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Nutrients Returned from Standing Litter of Four Monocultural And Diverse Land-Use Systems at Brazilian Atlantic Rain Forest: Research Article

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Abstract

The conversion of natural forests into conventional agricultural and cattle systems is very harmful to environmental sustainability. In Brazil, mainly at Atlantic Rain Forest, that deforestation can be observed by a great number of small widespread unconnected fragments, where genetic erosion is a result of reduced above- and belowground biodiversity, increased organic matter decomposition and thus, decreasing soil C storage. Agroforestry systems provide food production, but little is known about how standing litter can affect the nutrient supply for ecological-based agroforestry systems. This work was conducted in family small farms containing conventional agriculture, pasture, ecological-based agroforestry (summarized here as ecological agroforestry) and natural regeneration, where standing litter was collected, separated into different fractions, weighted and analysed for nutrient contents. Standing litter was greater in natural regeneration (13.7Mgha^{-1}) and ecological agroforestry (10.2Mgha^{-1}), than in pasture (4.8Mgha^{-1}) and conventional agriculture (3.6Mgha^{-1}), all mainly composed by leaves and branches. Standing litter of conventional agriculture was richer in N, P and Mg, due to external inputs. Standing litter of ecological agroforestry was richer in Ca, while pastures, in K. Standing litter from natural regeneration returned greater amounts of N (171.4Mgha^{-1}), P (37.7Mgha^{-1}), Ca (199.0Mgha^{-1}) and Mg (44.3Mgha^{-1}), while ecological agroforestry had greater amounts of K (346.9Mgha^{-1}). Ecological agroforestry results were similar to natural areas, and significantly higher than monocultures, indicating the importance of litter management for sustainability of diverse land-use systems.

Keywords: Conventional agriculture and pasture; Ecological-based agroforestry system; Multistate agroforestry system; Natural regeneration; Nutrient Additions

Introduction

Ever since in Brazilian history, agricultural policies based on monoculture species cultivated along large areas (e.g. sugar cane, maize, eucalyptus, pasture and/or soybean) had led to severe deforestation of natural forest landscapes, including some of world's biodiversity hotspots. At Atlantic Rain Forest, that deforestation can be observed by a great number of small widespread unconnected fragments; most of them lower than 50ha kilometres away from each other, strongly diversity loss due to edge effects and limited to less than 13% of its original area [1,2].

The conversion of natural forests into conventional agricultural and cattle systems alter soil attributes, specially decreasing soil C storage as a result of lowering the above- and belowground biodiversity and increasing organic matter exposure to decomposition [3-6]. Conversely, plant diversity can influence terrestrial net primary, decomposition and nutrient dynamics through changes in microclimatic conditions, complementary nutrient use and rhizosphere processes [7]. In addition, the amount and quality of plant litter, mainly fast C pools as leaves and fine roots, have a strong impact on nutrient cycling, CO_2 fluxes, soil organic matter formation, nutrient mineralization, and plant growth [8].

The development of an alternative agricultural model, linking food production concurrently to environmental conservation and human social development is, thus, strategically for modern sustainable and profitable agriculture [9].

Agroforestry is a land-use system in which woody perennials species is grown in association with herbaceous plants or livestock, in a spatial arrangement, rotation, or both Young [1997]. Ecological-based agroforestry, also known as multistrata agroforestry systems [10] concept advances toward to natural ecological succession, but with massive human design and management, mainly woody and foliage pruning for water and light/shade supply, nutrient additions and soil fertility maintenance. Litter production and decomposition are the main factors that enhance agroforestry system sustainability due to massive pruning management [11], but ecological-based agroforestry systems remain an unknown land-use productive/conservative model even with some local practical experiences [12,13], highlighting the importance of how litter and its nutrient additions can affect soil fertility and sustainability in those alternative ecological-based agroforestry systems.

Methods

Site description

This work was conducted at Barra do Turvo, Sao Paulo State, Brazil, characterized by a wavy relief, from30 to 1,000 meters height, and continuous fragments of Atlantic Dense Ombrophyllous Rain Forest [14]. Climate is a subtropical humid mesothermal, with precipitation ranging from 1,500 to 2,000mm, and 22°C mean annual temperature [15].

Family small and medium farms containing different agricultural systems (conventional agriculture, pasture, and ecological-based agroforestry system) and natural forests (natural regenerations) were chosen according to local partners indications and technical criteria. Three replications of each land-use were evaluated. Monoculture agricultural systems were represented by conventional agriculture and pasture, while diverse systems included ecological agroforestry system and natural regeneration.

Conventional agriculture included pumpkin (Cucurbita sp.), passion fruit (Passiflorine edulis) and oil palm (*Bactris gasipaes*) monocultures. In those areas, [10] also found 19 species of herbaceous plants, most of them belonging to Euphorbiaceae, Lamiaceae and Poaceae. No arboreal species, except oil palm, were found.

Pastures were mainly composed by Brachiaria spp. and *Cyperus meyenianus* and were characterized by different disturbing degrees (according to the presence of termite colonies, indicators vegetation, soil erosion and information about cattle productivity). The vegetation of those areas included 27 species of herbaceous plants, mainly Fabaceae, Asteraceae and Poaceae, and one specimen of *Psidium guajava* tree [10].

Ecological-based agroforestry and natural regenerations differed from each other by their age, as an indirect measure of system development and succession. So, agroforestry replicates were 4-, 8- and 16-years old, while natural regenerations were 5-, 20- and 30-years old. Moreover, in those ecological agroforestry systems, [10] found 46 arboreal and 62 herbaceous species of 33 botanical families (mainly Fabaceae, Lauraceae, Arecaceae, Euphorbiaceae, Sapindaceae, Verbenaceae and Poaceae). Natural regenerations were mostly composed by 45 arboreal and 58 herbaceous species, belonging also to 33 families, with emphasis to Fabaceae, Lauraceae, Myrtaceae, Euphorbiaceae, Moraceae, Annonaceae, Arecaceae, Rubiaceae, Verbenaceae and Asteraceae [10].

Table 1: Physical and chemical attributes at arable layer of soils collected from conventional agriculture, ecological agroforestry, pasture and natural regenerations, and the organic compost used for external fertilization on conventional agriculture areas, every three months (100g plant 1). Lower cases indicate statistical significance (Tukey, $p < 0.05$) among land-use system (LUS). nd – not determined. Source: Froufe et al. [10].

Land-Use System	Porosity Cm Cm^{-3}	Bulk Density Kg Dm^{-3}	Ph ($Cacl_2$)	Al^{3+}	$H^{+} + Al^{3+}$	M
Conventional Agriculture	0.6 a	1.1 b	6.3 a	0.02 b	3.2 b	0.2 b
Ecological Agroforestry	0.6 a	1.1 b	5.5 b	0.12 b	4.1 b	3.1 b
Pasture	0.5 b	1.2 a	5.4 b	0.05 b	3.8 b	1.4 b
Natural Regeneration	0.5 b	1.0 b	4.5 c	0.78 a	6.8 a	21.4 a
Organic Compost	*nd*	*nd*	*8.3*	*0*	*1.6*	*2.4*
	P mg.dm^{-3}	**K cmol.dm^{-3}**	**Ca cmol.dm^{-3}**	**Mg cmol.dm^{-3}**	**V %**	
Conventional Agriculture	16.8 a	0.2	7.6 a	7.1 a	81.6 a	
Ecological Agroforestry	11.0 b	0.2	4.3 b	3.0 b	62.9 a	
Pasture	10.6 b	0.2	2.9 b	2.2 b	55.0 a	
Natural Regeneration	10.6 b	0.2	1.3 c	2.2 b	34.7 b	
Organic Compost	*966.3*	*12.2*	*4.2*	*3.3*	*44.1*	
	N%	**COg kg^{-1}**	**Arboreal Biomass Mg ha^{-1}**	**Herbaceous Biomass Mg ha^{-1}**	**Soil Carbon Mg ha^{-1}**	
Conventional Agriculture	0.2 a	19.2 a	7.2 c	0.01	38.3	
Ecological Agroforestry	0.2 a	18.2 ab	32.4 b	0.01	38.6	
Pasture	0.1 b	15.6 b	0	0.01	33.9	
Natural Regeneration	0.2 a	18.5 ab	70.8 a	0.01	39	
Organic Compost	*1.2*	*142.5*	*nd*	*nd*	*nd*	

Three 25 x 10 m plots were installed at small farm containing each land-use system (LUS), totalizing nine plots per LUS. The soil was predominantly characterized as Inceptisol and Entisol [10], which physical and chemical attributes are shown at Table 1.

Standing litter biomass and nutrient contents

Standing little was collected directly from the soil, on all 36 plots, by randomized triplicate samplings. Standing litter was evaluated from July 2007 - March 2008. All 108 samples were gently washed to remove soil particles, dried (60°C) and separated into:

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a) leaves;

b) branches;

c) reproductive structures (flowers, fruits and seeds);

d) barks; and

e) fine roots and weighted in a dry basis (g m^{-2}, transformed to $Mgha^{-1}$ afterwards).

Litter fractions were summed to determine the total amount of standing litter accumulated aboveground. Replicates of litter fractions were grounded, sieved and analysed for their nutrient contents. Nitrogen was determined by Kjeldahl method; while P, K, Ca and Mg were evaluated by dry digestion followed by atomic absorption (Ca and Mg), emission spectrophotometry (K) and colorimetric spectrophotometry (P).

Statistical analysis

All data were analysed as randomly block (three replicates), and ANOVA and Tukey tests were performed with SPSS statistical package (SPSS, 1991). Because of their heterogeneity and to improve conformity to normal distributions, reproductive structures and barks data were transformed $(y=\sqrt{x+1,0})$ prior to statistical analysis.

Results

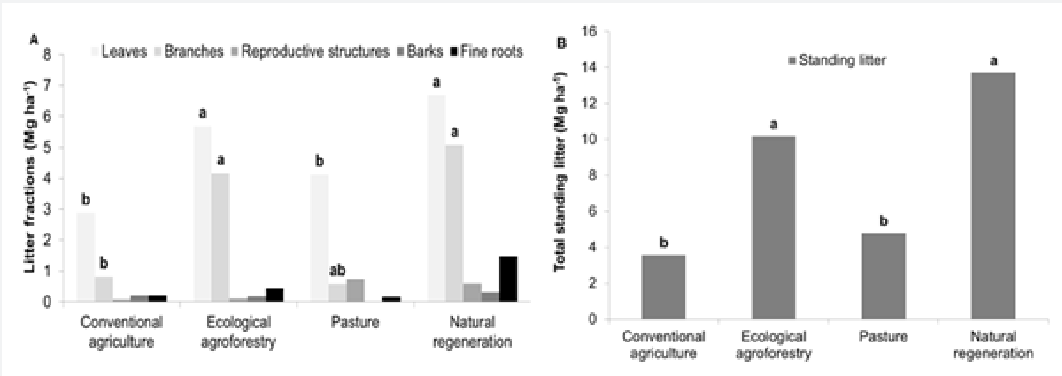

Figure 1: Litter fractions (A) and total standing litter (B) of four different land-use systems (LUS) at Barra do Turvo, SP. Lower cases indicate statistical significance (Tukey, $p < 0.05$) of (A) leaves and branches, and (B) standing litter, among LUS.

Table 2: Capital letters indicate statistical significance (Tukey, $p < 0.05$) among litter fractions of each land-use system (LUS); while lower cases indicate statistical significance of LUS for each litter fraction. Relative composition of standing litter from different agricultural and natural land-use systems at Barra do Turvo, SP.

	Leaves % of Total Standing Litter	Branches % of Total Standing Litter	Reproductive Strut% of Total Standing Literatures	Barks % of Total Standing Litter	Fine Roots % of Total Standing Litter
Conventional Agriculture	80.0 A a	22.6 B bc	2.5 B	5.8 B	6.1 B
Ecological Agroforestry	55.9 A b	40.9 A a	1.2 B	1.7 B	4.4 B
Pasture	85.8 A a	12.1 B c	15.4 B	0.2 B	3.4 B
Natural Regeneration	48.7 A b	36.9 B ab	4.4 C	2.3 C	10.7 C

Standing litter was significantly greater in diverse systems (natural regeneration and ecological agroforestry) than monocultures (conventional agriculture and pasture), varying from 3.6 to 13.7Mg ha^{-1} (Figure 1), and was mostly composed, among all land-use systems, by leaves (66.1%) and branches (29.2%). The other litter fractions greatly varied among LUS, and represented only 7.2% (fine roots), 4.3% (reproductive structures) and 2.1% (barks). Regarding each LUS, diverse systems also generate a more diverse litter (Table 2), while monocultures standing litter were predominantly formed by leaves.

Regarding the entire data set, conventional agriculture generated a richer standing litter on nitrogen, phosphorous, calcium and magnesium as compared to ecological agroforestry and natural regenerations, while pastures produced a poorer standing litter for all nutrients, except potassium (Table 3). Additionally, leaf litter was richer in all nutrients, while branches, barks and fine roots had the lowest nutrient contents.

Litter fractions of conventional agriculture had highest nutrient content values than ecological agroforestry, natural regenerations and pasture (Table 4). As a result of biomass production and chemical quality, the total amount of nutrients returned to soil system from standing litter varied from 11.5kg ha^{-1} (Mg) to 346.9kg ha^{-1} (K).

Despite their higher efficiency on nutrient use (Table 5), lower amounts of nutrients returned to soil systems from standing litter of pastures and conventional agriculture, while standing litter from natural regeneration was responsible for greater amounts of N, P, Ca and Mg return, and greater amounts of K were observed from standing litter of ecological agroforestry (Figure 2).

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Table 3: Nutrient contents (g kg-1) of all standing litter (upper data) and litter fractions (bottom data) collected from different agricultural agrosystems and natural regenerations, at Barra do Turvo, SP.

Land-Use System	N g.kg-1 (= kg. Mg-1)	g.kg-1 (= kg. Mg-1)	K g.kg-1 (= kg. Mg-1)	Ca g.kg-1 (= kg. Mg-1)	Mg g.kg-1 (= kg. Mg-1)
Conventional Agriculture	13.3 A	4.3 A	12.5 B	13.2 A	5.2 A
Ecological Agroforestry	11.7 B	2.9 B	17.8 AB	13.6 A	2.9 B
Pasture	9.8 C	2.9 B	22.3 A	7.7 B	2.2 C
Natural Regeneration	11.3 B	2.5 B	14.0 B	12.0 A	3.0 B
Litter Fractions	N g.kg-1 (= kg. Mg-1)	P g.kg-1 (= kg. Mg-1)	K g.kg-1 (= kg. Mg-1)	Ca	Mg g.kg-1 (= kg. Mg-1)
Leaves	15.8 a	3.9 a	39.7 a	14.5 ab	3.9 a
Branches	7.5 d	2.2 c	4.4 b	11.3 bc	2.9 bc
Reproductive Structures	12.6 b	2.7 bc	6.9 b	10.1 c	2.3 c
Barks	10.1 c	2.4 c	2.5 b	15.0 a	2.8 bc
Fine Roots	10.0 c	3.2 b	8.2 b	6.4 d	3.1 b

Table 4: Lower cases indicate statistical significance (Tukey, $p < 0.05$) of litter fractions amounts and nutrient contents among land-use system (LUS). Nutrient contents (g kg-1) and ratios of litter fractions of standing litter collected from different agricultural agrosystems and natural regenerations, at Barra do Turvo, SP.

Land-Use System	N	Pg.kg-1 (= kg. Mg-1)	Kg.kg-1 (= kg. Mg-1)	Ca g.kg-1 (= kg. Mg-1)	Mgg.kg-1 (= kg. Mg-1)	CN	NP
Leaves							
Conventional Agriculture	18.7 a	6.5 a	16.5 b	17.2 a	6.8 a	25.2 b	3.2 b
Ecological Agroforestry	17.0 a	3.0 b	46.8 a	16.7 a	3.4 b	27.8 b	6.6 a
Pasture	10.2 b	3.5 b	54.4 a	8.6 b	1.8 c	46.5 a	3.4 b
Natural Regeneration	17.3 a	2.6 b	41.9 a	15.4 a	3.4 b	27.1 b	7.3 a
Branches							
Conventional Agriculture	8.3 a	1.5 b	7.9 a	11.2 ab	4.1 a	54.9	6.9 ab
Ecological Agroforestry	7.5 ab	1.6 b	3.3 b	11.1 ab	2.1 b	62	9.2 a
Pasture	7.4 ab	3.0 a	4.0 b	9.2 b	2.7 b	58.3	2.2 b
Natural Regeneration	7.2 b	2.6 a	3.0 b	13.4 a	2.8 b	64.4	2.8 b
Reproductive Structures							
Conventional Agriculture	12.4 a	4.8 a	13.1	3.4	2.2 b	36.5 a	2.7 b
Ecological Agroforestry	12.0 a	3.3 ab	7.2	17	2.6 b	37.7 a	3.9 b
Pasture	14.8 b	1.7 b	5.1	17.4	4.3 a	30.4 b	8.6 a
Natural Regeneration	12.7 a	2.3 b	6.3	6.5	1.9 b	35.3 b	6.1 ab
Barks							
Conventional Agriculture	8.6 b	3.6 a	5.3 a	8.4 ab	3.3	52.8	2.4
Ecological Agroforestry	11.6 a	2.8 ab	2.6 ab	14.9 ab	2.9	38.8	5
Pasture	10.5 ab	1.8 ab	2.2 ab	6.0 b	1.9	43.1	5.7
Natural Regeneration	8.7 b	1.6 b	1.8 b	18.2 a	2.6	56	5.7
Fine Roots							
Conventional Agriculture	8.8 b	4.3 ab	14.5 a	6.6	3.1 ab	51.4	2.2 b
Ecological Agroforestry	8.8 b	5.2 a	12.0 a	7.4	3.8 a	52.1	2.4 b
Pasture	11.9 a	2.3 c	4.6 b	3.8	2.0 b	40.5	5.5 a
Natural Regeneration	9.4 ab	2.7 bc	8.0 ab	7.9	3.7 a	50.4	3.7 b

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Table 5: Lower cases indicate statistical significance (Tukey, $p < 0.05$) among land-use systems.

Land-Use System	N Mg Stand Litter kg^{-1} Nutrient	P Mg Stand Litter kg^{-1} Nutrient	K Mg Stand Litter kg^{-1} Nutrient	Ca Mg Stand Litter kg^{-1} Nutrient	Mg Mg Stand Litter kg^{-1} Nutrient
Conventional Agriculture	78.6	356.7	426.9 a	84.8 b	221.2 c
Ecological Agroforestry	81.2	496.2	74.1 ab	84.9 b	390.7 b
Pasture	102.7	343.9	59.9 b	148.0 a	606.1 a
Natural Regeneration	83.7	405	51.3 b	80.6 b	349.9 bc

Nutrient use efficiency for standing litter production of different agricultural agrosystems and natural regenerations, at Barra do Turvo, SP.

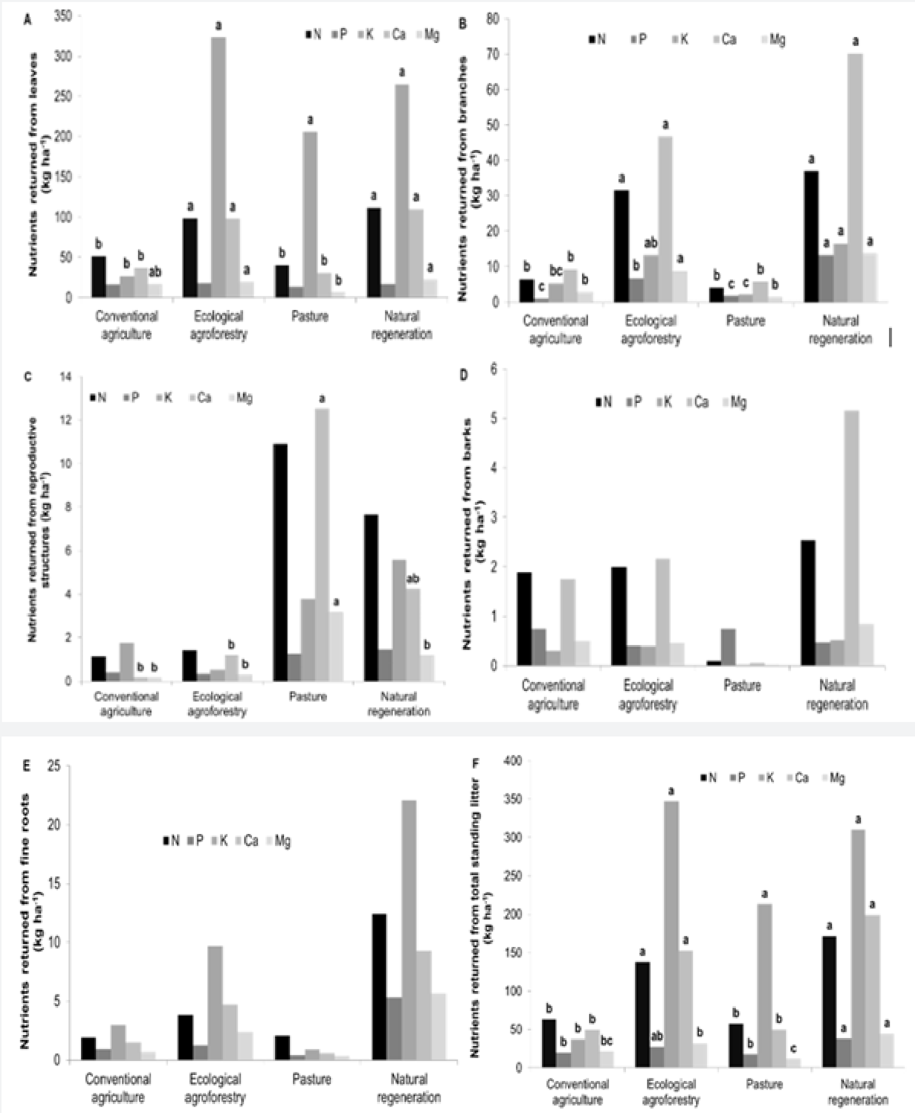

Figure 2: Nutrients (N, P, K, Ca, Mg) returned to soil (kg ha-1) from litter fractions and total standing litter of four different land-use systems (LUS) at Barra do Turvo, SP. Lower cases indicate statistical significance (Tukey, $p < 0.05$) for each nutrient, among LUS. (A) leaves; (B) branches; (C) reproductive structures; (D) barks; (E) fine roots; (F) total standing litter.

Discussion

Standing litter amounts of ecological agroforestry and natural regeneration were strongly lower than previous results on similar land-use systems [13]. Litter production is a result of age and vegetation diversity [16] and leaves usually represent over than 60% of litter fractions on natural and agroforestry systems [17-19].

Ecological agroforestry and natural forests, because of their higher diversity, generate a diverse litter layer, where soil macrofauna community and animal activity contribute to enhance litter decomposition, biogeochemical cycles and the long-term functioning of ecosystems [13,20-23] By the other hand, herbaceous dominated landscapes have low potential to mitigate carbon losses from agroecosystems and need strong management strategies toward to sustainability [24].

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The great production of standing litter on ecological agroforestry can be a response of intensive pruning management. Those ecological agroforestry systems usually reach their maximum production until 8 years old [25]. After that age, the agricultural management is usually stopped, because of massive arboreal development and legal restrictions to forest management, thus those areas turn to natural regenerations.

Under forestry and agricultural management, biomass removals of logs, fruits and seeds imply a great loss of soil nutrients and the reduction of soil fertility [26,27] Despite agricultural and timber production, pruning management and the maintenance of foliar structures on soil appear to represent a boundary line towards to the sustainability of ecological agroforestry [28-31].

According to our results and the nutrient use efficiency, proposed by [32]. as an index to define better strategies to produce biomass in response to nutrient availability, it could be expectable that pastures and conventional agriculture would be more efficient on biomass production. Despite this, and because pastures were mainly composed by Cuphea racemosa, Desmodium adscendens, Oxalis corymbosa, Panicum maximum, Solidago chilensis, Thelypteris dentate, Vernonia polyanthes and Waltheria indica [10], all acid soil resistant and/or invasive plants [33,34], those pastures advance toward a high stressed level of unsustainable management. Still, conventional agriculture productivity is guaranteed only because of the addition of external mineral and organic fertilization [10] being naturally unsustainable at long time.

For ecological agroforestry, characterized by no exogenous inputs used to maintain its productivity, midterm NUE values were similar to those of natural regenerations. Along with its pruning management linked to biomass production and decomposition, ecological agroforestry sustainability thus resembles to natural forest areas.

Despite all results indicating the sustainability of the ecological-based agroforestry here evaluated, it cannot be considered as a simple solution to environmental and/or pollution mitigation. An optimal strategy for these purposes depends on a wide range of technical criteria, also including yield production, economical returns to farmers, environmental issues, current and future scenarios and trade-offs among all these variables [35] However, ecological-based agroforestry systems appear to positively contribute to expand the range of possibilities of small farmers on food and wood production [36] and also regulate ecosystems functions in agricultural and boundary landscapes [24,37], by carbon and nutrient additions to soil from litter structures [38-42].

Conclusion

Species diversity land-use systems imply greater amounts of stand litter than monocultures. Similar patterns are observed for nutrients returned to soil from standing litter. Ecological-based agroforestry systems is an environmentally friendly land-use system, regarding to their sustainability and have elevated potential to recover soil fertility in agroecosystems.

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