and NPK contents in Arabica coffee – based agroforestry systems of Atok, Benguet

PARAMETER	HIGHLY SUSTAINABLE (RATING=3)[a]	MODERATELY SUSTAINABLE (RATING=2)[b]	LOW/ UNSUSTAINABLE (RATING=1)[a]	REFERENCE
a. Litter production (kg/ha/yr)	> 50	>25 – 50	≤ 25	Beer, 1988
b. Litter decomposition rate per year (%)	> 15	10– 15	< 10	Connel and Sankaran, 1997
c. Litter content				
i) N content (%)	> 3.0	2.6– 3.0	< 2.6	Nagao, *et. al*, 1986
ii) P content (ppm)	> 0.17	0.14 – 0.17	< 0.14	-do -
iii) K content (%)	> 2.50	1.90 – 2.50	< 1.90	-do -

a = Based on the ratings used by Barcellano (2005)
b = Based on values or limits cited/recommended by the authors under the reference column; the highly sustainable and low/unsustainable levels were formulated

RESULTS AND DISCUSSIONS

Litter Production

Litter production in the coffee-based agroforestry system in Atok, Benguet averaged 10.585.2 t/ha/yr based on oven dry weight with a range of 4.421–17.650 t/ha annually (Table 2). Total litter production can be between 5 - 20t/ha/yr, including the trimmings from pruning operations for both shade and crop trees (Beer, 1988 as cited by Gascon, 1994). The recorded rate of litterfall in the study site was within the range reported by the latter and a little bit higher than the value reported by the former. Litter production in the study site was high during the rainy season, most especially during the occurrence of typhoons, and low, during dry season (Figure 6). This is in contrast to the report of Hayashi *et al.* (2012) where litterfall was observed to have the highest rates during the

Table 2. Mean litter production in the Arabica coffee-based agroforestry systems in Atok, Benguet

	TREATMENT	MEAN LITTER PRODUCTION (T/Ha/Yr)
A. Elevations:	≤1,500masl (lower elevation)	10,668.8a
	>1,500masl (upper elevation)	10,501.7a
B. Arabica coffee-tree integrations or agroforestry:		
	Arabica coffee plus Alnus	11,553a
	Arabica coffee plus fruit trees	9,617.4a
C. Arabica coffee age:	3-10 years old A. coffee	9,376.1a
	11-20 years old A. coffee	10,954.5a
	>20 years old A. coffee	11,062.2a
D. ≤1,500masl:	Arabica coffee plus Alnus	11,189.2a
	Arabica coffee plus fruit trees	10,148.3a
>1,500masl:	Arabica coffee plus Alnus tree	11,916.9a
	Arabica coffee plus fruit trees	9,086.5a
E. ≤1,500masl :	3-10 years old Arabica coffee	8,753.15a
	11-20 years Arabica coffee	12,083.10a
	>20 years Arabica coffee	11,170a
>1,500masl:	3-10 years old Arabica coffee	9,999.08a
	11-20 years Arabica coffee	9,825.80a
	>20 years Arabica coffee	11,680.2a
F. Arabica coffee plus Alnus:		
	3-10 years old Arabica coffee	9,895.95a
	11-20 years old Arabica coffee	12,364.3a
	>20 yrs Arabica coffee	12,398.9a
Arabica coffee plus Fruit trees :		
	3-10 years old Arabica coffee	8,856.3a
	11-20 years Arabica coffee	9,544.63a
	>20 years old Arabica coffee	9,895.95a
G. ≤1,500m asl X Arabica coffee plus Alnus:		
	3-10 years old Arabica coffee	8,468.67a
	11-20 years Arabica coffee	12,781.7a
	>20 years Arabica coffee	12,317.1a
≤1,500m asl X Arabica coffee plus fruit trees:		
	3-10 years old Arabica coffee	9,037.63a
	11-20 years Arabica coffee	11,384.5a
	>20 years Arabica coffee	10,022.9a
>1,500masl X Arabica coffee plus Alnus:		
	3-10 years old Arabica coffee	11,323.2a
	11-20 years Arabica coffee	11,946.9a
	>20 years Arabica coffee	12,480.6a
>1,500masl X Arabica coffee plus fruit trees:		
	3-10 years old Arabica coffee	8,674.93a
	11-20 years Arabica coffee	7,704.73a
	>20 years Arabica coffee	10,879.8a
	GRAND MEAN	**10,585.2**

Note: Means followed by same letter are not significantly different at 5% level by Bonferroni

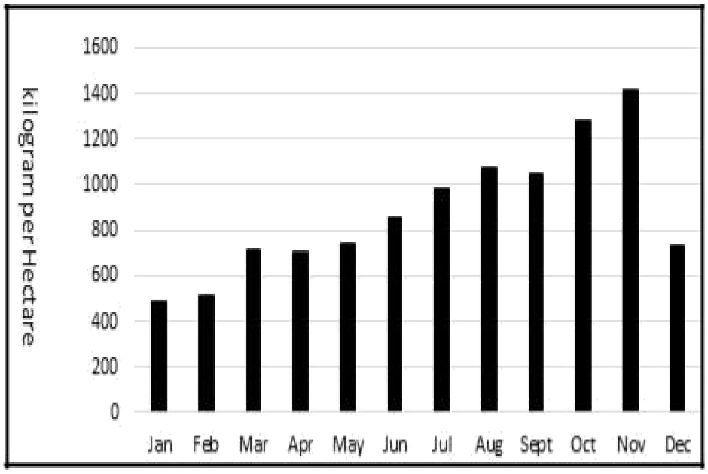

Figure 6. Average monthly litter production within the one-year study period

dry season and lower rates during the wet season in all forest age classes. Dropping of old leaves and the production of a flush of new leaves before the end of the dry season in evergreen forests is common, however, in this study, higher litterfall was observed especially during the occurrence of typhoons that caused increase in litter production.

Effect of elevation. Elevation has a direct correlation to temperature. Temperature decreases with increase in altitude. A fall of 1°F in temperature results from a rise of 300 feet (Chang, 2007). The annual average litter production in the experimental plots at lower elevation was higher than that at upper elevations. The higher temperature results to faster growth of vegetation due to higher litter production. This result conforms with the report of Lu and Liu (2012) that annual litterfalls of evergreen hardwoods in Central Taiwan decreases with the increase in elevation, and that the total litterfall is correlated positively with temperature and rainfall conditions.

Effect of shade trees. The average annual litter production in plots with Alnus as shade trees was higher than those with fruit trees at both upper and lower elevations. Alnus is a fast-growing, semi-deciduous evergreen tree producing huge litterfalls (Aussie Gardening, 2015). Some fruit trees, however, produce huge litters, most especially during fruiting season. This may be one of the reasons for the insignificant difference of the quantity of annual litter production under the two types of shade trees.

Effect of coffee tree age. The highest amounts of litterfalls were recorded in plots with more than 20 year old coffee trees, followed in descending order by those in plots with 11-20 years old trees, and those with 3-10 years old coffee trees. The higher litter production under older agroforestry systems is the result of the larger sizes of older trees. Hayashi *et al.* (2012) reported that litter production in mature forests is higher (9.82 t/ha/ yr) than in 6-year old forests (7.37 t/ha/yr).

Factor interaction effects. The analysis of the interaction of the experimental treatments (elevation, type of shade tree and age of coffee trees) indicated complicated results. In order to understand said effects, it is necessary to consider other modifying factors such as the stem and crown densities, species, and health and structure of plants in the study area. Scherer-Lorenzen *et al.* (2007) reported that highly diverse mixtures showed variable litter production among observed tree species. Luhende *et al.* (n.d.) also studied the leaf litter contributions of selected species and found that they varied as follows: *A. crassicarpa* accounted for over 95%; *A. julifer*, 86%; *A. letocarpa*, 83%; *S. simea*, 76%; and *L. pallid*, 12%.

Litter Decomposition Rate

The average monthly litter decomposition rate in the study area based on 7-months data is 7.31% or an overall average of 43.03%. This is significantly affected by the type of shade trees but not by elevation, coffee age, nor any combination of the three treatments (Table 3). The fastest rate was observed during the months of July (12.96%) and August (13.37%) which are the peak months of the rainy season. The slowest rate was observed during the month of February (3.36%) (Figure 7). This result approximates that of the findings of Xuluc-Tolosa *et al.* (2002) wherein in the secondary dry forests of Campeche, Mexico, decomposition increased with the onset of the rainy season from June to the beginning of August (63-125 days) then stayed relatively constant for the latter part of their study (125-190 days). February is the month considered as the tail end of the cold season with minimal rainfall which may account for the low

Table 3: Mean litter decomposition rate in the Arabica coffee-based Agroforestry systems in Atok, Benguet

TREATMENT		MEAN LITTER DECOMPOSITION RATE (%)
A. Elevations:	≤1,500masl (lower elevation)	46a
	>1,500masl (upper elevation)	43.8a
B. Arabica coffee-tree integrations or agroforestry:		
	Arabica coffee plus Alnus	48.04a
	Arabica coffee plus fruit trees	41.75b
C. Arabica coffee age:	3-10 years old Arabica coffee	43.26a
	11-20 years old Arabica coffee	47.20a
	>20 years old Arabica coffee	44.22a
D. ≤1,500masl:	Arabica coffee plus Alnus	49.50a
	Arabica coffee plus fruit trees	42.52a
>1,500masl:	Arabica coffee plus Alnus tree	46.57a
	Arabica coffee plus fruit trees	40.97a
E. Arabica coffee plus Alnus:	3-10 years old A. coffee	46.58a
	11-20 years old Arabica coffee	52.85a
	>20 years Arabica coffee	44.68a
Arabica coffee plus fruit trees :		
	3-10 years old Arabica coffee	39.94a
	11-20 years Arabica coffee	41.54a
	>20 years old Arabica coffee	43.76a
F. ≤1,500masl :	3-10 years old Arabica coffee	45.43a
	11-20 years Arabica coffee	45.72a
	>20 years Arabica coffee	46.89a
>1,500masl:	3-10 years old Arabica coffee	41.09a
	11-20 years Arabica coffee	48.68a
	11-20 years Arabica coffee	48.68a
	>20 years Arabica coffee	41.55a
G. ≤1,500 m asl X Arabica coffee plus Alnus:		
	3-10 years old Arabica coffee	50.66a
	11-20 years Arabica coffee	49.60a
	>20 years Arabica coffee	48.24a
≤1,500m asl X Arabica coffee plus fruit trees:		
	3-10 years old Arabica coffee	40.19a
	11-20 years Arabica coffee	41.84a
	>20 years Arabica coffee	45.54a
>1,500masl X Arabica coffee plus Alnus:		
	3-10 years old Arabica coffee	42.49a
	11-20 years Arabica coffee	56.11a
	>20 years Arabica coffee	41.12a
>1,500masl X Arabica coffee plus fruit trees:		
	3-10 years old Arabica coffee	39.68a
	11-20 years Arabica coffee	41.25a
	>20 years Arabica coffee	41.97a
GRAND MEAN		**44.891**

Note: Means with the same letters do not differ significantly at 5% level by Bonferroni

decomposition rate.

Effect of elevation. There was faster average decomposition rate at lower elevation (46%) than at upper elevation (43.8%) but the difference was not statistically significant. This result is similar to the findings of a study conducted in Central Taiwan showing that decomposition rate decreased as the elevation increased (Lu and Liu, 2012). The effect of elevation to decomposition is seen as its indirect influence on temperature. As elevation increases, temperature decreases. The rate of organic matter decomposition is faster in a warm climate than in cold climate (Kozlowski *et al*. 1991). Likewise, moist and warm environments favor fast disintegration of litters by soil microorganisms (Hasset *et al.* 1992).

Effect of shade trees. The litter decomposition rate in plots with Alnus as shade trees was

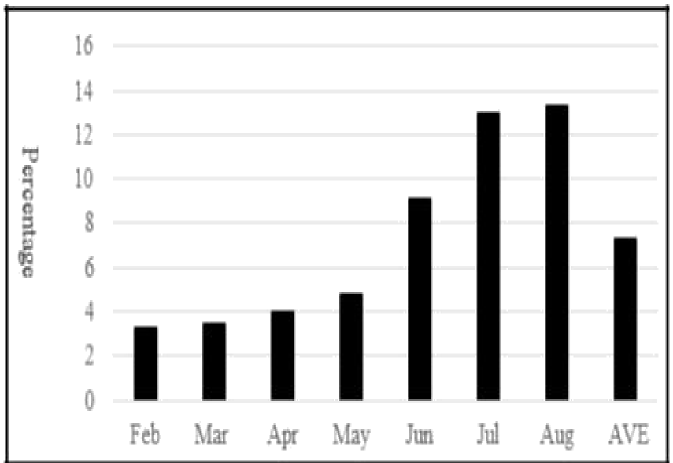

Figure 7. Mean litter decomposition rate within 7 months of observation

significantly faster than those with fruit trees as shade trees. The faster decomposition rate under the coffee-alnus integration is attributed to Alnus, a known N-fixing species. As reported by Li *et al.* (2011), among the species studied, *Pennisetum flaccidum* had the lowest N concentration and the lowest decomposition rate, while *Artenisia scorparica, Chenopodium acuminatum,* and *Cannabis sativa* had higher N contents and faster decomposition rates. Related to this observation is the report that the decomposition of the litters of *Eucalyptus grandis* is slow but is significantly improved with the admixture of *Alder spp*. litters (Wu *et al.* 2014).

Effect of coffee age. Litter decomposition rate is fastest in plots with 11- 20 years old coffee trees (47.20%), followed by plots with >20 years old coffee (44.22%) and that of the 3-10 years old coffee (43.26%), but the differences are not statistically significant. This result may be due to the fact that decomposition is mainly affected by the nature of the materials (litter), climatic factors and biological factors and not by the age of the source (litter producers).

Factor interaction effects. Average decomposition rate was found to be higher in plots under coffee-Alnus integration than in plots under the coffee-fruit trees integration in all coffee tree ages. This could be attributed to the N-fixing ability of Alnus. Xuluc-Tolosa *et al.* (2002) reported that the leaf quality, especially the carbon/nitrogen (C/N) ratio, is a sound predictor of decomposition rates of litters of tree species in home gardens. Singh and Gupta (1997) explained that during decomposition, C is used as energy by decomposers while N is assimilated into cell proteins essential for microbial growth and activities, thus, a higher N concentration in the leaf promotes decomposition.

The interaction of the experimental factors (elevation, coffee age and type of shade trees) showed varying results. This may be attributed to the mixture of different species in the coffee-based agroforestry system. Zhang *et al.* (2012) mentioned that litter decomposition could be affected by many factors such as litter quality (e.g. N concentration, lignin concentration, C:N ratio, leaf dry matter content, holocellulose concentration), environmental variables (e.g. climate, vegetation, soil fertility, etc.), and decomposers.

<u>Nutrient Content of Litters</u>

NPK content of litters (based on the oven-dry weights) in the study site are shown on Table 4.

Nitrogen content. The average N content of the litters ranged from 1.495% to 2.085% with a grand average of 1.75%. It was observed to be significantly higher in plots with Alnus trees integrated than those integrated with fruit trees. It was also slightly higher in plots with 11–20 years old coffee trees as compared to the amount in plots with 3–10 years and >20 years old coffee trees. The significantly higher N content of litterfalls in plots with Alnus trees integration can be attributed mainly to the N-fixing ability of Alnus. The higher N content of litters from plots with 11–20 years old trees may be attributed to the greater vegetative growth of the trees towards their middle age growth period. It is expected that at the grand period of growth, considerable amount of young tissues form part of the litters. Hayashi *et al.* (2012) reported that N concentration in litters can be affected by the season. The small quantity of litters that fall during wet season is richer in N than litters that fall during dry season because of the retranslocation of N prior to litterfalls during this time.

Phosphorous content. The grand mean P

Table 4. Mean Nitrogen, Phosphorous and Potassium contents of litters (based on oven-dry weights) in the coffee-based agroforestry system in Atok, Benguet

TREATMENT	LITTER NUTRIENT CONTENTS		
Elevation:	N (%)	P (ppm)	K (%)
≤1,500masl (lower elevation)	1.685a	0.14a	0.825a
>1,500masl (upper elevation)	1.82a	0.14a	0.7883a
Arabica coffee-tree integration or agroforestry			
Arabica coffee-Alnus tree integration	1.915a	0.1383a	0.6117a
Coffee-fruit trees integration	1.59b	0.1417a	1.0017a
Arabica coffee age:			
3-10 years old Arabica coffee	1.7475a	0.135a	0.6725a
11-20 years old Arabica coffee	1.87a	0.125a	0.8400a
>20 years old coffee	1.64a	0.16a	0.9075a
Arabica coffee-tree integration X coffee age:			
Arabica coffee-Alnus:			
3-10 years old Arabica coffee	1.875a	0.16a	0.595a
11-20 years Arabica coffee	2.085a	0.115a	0.69a
>20 years Arabica coffee	1.785a	0.14a	0.55a
Arabica coffee- fruit trees:			
3-10 years old Arabica coffee	1.62a	0.11a	0.75a
11-20 years Arabica coffee	1.655a	0.135a	0.99a
>20 years Arabica coffee	1.495a	0.18a	1.265a
MEAN	**1.752ns**	**0.14ns**	**0.8067**

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

contents of litters was 0.14ppm with an average range of 0.11ppm to 0.18ppm. The P contents of litters of the coffee-based agroforestry systems at both lower and upper elevations are the same (0.14ppm), and are higher in plots with fruit trees integrated (0.142ppm) than in plots with Alnus trees integration (0.138ppm). This was also true in plots with more than 20 years old coffee (0.16ppm) than in those with 3–10 years old coffee trees (0.135ppm) and 11–20 years old coffee trees (0.125ppm). However, statistical analysis indicated insignificant differences between and among the data means under the various treatments.

The higher P content of litters in agroforestry systems with fruit trees as shade trees can be due to the higher amount of fruits in the litters, while that under the older agroforestry system can be due to the deeper established roots of other trees that keep trees in more active growth especially during the dry season. Hayashi *et al.* (2012) reported that there is high P concentration in younger leaves, and the large amount of litterfall during dry season has P concentrations lower by about 50%, indicating a phenologically-controlled translocation of foliar P prior to the falling of old leaves.

K Content. The grand average K content of litters in the experimental plots was 0.807% of the oven-dry weight with a range of 0.55% to 1.265%. This is slightly higher in plots at upper elevations (0.788%) than those at lower elevations (0.825%) and in plots with fruit trees integration than those with Alnus. In plots with Alnus trees integration, K was highest in those with 11–20 years old coffee trees (0.69%) and lowest in those with >20 years old coffee trees (0.55%). This differs from plots with fruit trees as shade trees wherein the K level is highest in those with >20 years old coffee trees (1.265%) and lowest in those with 3–10 years old coffee trees (0.75%). The differences in data means in all treatments are, however, not statistically significant.

<u>Amount of NPK Returned to the Soil Through Litterfalls</u>

As applied from Luna (1998), the oven dried weight of collected leaf litters each month was multiplied with the corresponding nutrient content (%) to obtain the monthly total weight of NPK returned to the soil. The estimated amount of NPK returned to the agro-forest floor by litters was at a monthly average of 15.46kg of N, 2.37kg of P, and 7.12 kg of K per ha, or an annual average of 185.51kg N, 28.5kg P, and 85.39kg K per ha (Table 5). The peak nutrient return was recorded in November. Among the three elements, the rate of return to the soil by litters was highest for N and lowest for P. This computed average N returned to soil annually is 2.31 times of the findings of Roskoski (1980) that shade tree leaf litters within the coffee plantations contributed over 80kg N per hectare per year; however, it is less by 2.34 kg than the lost nutrients through crop harvest. The low amount of P being returned to the soil is consistent with the findings of Clifford and Willson (1985) that the amount of phosphate removed through coffee crop harvest is small, nonetheless, plants use P in much smaller quantity than N and K. There could be a problem only in more acid soils as phosphate fixation may prevent the trees from absorbing sufficient phosphate.

Table 5. Estimated amount of NPK returned to the agro-forest floor by leaf litters within a one-year period in Arabica coffee-based agroforestry systems

MONTH	N (kg/ha)	P (kg/ha)	K (kg/ha)
January	8.604	1.32	3.96
February	9.08	1.40	4.18
March	12.55	1.93	5.78
April	12.42	1.91	5.72
May	13.06	2.01	6.01
June	15.06	2.31	6.93
July	17.28	2.65	7.95
August	18.91	2.90	8.70
September	18.33	2.82	8.44
October	22.51	3.46	10.36
November	24.8	3.81	11.41
December	12.91	1.98	5.94
Annual Nutrients Return	**185.51**	**28.50**	**85.39**

The estimated soil nutrients removed by coffee trees to produce one ton of Arabica coffee beans were as follows: 45.5 kg N, 3.37 kg P, and 31.46 kg K in green beans; 2.27 kg N, 0.13 kg P, and 1.55 kg K in parchment; and 15.33 kg N, 1.61 kg P and 22.74 kg K in pulp (Ripperton, Goto and Pahau, 1935). Based on this report, the estimated NPK removed in the study site via coffee harvest was 187.8kg of N, 15.51 kg of P and 165.97 kg of K per ha/yr. This implies the need to supply K every after harvest. The minimal N deficit can be supplied by rainfall. Kramer and Kozlowski (1960) reported that in England, 2 kg/ha/yr of Nitrogen is returned to the soil through rain while Baker (1950) estimated that in the United States, 2.27 kg/ha/yr of N is returned via rainfall to the soil.

The estimated annual nutrient uptake per hectare of vigorously growing block of Arabica coffee yielding 1.0 t/ha green coffee beans is estimated at 135 kg N, 34 kg P_2O_5 and 145 kg K_2O (Andrea & Viani, 2005). To have a more accurate estimate of the rate of fertilizer application, there is a need to determine nutrient loss via leaching, erosion, surface runoff, harvesting, grazing, etc. in the agroforestry systems. These were not covered by the study. Clifford & Willson (1985) suggested that soil and leaf analyses should be done if there is a need to determine the balance of nutrients and plant tissues, and to provide good guidance for fertilizer application especially so that several factors are involved in nutrient losses and immobilization.

Combined Sustainability Rating for Litter Production, Decomposition Rate and NPK Contents

Litter production in the agroforestry system under study is rated with a weighted average mean of 2.47 or “highly sustainable” (Table 6). Litter production in all plots surpassed the 50 kg/ha/ yr threshold level. Litter decomposition rate in the experimental area has an average weighted mean of 3.0 or “highly sustainable”. This rating indicates that decomposition is highly efficient in the area.This is important in replenishing nutrient losses via plant use, leaching, erosion, etc.

The N levels in litters in all the experimental plots have an average weighted mean of 1.0 or “low or unsustainable”. However, this low N content is compensated by the high volume of litter production that gives an equivalent of 185.51 kg of N/ha/yr. The computed total N returned via litterfalls in the area almost fully returns the estimated N lost via crop harvest. The P levels in litters in all the experimental plots had an average weighted mean of 1.56 or “moderately sustainable”. This P level is equivalent to 28.50 kg/ha/yr. The K content of litters in the coffee-based agroforestry systems in the study site

Table 6. Combined sustainability rating of litter production, decomposition rate and NPK concentration in the coffee-based agroforestry system in Atok, Benguet

PARAMETER	SUSTAINABILITY RATING	DESCRIPTIVE EQUIVALENT
A. Litter Production and Decomposition		
1. Litter production	2.47	Highly sustainable
2. Decomposition rate	3	Highly sustainable
B. Litter Nutrient Contents		
1. Nitrogen	1.0	Low/Unsustainable
2. Phosphorous	1.56	Moderately sustainable
3. Potassium	1.0	Low/Unsustainable
Average	1.61	Moderately sustainable

Legend: 2.50 – 3.00 – Highly Sustainable; 1.50 – 2.49 – Moderately Sustainable; 1.00 – 1.49 – Low/Unsustainable

had an average weighted mean of 1.0 or "low/ unsustainable". This content is equivalent to 85.39 kg/ha/yr. Clifford and Willson (1985) explained that coffee can extract sufficient potassium from deep fertile soils, hence, this low return from litters in the study site can be augmented through absorption of the element from the deep soil layers by the coffee roots.

The amount, decomposition rate and NPK content of litters in the study areas obtained an overall average weighted mean of 1.61 or "moderately sustainable".

Larger amounts of P is required by younger coffee trees and K is important in the development of its fruits (Clifford and Willson, 1985). Furthermore, they reported that direct responses of mature coffee to experimental applications of phosphate are rare, but phosphate is often applied in small quantities to mature coffee. If crops need more K than what is available in the soil, this element in the leaves is translocated resulting to leaf fall and/or die-back.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results, the following are concluded: (1) low nutrient content of litterfalls is compensated by high litter production and decomposition rate in the Arabica coffee-based agroforestry system that makes this system moderately sustainable; (2) Alnus as shade trees significantly promote higher litter decomposition rates and produce litters with significantly higher N content being a Nitrogen-fixing and a fast-growing species; and (3) NPK return via litterfalls in the study area is deficient.

Recommendations

To improve the sustainability of the Arabica coffee-based agroforestry system in Atok, application of NPK fertilizers and adoption of soil conservation measures are recommended. The integration of Alnus in Arabica coffee plantation sites in other places in Benguet or even the Cordillera Administrative Region is also recommended to increase the N content and hasten decomposition rate.

The following are further suggested: conduct separate nutrient contents analysis and decomposition rate determination of the litters of coffee crop and shade trees within the agroforestry system;integrateotherN-fixingtreespeciessuitablein the plantation; concentrate other important elements in the litters towards determining their sufficiency in agroforestry systems; correlate litter nutrient contents to soil nutrient content, and in relation to nutrient losses in agroforestry systems; use symbiotic microorganisms present in each type of agroforestry at different elevations; increase carbon sequestration capacity of the coffee-based agroforestry system; satisfy required density of shade trees and the amount of nutrient returns in the soil as affected by the density of shade and coffee trees; undertake similar studies but under higher and narrower elevation ranges and compensate for the low sustainability ratings for P and K contents by applying appropriate and ample fertilizers and soil conservation measures.

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