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THE FUNCTIONING OF A PRE-MOUNTAIN AGROECOSYSTEM AND ITS PROSPECTIVE ORIENTATION TOWARDS SUSTAINABILITY: THE ROLE OF AGROBIODIVERSITY

El funcionamiento de un agroecosistema premontañoso y su orientación prospectiva hacia la sostenibilidad: rol de la agrobiodiversidad

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ABSTRACT. The research was carried out in "Finca La Loma" agroecosystem, Limonar de Monte Rous community, Guantanamo province, Cuba and had the objective of characterizing the integral functioning of a pre-mountain agroecosystem, for its prospective orientation towards sustainability, based on its agrobiodiversity. The initial diagnosis showed that the agroecosystem possessed acceptable socioeconomic and environmental conditions, revealed in the quality of life of the actors and the abundant agrobiodiversity. The analysis by subsystem, showed the existence of 249 species of 79 families; of them 41 forest species, being *Hura crepitans* L., the one with the highest carbon retention and *Poeppigia procera* Presl., the one with the highest frequency. 28 new species were introduced to meet food needs. The value of the Agrobiodiversity Index (IDA) went from 0,67 to 0,77 in three years. The Human Food Index was based on 56 species. The contributions to the sustainability of the agroecosystem showed positive effects for the qualitative and quantitative indicators. Problems related to the lack of: attachment to "the land" among the young, training, afforestation and areas to be developed were detected; limiting to the prospective development of the agroecosystem.

Key words: species diversity, estimation of carbon stocks, reforestation, carbon sequestration, sustainability

RESUMEN. La investigación se realizó en el agroecosistema "Finca La Loma", comunidad de Limonar de Monte Rous provincia Guantánamo, Cuba y tuvo como objetivo caracterizar el funcionamiento integral de un agroecosistema premontañoso, para su orientación prospectiva hacia la sostenibilidad, basado en su agrobiodiversidad. El diagnóstico inicial mostró que el agroecosistema poseía condiciones socioeconómicas y medioambientales aceptables, reveladas en la calidad de vida de los actores y la abundante agrobiodiversidad. El análisis por subsistema, mostró la existencia de 249 especies de 79 familias; de ellas 41 especies forestales, siendo *Hura crepitans* L., la de mayor retención de carbono y *Poeppigia procera* Presl., la de mayor frecuencia. Se introdujeron 28 nuevas especies, para cumplimentar necesidades alimenticias. El valor del Índice de Agrobiodiversidad (IDA) pasó de 0,67 a 0,77 en tres años. El Índice Alimentario Humano se sustentó en 56 especies. Los aportes a la sostenibilidad del agroecosistema mostraron efectos positivos para los indicadores cualitativos y cuantitativos. Se detectaron problemas vinculados a la falta de apego a "la tierra" entre los jóvenes, capacitación, forestación y rubros por desarrollar; limitantes para el desarrollo prospectivo del agroecosistema.

Palabras claves: diversidad de especies, estimación de las existencias de carbono, reforestación, secuestro de carbono, sostenibilidad

INTRODUCTION

On a global scale, research aimed at understanding the functioning of integral agroecosystems is still incipient. There are specific experiences fundamentally linked to the knowledge of the pro-cesses that allow the establishment of indicators and indices (1-4), to show the progress of the basic dimensions of sustainable

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development. These works focus on a comparative, retrospective or prospective vision; the latter being the most useful for the planning and adoption of technologies, seen through monitoring over time or evaluation of trends (5).

In Cuba, the studies of integral agroecological productive scenarios are not abundant, even though there are many agroecosystems that erect their projection towards an integral agriculture. Successful and outstanding experiences are framed by farms of small producers (6,7) or excep-tional cooperatives within the urban agriculture movement (8). The ANAP programs stand out from the cooperative vision, through the peasant to peasant movement (9,10) and the research carried out, through the use of indicators and indexes, in search of an approach to sustainability (11,12) .

Under mountain conditions, experience has evolved on the basis of the agroforestry principles and through environmental programs, trying to strengthen the diversification of local food produc-tion, while advocating the agroforestry strengthening (13).

In this context, "analogous agroforestry" has emerged (14); a relatively new current that spreads throughout the world, in search of a harmonious encounter between food production and forest production, in the direction of a productive system similar to the initial natural view (15,16).

Scientific studies, initiated in 1984 with the support of the FAO, demonstrated from the agro-forestry vision the importance of this productive system as an alternative to increase food produc-tion in mountainous areas (17). The silvopastoral systems were included in order to strengthen the production of proteins of animal origin. In all the mountainous areas of Cuba there are integral forest farms and the results of the investigations framed in a recently concluded analog agroforest-ry project are included (18).

The holistic approach to studies for the sustainable development of an agroecosystem should address issues to which modern science pays special attention. These include functional and accompanying biodiversity, competition for interference and the influence of possible allelopathic effects (19). Biodiversity, considered one of the fundamental principles of sustainable agriculture within an agroecosystem whether mountainous or not, must meet the food and spiritual needs of man, the demands of animals and the natural resource soil, provide market security, self-supply, protection of natural resources; in addition, provide stability to the agroecosystem, the basis of ecological balance (5).

In Cuba, it is still necessary to carry out research to visualize the contributions of mountainous agroecosystems to food security, taking into account the quality of the food produced and their nutri-tional requirements as a basis for food sovereignty. On the other hand, it is necessary to deepen in topics related to the optimal use of space in time, through polycultural systems within the complex mountain and premontane systems. We must promote more efficient production systems from the spatial and temporal perspective, which guarantee harmony and productive efficiency from an agro-ecological perspective, avoiding the disadvantages of competition due to interference or allelopathy (20-22).

On the basis of the aforementioned background, the following problem is derived: How to achieve the reorientation towards the sustainability of the pre-mountain agroecosystem "Finca La Loma"? To find alternative solutions to this problem, the objective of this work was to character-ize the functioning of the pre-mountain agro-ecosystem "Finca La Loma" in Limonar de Monte Rous locality, El Salvador municipality, Guantanamo province, for its prospective reorientation towards sustainability, through the characterization of enrichment and monitoring of agrobiodiver-sity.

MATERIALS AND METHODS

Location and geographical characterization of the study area, "Finca La Loma"

The research was carried out in the agro-ecosystem "Finca La Loma", located in the town of Limonar de Monte Rous, belonging to El Salvador municipality located in the mountainous region of Guantanamo province, Cuba; at a height of 405 m a.s.l., and 250 m north of Guantánamo to Sagua de Tánamo highway. This territory has a high diversity of species typical of the mountain rainforest and semi-deciduous forests, according to inventories carried out in the locality (23).

Methodology of the research carried out

The general scheme of research was elaborated on the basis of the methodological proposal MEDEBIVE (11), adjusted to the objectives of this research. The climatic variables were regis-tered monthly: precipitation (mm); average monthly temperature (^{o}C) and relative humidity (%), during the 2007-2011 periods. The meteorological station of the Mountain Development Center (CDM), located in Limonar de Monte Rous, El Salvador municipality, Guantánamo province, was taken as reference.

The main variables that describe water quality were determined, both for domestic uses and for irrigation. These analyzes were carried out in the laboratories of the Department of Water Quality for consumption in the Guantanamo province, which respond to the Directorate of Hy-draulic Resources. The analysis techniques used were established according to Cuban Standards of the Ministry of Public Health.

The soil was classified as brown (genetic type: sialitic brown, subtype: mollic, genus: car-bonated) by the New Version of Genetic Classification of the Soils of Cuba (24). To determine the main chemical properties of the soil, three to five samples were taken in each subsystem, cor-responding to the size of the area, at a depth of 0 to 20 cm, at the beginning and end of the inves-tigation. The samples were processed in the soil laboratory of the National Institute of Agricultural Sciences (INCA) and for the chemical characterization of the soil the following analytical methods were used (25):

- pH in H_2O: potentiometry, soil-water ratio: 1: 2.5.
- OM: Walkley and Black.
- Interchangeable cations: extraction with NH_4Ac 1 mol L^{-1} at pH 7 and determination by complexometry (Ca and Mg) and flame photometry (Na and K).
- P_2O_5 assimilable: Oniani (extraction with H_2SO_4 1 mol L^{-1}).

The carbon sequestered in the soil was determined on the basis of the OM value by subsys-tems, during the three years of research (26).

Diagnostic stages

In stage I, a general diagnosis was made, which included 17 basic indicators of the farm sus-tainability, assumed participatively and aided by the literature (5), which made it possible to de-termine the General Sustainability Index (IGS) (2), calculated by the formula:

$$IGS = \frac{\sum_{1}^{n}(VI)}{VMI * N}$$

where:

VI is the value of the indicator; VMI is the maximum possible value of an indicator and N is the number of indicators.

In stage II, a specific diagnosis was made, which made it possible to assess the productive sce-nario in the ecological, economic and sociocultural dimensions, define and analyze, in a participa-tory way, the main problems that limit its sustainable agrarian development; for which the Vester Matrix (27) was used.

For its fulfillment, various tools were combined such as exploratory tours, informal interviews, formal surveys and semi-structured dialogues, with observations and measurements, in each of the scenarios where the actors and their families have an impact.

Evaluation of the agroecosystem by subsystems

The study by subsystems, made it possible to establish a strategic proposal according to the results based on the increase of agrobiodiversity (Table 1). The introduction of efficient agro-ecological alternatives not practiced on the farm to complement food requirements was promoted.

Table 1. Subsystems evaluated in the agroecosystem

Subsystem I	Production of animal feed (crops and pastures)
Subsystem II	Production of human food and for marketing
Subsystem III	Production of food for family self-supply
Subsystem IV	Agroforestry and silvopastoral production
Subsystem V	The houses and their surroundings
Subsystem VI	The sources of water supply (stream and reservoir) and its surroundings
Subsystem VII	Animal production and its components (meat, egg and milk)

Quantification of carbon sequestered by tree species in the agroecosystem

As part of the Agrobiodiversity Index (IDA), the indicators used to estimate carbon seques-tration and its formulas are shown in Table 2.

The estimate of carbon sequestration by fruit and forest species (arboreal) was carried out by the methodology proposed in the Forest Research Institute (28, 29), which established that the total carbon retained in the farm is given by the sum of the value of the carbon retained in the bio-mass, in the necromass and in the soil, using coefficients determined for the Cuba conditions. All the data obtained was processed using the Microsoft Excel program. The process concluded with a biological analysis of agrobiodiversity as the supreme indicator of sustainability (6).

Table 2. Formulas for estimating carbon sequestration on the farm

Total carbon (CT)	CT = CBM + CNM + CS
Carbon of biomass (CBM)	CBM = BMT * 0,48
Total biomass (BMT)	BMT = BMf + BMA + BMR
Total Biomass coffee (BMTc)	BMTc (kg ha^{-1}) = (10(-1,15+log (basal diameter) + (0,54*log (height))) * density
Biomass of the stems (BMf)	BMf = volume * 610/1000
Aerial biomass (BMA)	BMA = stem biomass * 1,74
Biomass of roots (BMR)	BMR = aerial mass * 0,3
Carbono de la necromass (CNM)	CNM = NM * 0,45
Necromass (NM)	NM = area * 18,2
Soil carbon (CS)	CS = area * 123 (123- is a coefficient established according to the type of soil)
Tree volume	Volume = 0,7854 *(height + 3) * potency (diameter;2) * 0,32
Tree height and stem Diameter to 1,3 m of soil: with instruments (Suunto and diametric tape respectively)	

Biodiversity assessment and calculation of the Agrobiodiversity Index (IDA)

The agroecosystem was studied on the basis of the functions and utilitarian values of agrobio-diversity and an analysis was made of the functional and associated diversity of each subsystem, where the Agrobiodiversity Index (IDA) was determined (11).

$$IDA = \frac{\sum_1^S \cdot VRG}{S_t * VMG}$$

where:
VRG is the real value of the species group and VMG the desired value.

Quantitative and qualitative assessment of the contributions of work

An assessment was made of the economic, ecological and social contributions made to the agroecosystem, during the course of the research based on the value of qualitative and quantitative indicators (30), for which we evaluated the effects (positive or negative) of the actions carried out, in their contribution to the three dimensions of sustainability. To quantify the results of the data, they were taken to a weighted scale that used values from 1 to 10 (being 1, the least desirable value and 10 the most desired). The indicators with their variables and the design of the scheme used for the analysis were carried out according to the proposal of Torres *et al*. (30) and accord-ing to the results of its application (31).

RESULTS AND DISCUSSION

Agroecological diagnosis

Diagnosis of the agroecosystem "Finca La Loma"

The "Finca La Loma" has edaphoclimatic characteristics representative of the community. It has a total area of 48,72 ha; productive soils with acceptable content of organic matter and a total of 62 actors between assets and liabilities, of which 71 % work on the farm. The distribution by gender amounts to 46,8 % for the female gender and an average age of 41 years, a figure that exceeds that registered in the province (32).

Socioeconomic situation of the agroecosystem "Finca La Loma"

Figure 1 represents the value of the General Sustainability Index (IGS), which allows visualizing some of the main indicators of greater relevance, linked to the socioeconomic and environmental life of the members of the agroecosystem. It stands out that of the 16 families involved in the ac-tion of the farm, 100 % own homes, 92 % in good condition, the rest, under repair. They have the necessary means for the home, in acceptable operation. The availability of water is of high quality, due to the existence of a source of supply within the farm from a spring, which represents its greatest strength. As a main resource of capital they have a tractor for farming and marketing.

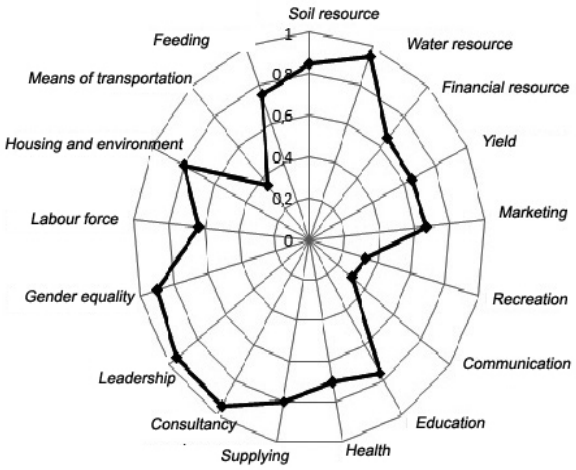

Figure 1. General indicators of sustainability on the farm

79 % of the people who inhabit the agroecosystem are of working age; however, only 28,9 % work directly on it, which limits the progress of the agroecosystem. The daily food consumption of the actors and their relatives coming from the basic basket and the own productions of the farm, this exceeds what is established at the national level (Table 3) according to the described stand-ards (33). The consumption of carbohydrates (roots, tubers, cereals and corms), proteins (animal and vegetable origin) and fats (mainly of animal origin), is much higher than the territorial average and exceeds the international average (34).

These data explain a possible excess of daily calories per capita among the inhabitants of the agroecosystem (33), although it is not reflected in obesity, given the high levels of daily energy expenditure of actors. These results reveal the need to deepen food studies by territorial groups in their demands, excesses or deficits, according to local conditions of life and work.

Environmental situation of the agroecosystem "Finca La Loma"

Predominant vegetation typical of mountain rainforests and semi-deciduous forests interspersed with coffee trees. There is a stream inside, the fruit of a spring that emerges from the mountain and supplies water to the farm.

Its quality is considered as water suitable for use, according to the program of the National Insti-tute of Hydraulic Resources CEPIS / OPS (2008). However, there was a lack of reforestation on the banks of the stream, which endangers its sustainability over time.

Problems that affect the production of the farm and its hierarchy

It was demonstrated that of the 12 main problems determined, the demotivation of young people and the lack of training are the two critical problems and therefore the main limiting factors of de-velopment according to the Vester Matrix (Figure 2) (27).

An action plan was developed jointly with the actors, to eradicate or mitigate the problems de-tected, through training in exchange workshops. This process formed the basis of the analysis to-wards the realization of a development program, aspects in which it agrees with previous investi-gations (35-37).

Strategic analysis of the "Finca la Loma"

In order to know the diversity and degree of productive efficiency of the agroecosystem, its de-termining components were evaluated by subsystems, according to the proposal of Lores *et al.* (38).

Diversity of the farm by subsystems

Subsystems I, II and III, with a surface area greater than 20 hectares, constitute the main source of agricultural production, both for commercialization and self-supply and the production of food for animals. As relevant aspects, the following stand out: (I) adequate plant agrobiodiversity, but with a lack of species that contribute fats (oleaginous), as well as species to protect and improve the soil and a gradual increase in the production of animal feed, which included the moringa and mulberry as new species in the agroecosystem; (II) the number of species increased in space and time, which made it possible to distribute the workforce equally, avoiding inequality in the number of crops to be cared for over time and (III) crop yields that exceed the average of the territory; however, far from approaching their productive potentials. This situation could be improved with the use of the rotation principles, polycultures and efficient agro-ecological techniques.

Table 3. Proportion and composition of the daily diet

Components	Breakfast	Lunch	Dinner	Snacks and others	Total daily consumption
Energy (Kcal)	275,16	1071,24	1058,36	591,32	2996,08
Carbohydrates (g)	68,79	267,81	264,59	147,83	749,02
Proteins (g)	17,22	44,37	88,44	15,07	165,1
Fat (g)	16,23	30,29	124,98	4,48	175,98

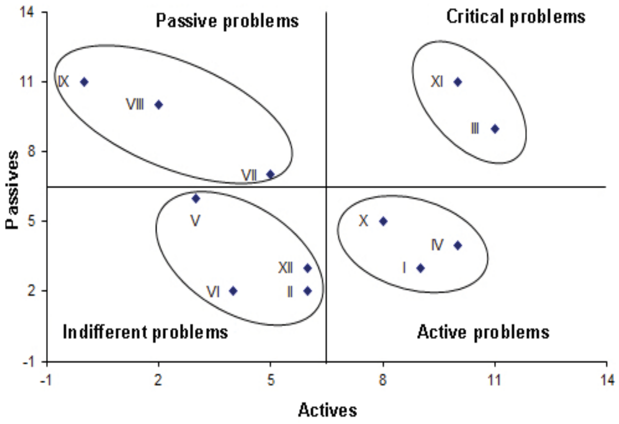

Figure 2. Ranking of the problems found in the agroecosystem

The IV system (agroforestry) presented low yields of the coffee crop (0,26 t ha^{-1}) due to scarce use of the crop technical norms, among other aspects (39); high diversity of forest species (41 species), high ecological value as timber and for carbon sequestered. Presence of a rich diversity, such as fruits and medicinal in interspecific coexistence with the coffee tree, without harming their yields, but the soil has little coverage due to the absence of live cover (*Zebrina pendula* L.) with only 14 % of the area planted with coffee and scarce use of nutritional alternatives (40) and high efficiency biofertilizers (41,42).

The house and its surroundings is a subsystem that has the peculiarity of grouping 16 houses, where 73 species were registered in the gardens and medicinal gardens of 68 existing species at the beginning of the project, indicating the level of acceptance especially of the female gender, improve the environment of homes.

The source of water supply has a small vital reservoir for the agroecosystem, where fish like clary (*Clarias* spp.) Appear freely, when there is heavy rain and is used as a complement to human food; the biajaca (Nandopsis tetracanthus) and the tilapia (*Oreochromis* spp.), which are used as a complement for animal feed, ground, boiled and mixed with other foods (commonly called yogurt). The subsystem suffers from adequate reforestation, even though actions were taken to achieve a balance, specialized technical assistance was deficient.

The diversity of animal species amounted to 11 species, in an area of 2,3 ha from those dedicated to food and sale such as poultry and cattle and their derivatives for food. For transport, the horse and mules are used to transport merchandise. This subsystem strengthens the training foods (meats, milk, eggs and their derivatives), very necessary to balance the diet and provide the body with adequate nutritional supplements (33,34,43) and for the recreation the fine roosters and the Cuy (*Cavia porcellus*) as complementary elements of pleasures of the actors and their relatives. The gradual increase of the livestock and the raising of pigs have raised the economic base of the farm; however, environmental impacts are not being monitored.

The diversity of free animals is appreciable (according to the opinion of the actors), with a rich wildlife protected by families against itinerant hunters, who usually prowl around the agroecosys-tem. In addition, the great diversity of beneficial insects associated with plants contribute to the balance of the agroecosystem (44,45).

The total diversity of the agroecosystem "Finca La Loma"

There are currently many examples of successful agricultural systems, but the key to success lies in knowing if the existing diversity satisfies the human needs, the animals, the soil resource and the agroecosystem itself that must be the main task of a producer (22,46).

There were 249 species belonging to 79 families. The most abundant family (Fabaceae) that groups 156 genera, is represented by 22 species, followed by the Poaceae with 19 species, the Malvaceae with 15 species and with 13 species the Asteraceae and the Lamiaceae. The majori-ty of families (of 66 families) were found only between one and four species. This agroecosystem can be considered rich from the floristic point of view, because generally the agroecosystems di-minish much their initial diversity, because of the man intervention and they do not exceed the fig-ure of some 200 species corroborated with the results obtained in other investigations (11).

The pre-mountainous and mountainous characteristics, where the temperatures and periodic pre-cipitations favor the presence of a high diversity of trees of varied shades within the green color, combine to provide a diverse, attractive and unique panorama that is admired by visitors and tour-ists. In this agroecosystem, the greatest number of species is grouped in those that contribute to improving the health of the ecosystem, which represents 43 % of the total (26 % weeds and 17 % forest), followed by complementary species (27 %) and for the human diet 23 % (mainly regula-tors with 17 %); the rest was found in smaller quantities (Table 4), results similar to those ob-tained in investigations under other environmental conditions (47).

Table 4. General distribution of the agrobiodiversity of the agroecosystem "Finca La Loma"

Species groups	Components	Years				Gained species
		2008	2009	2010	2011	
Main crop (permanent)	Coffee	1	1	1	1	0
Human food (total)		46	51	56	56	10
Animal food (total)		10	13	13	13	3
Ground feeding (total)		2	3	3	3	1
Complementaries (total)		56	62	67	67	11
For the agroecosystem health (total)		107	108	109	109	2
Forest		40	41	42	42	2
Weeds		67	67	67	67	0
Total plant species		222	238	249	249	27
TOTAL SPECIES (vegetal + animal)		231	247	259	259	28

The fact that more Fabaceae species have been found than Poaceae is interesting, since in the non-mountain agroecosystems, Poaceae usually predominate according to other studies (48). Because they have received high doses of herbicides derived from urea and symmetrical triazines, creating some resistance in Poaceae; however, pre-mountain and mountainous agroecosystems have not usually suffered the same damage, except for systems that have been driven to full solar exposure, as has occurred in some coffee-growing countries in Latin America (49).

The diversity of fruits present in the agroecosystem is high, but only six species are frequently con-sumed (*Musa Paradisiaca* L. var. Sapientum, *Psidium guajava* L., *Mangifera indica* L., *Citrus* sp., *Calocarpum sapota* Jacq and *Carica papaya* L), the rest of the fruit trees are con-sumed occasionally and in smaller quantity they are commercialized, like the roots and tubers with six exploited species. There is a habit of consuming two species of vegetables (*Cucumis sativus* L. and *S. lycopersicum*); however, they are little cultivated in the region. These results show, on a small scale, the alimentary customs that the actors possess, and therefore, it is what most influ-ences when choosing the crops to be produced and determines the general agrodiversity of the agroecosystem (50).

The total of species only two contributes fats (*Persea americana* Mill and *Arachis hypogaea* L.). However, there are conditions to produce other crops such as sunflower (*H. annuus*) for the extraction of its oil, which would avoid resorting to the market to acquire it at a high price; in addi-tion, of the additional contribution in by-products for animal feed.

Also, it is very important to strengthen the training and improvement of varieties for these mountain and pre-mountain conditions with the participation of the producer and those interested in the de-velopment of these agroecosystems, taking as a base the results obtained in other agroecosystems of the country (51-54).

Carbon sequestered by tree species in each subsystem

The coffee agroecosystems with diversified shade, are potential systems for the sequestered of carbon, therefore, these systems constitute an economic option with added ecological value. Based on this precedent, the total carbon sequestered by tree species was recorded and calculat-ed by subsystem in the "Finca La Loma" (Table 5).

For this indicator, a sample of 33 arboreal species was evaluated (67 % of the total present in the farm). The most frequent species is the tengue (*Poeppigia procera* Presl.) Present in seven sub-systems, for an 87,5 % of appearance which indicates its degree of relative importance for the agroecosystem, given its ecological plasticity in the area and as an economic reservoir due the quality of its wood.

It is followed by the carob tree (*Samanea saman* Merr); búcaro (*Erythrina peoppigiana* Walp) and the mapen (*Arctocarpus altilis* (Parkinson) Fosberg), found in six and five subsystems with 75 and 62,5 % of appearance respectively. These species are used as shade of the coffee tree and from the economic dimension their wood can be used for diverse purposes. The greatest di-versity of species was recorded in the subsystem of agroforestry production (Table 5).

Another aspect of great relevance is the contribution that this research offers to the carbon gain of the soil in the different subsystems studied. It was calculated from the MO values resulting from the soil analysis, which was carried out to the different subplots of the agroecosystem during the years of investigation (Table 6).

The range of sequesteredd carbon gains moved between 1,76 and 10,56 t ha^{-1}, results that consti-tute the basis to initiate deeper investigations in this subject, still virgin under pre-mountain and mountainous conditions. The results also corroborated that carbon sequestration capacity is higher in arboreal species with higher biomass and includes their contributions to the soil, which agrees with the results of other authors (55,56).

Table 5. Total carbon sequestered (ton) by the tree species, in each subsystem of the "Finca La Loma"

Species	Acronym*	Subsystem I	Subsystem II	Subsystem III	Subsystem IVa	Subsystem IVb	Subsystem V	Subsystem VI	Subsystem VII
Apricot	EUJAM	9,36	-----	-----	-----	-----	-----	-----	-----
Pinion F	GLISE	22,04	53,22	-----	102,90	-----	-----	-----	15,38
Tenge	POPRO	13,97	14,58	72,76	6,79	15,54	-----	11,30	40,52
Guava	PSIGU	24,60	-----	-----	2,90	-----	-----	-----	3,94
Tangerine	CIRET	54,36	-----	-----	2,65	-----	-----	10,63	13,16
Almond	TERCA	-----	13,40	-----	6,54	11,35	-----	-----	9,18
Carob tree	SAMSA	-----	32,55	17,95	19,95	4,37	9,82	-----	11,82
Salvadera	HUCRE	-----	108,60	-----	-----	55,20	-----	-----	-----
Búcaro	ERYPE	-----	-----	42,32	58,58	23,25	20,80	11,33	-----
Mapen	ARTAL	-----	-----	63,04	3,21	-----	40,43	13,57	12,22
Guásima	GUATO	-----	-----	26,73	-----	48,01	-----	44,28	9,97
Soursop	ANOMU	-----	-----	-----	0,13	-----	-----	-----	-----
Anon of garlic	ASQUA	-----	-----	-----	0,13	-----	-----	-----	-----
Lime	LIMET	-----	-----	-----	1,33	2,66	-----	52,65	-----
Lemon	CILIM	-----	-----	-----	1,32	-----	-----	-----	-----
Júcaro	BUCBU	-----	-----	-----	3,82	-----	-----	11,32	-----
Fruta pan	CASSA	-----	-----	-----	5,61	-----	-----	-----	-----
Yamagua	GUTRI	-----	-----	-----	3,67	-----	-----	-----	-----
Jagüey	FICRA	-----	-----	-----	12,58	14,83	-----	-----	-----
Cocoa	TEOCA	-----	-----	-----	2,59	-----	-----	-----	-----
Mango	MANIN	-----	-----	-----	23,20	17,86	-----	28,36	10,40
Orange D	CISID	-----	-----	-----	1,67	4,24	-----	6,60	-----
Yagrumo M	DIDMO	-----	-----	-----	5,35	-----	-----	-----	-----
Yagruma	CECPA	-----	-----	-----	1,33	31,88	-----	-----	-----
Majagua	HIBEL	-----	-----	-----	3,28	7,12	-----	-----	-----
Sapodilla	CALSA	-----	-----	-----	-----	7,03	29,49	-----	-----
Mamey A	MAMRI	-----	-----	-----	-----	11,67	39,38	-----	-----
Avocado	PERAM	-----	-----	-----	-----	-----	13,14	-----	-----
Rubber	CASEL	-----	-----	-----	-----	-----	-----	-----	9,21
Ipil ipil	LEGLA	-----	-----	-----	-----	15,55	26,55	-----	1,38
Ocuje	CALAN	-----	-----	-----	4,16	23,16	-----	-----	-----
Orange A	CISIA	-----	-----	-----	1,33	0,82	-----	26,41	-----
Coffee	COFAR	-----	-----	-----	1,59	------	-----	-----	-----

*Acronyms of scientific names

Table 6. Percentage of carbon in the soil per subsystem; Total profit and profit range during the four years of research in the "Finca la Loma"

Subsystems	MO %		Difference of MO	% of carbon	Total carbon gain (t ha-1)	Gain range (t ha-1)	
	Start	Final				Minimum	Maximum
1	3,10	3,93	0,83	0,48		0,08	0,48
2	3,62	4,07	0,45	0,26			
3	3,56	4,00	0,44	0,26			
4	4,24	4,42	0,18	0,10			
5	3,48	3,62	0,14	0,08			
6	3,67	3,86	0,19	0,11	5,09		
7	3,10	3,66	0,56	0,32			
	Average carbon %			0,23		1,76	10,56

Behavior of the Agrobiodiversity Index (IDA)

The values in Table 7 are indicating that the research work contributed to raising the ADI in only four years, from an initial value of 0,67 to a value of 0,77. On the other hand, two new sub-indexes of great value are added to the proposal, because besides enriching the index, it manages to deepen more in the knowledge of the agroecosystem (11).

Altieri and Nicholls have pointed out the need to know scientifically the events of mutual dependence and facilitation within the agroecosystem itself; and they indicate that even this topic has been little investigated (57). It was interesting to appreciate the advances by sub-index, values that stimulate to promote the strategy followed prospectively, towards a greater approach to sustaina-bility in a short time.

The flexibility of the actors when assuming proposals seems to be a determining factor in these purposes.

Relevance of the application of an agroecological strategy for pre-mountain agroecosystems

The systemic and holistic view of the agroecosystem

The investigation proved that the whole is much more than the sum of the parts, when detecting the existence of determining elements in their interactions, which do not show all their importance in the parts, independently. The sum of the inputs to the system is much lower than the outputs, the result of well-conducted internal processes (Figure 3).

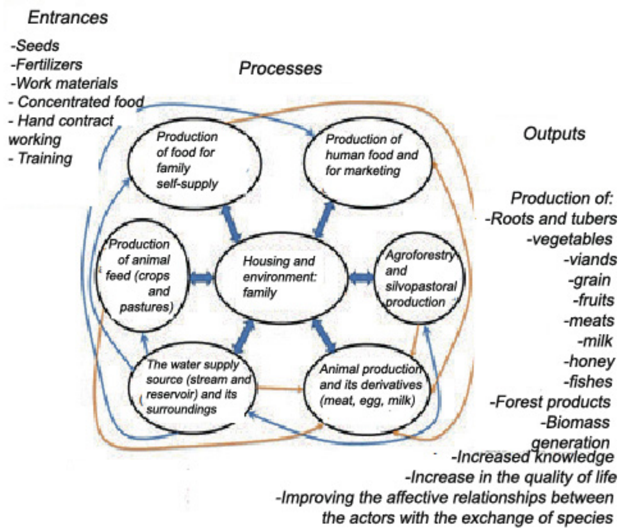

Figure 3. Interactions between the subsystems of the agroecosystem. Analysis of inputs, processes and outputs

The integral analysis of the agroecosystem with its interactions presents the housing and its environment as the center of the holistic development process, so that the remaining subsystems con-tribute to its strengthening, considering that this subsystem represents the central axis of the devel-opment of the productive system.

The inputs to the system are well used by human resources, which provide greater outputs, thus showing the value of the leader's management capacity, even though the analysis of energy ex-penditure would be lacking, to verify the efficiency of its use (58).

Table 7. Values of the Agrobiodiversity Index (ADI) and the sub-indices that make it up

Species groups	Components	Years			
		2008	2009	2010	2011
Human food (total) Subindex FER	IFER	0,77	0,85	0,90	0,90
	Trainer (vegetal y animal)	0,63	0,84	0,84	0,84
	Energetics	0,91	0,91	1,00	1,00
	Regulators	0,78	0,82	0,88	0,88
Animal feed (total) Subindex FE	IFE	0,69	0,76	0,81	0,81
	Trainer	0,54	0,61	0,70	0,70
	Energetics	0,84	0,92	0,92	0,92
Ground feeding (total) Subindex IAVA	IAVA	0,52	0,61	0,62	0,62
	Green manure	0,22	0,51	0,51	0,51
	Live coverages	0,53	0,53	0,53	0,53
	weeds	0,82	0,80	0,82	0,82
Complementaries (total) Subindex COM	ICOM	0,73	0,77	0,77	0,78
	Condiments	0,66	0,72	0,72	0,72
	Ornamentals and flowers	0,64	0,76	0,76	0,76
	Trees and shrubs	0,70	0,70	0,70	0,70
	Free animals	0,88	0,88	0,82	0,87
	Medicinal	0,77	0,85	0,85	0,85
Agrobiodiversity index	IDA	0,67	0,74	0,77	0,77

Efficiency of contributions made to the agroecosystem during the experimental period

In agroecology, the three dimensions of sustainability (Economic-Ecological-Social) are valued (46,59); therefore, an analysis beyond the purely economic is required (Tables 8 and 9), to reflect the total of indicators (quantitative and qualitative) using weighting of values.

A general total index of 0,65 was obtained (qualitatively), therefore, the contribution made was relevant, even though it was limited by the lack of local resources; while the quantitative indicators obtained a general index of 0,75, which were favored by other contributions introduced by the local government, which would require cost analysis.

Table 8. Qualitative evaluation of the indicators evaluated in the agroecosystem during the experimental period

Contributions	Quantity	Weighting value	Index value
1- Introduced species (biodiversity)			
Human feed	11	7,4	0,74
Animal feed	3	7,5	0,75
Ground feed	1	4	0,40
Complementaries	11	7,1	0,71
For the balance of the agroecosystem	2	3,5	0,35
Sub total		5,9	0,59
2- Agroecological techniques			
Polycultures	8 associations	6,9	0,69
Introducción de biofertilizantes	2 biofertilizers	9,0	0,90
Introduction of bioproducts (pest)	2 bioproducts	9,0	0,90
Reorganization of reforestation	2 activities	7,5	0,75
Containment belt (for the lagoon)	1 activity	1,0	0,10
Sunflower handicraft processing	2 activities	1,0	0,10
Milk production	2 activities	7,0	0,70
Soil production	1 activity	7,0	0,70
Sub total		6,1	0,61
3- Training			
Agroecology themes	5 topic	7,4	0,74
Sub total		7,4	0,74
4- Contribution to government proposals			
Contribution	Protected crop	5,0	0,50
	Semi protected crop	7,0	0,70
	Pig breeding	8,0	0,80
	Bull breeding	7,0	0,70
Sub total		6,8	0,68
Total		6,5	0,65

Table 9. Quantitative evaluation of indicators incorporated into the agroecosystem during the experimental period

Agroecological techniques	Cultures (in associated systems)	IET individuals	IET of the association	Index value
Polycultures	Sunflower	0,49	1,03	0,63
	Tomato	0,54		
	Corn	0,51	0,99	0,59
	Tomato	0,48		
	Sunflower	0,73	1,29	0,89
	Bean	0,56		
	Corn	0,56	1,06	0,66
	Bean	0,50		
Subtotal				0,69
	Initial production (liters)	Final production (liters)	% of increasing	Index value
Milk production	3	5	76,6	0,8
Total				0,75

Strategic proposal for the prospective development of the agroecosystem

The strategic proposal for the prospective development of pre-mountain agroecosystems is based on the results achieved, using new sustainability indicators with their qualitative and quantitative evaluation. The steps to follow are summarized in Table 10.

Diagnosis as a primary element of the strategy allowed us to know the historical context, decipher its benefits and limitations in its approach to sustainability; for this reason, the variables that define the determining indicators of each dimension were assumed. It was possible to know the critical problems in the agroecosystem, which were hierarchically defined critical problems. The realiza-tion of workshops, supported by a questionnaire pre-prepared and participatory enriched at local scale, depending on the problems to be determined for its solution, showed its validity in coinci-dence with the critical problems detected at the beginning of the investigation.

The delivery of a training program, to try to create an attraction base in favor of the cancellation of the main critical problems was efficient; given the level of acceptance achieved. These proposals have full force, although their solution also depends on the resources that would be needed to comply with the support of the local government.

The evaluation in space and time of the agrobiodiversity through its quantification and characteri-zation according to its utilitarian values has been one of the basic actions of the strategy, which suggested establishing new species as an adequate food complement.

The species with the greatest capacity for carbon sequestration were determined and suggestions are made for reforestation aimed at the protection of depopulated and sensitive surfaces to be eroded. The foundations were laid for the calculation of an index of carbon retention at the agroe-cosystem scale.

Table 10. Proposal of the agroecological strategy to follow in the "Finca la Loma"

Actions	Disclosure of problem	Proposed Solution
The local diagnosis is made and the specific	The critical problem (s) is determined Indicators of the three dimensions of sustainability are included and dominant technologies are defined (agro-ecological or high-input)	Development of a training program. Workshops are held to reveal the agroecological richness of the farm, its limitations, potential development possibilities and market opportunities. It is proposed to create a network of young agroecologists. A network of agroecologists is created with the young people of the community. The authorities are informed about critical problems and proposed solutions
Evaluation of agrobiodiversity and the accompanying or complementary diversity	Biodiversity is quantified and classified by its utilitarian values. Deficits and spatial and temporal availability are revealed	Absent diversity is introduced and study of its inclusion in the system The analysis of the spatial and temporal use is made and the technique of multiple crops is applied
Space arrangements	The problems of competition due to interference, allelopathy or both are detected	The most compatible crops are associated and negative allelopathic actions between incompatible crops are avoided, through spatial and temporal arrangements that provide an ATER > 1
Calculation of carbon sequestration	The species with the highest levels of carbon sequestration are quantified and the need for balanced reforestation of the agroecosystem is calculated through an Arboreal Carbon Sequestration Index (ISCa). The state of the agroecosystem is revealed in this indicator	Reforestation is reoriented for the agroecosystem, according to its needs, which includes the containment strips of the stream and water reservoir. A sowing or plantation program of regulatory tree species (from food analysis) and precious wood (from forest analysis) with high capacity to capture carbon is established
The systemic and holistic view of the agroecosystem	The nonexistent or existing items are defined with limited contributions	It is proposed an equitable distribution of human and material energy resources that favor less favored areas (reforestation, fish farming and beekeeping) so that the relevance of the agroecosystem in favor of economic, ecological and environmental sustainability is raised

The new spatial and temporal arrangements and the existence verification of interference competi-tion, or allelopathy, served as a complement to the research and showed relevance and need to identify the most efficient, as a basis for the use of the surfaces, to benefit the synergies, and avoid the adverse effects.

CONCLUSIONS

- ♦ The agroecological principles applied to the locality for the systemic characterization of a pre-mountain agroecosystem were pertinent, by detecting the external and internal problems limiting development and proposing ways and methods to solve them.
- ♦ The high floristic wealth of the agroecosystem is enriched to meet vital nutritional needs and its conduction with timely spatial and temporal arrangements are relevant for a proper food balance with productive efficiency under systems of polycultural production.
- ♦ The calculation of carbon sequestration by species and subsystem shows the importance of this indicator, to stop deforestation and lay the foundations of the necessary balance, through an Index of Arboreal Carbon Sequestration (ISCa) applicable to pre-mountain agroecosystems.
- ♦ *H. annuus* cultivar 'Caburé-15' cultivated in the pre-mountain agroecosystem produces chem-ical substances that inhibit the growth of S. lycopersicum cultivar 'Vyta', which may be responsi-ble for the negative effect on the development of this culture in association.
- ♦ The strategic proposal of prospective management of the pre- mountain agroecosystem, allows to tracing the guidelines to follow with a view to the desired integral development, with the use of new indices and indicators for a closer approach to the local agrarian sustainability, assuming di-versity as its central axis.

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