American Journal of Environmental Science and Engineering
2024, Vol. 8, No. 4, pp. 138-145
https://doi.org/10.11648/j.ajese.20240804.15

Research Article

Design of Agroforestry Systems for the Santa Rita Micro-Watershed in the Southeastern Region of Cuba

José Ángel Chang Porto[1, *], Mercedes Aguilar Castañeda[1], Yisel Rojas Serrano[2], Rolando Arteaga Duran[1], Rafael Avadi Perez[3], Yaquelin Puchades Izaguirre[4]

[1]Technical Sciences Department, Municipal University Center, Palma Soriano, Cuba
[2]Hydrometeorology Department, Provincial Meteorological Center, Santiago, Cuba
[3]Municipal Company of Hydraulic Resources, Palma Soriano, Cuba
[4]Biotechnology and Genetics Department, Sugar Cane Research Institute, Palma Soriano, Cuba

Abstract

The high demand for food and the overexploitation of natural resources to provide goods and services permanently to the population cause negative effects on the balance of ecosystems; however, depending on the management, systems intervened by man can offer a variety of services in a sustainable manner. Agroforestry systems(AFS), through the combination and interaction of all their components, seek to contribute to food security and to the improvement of the quality of life of peasant families, allowing at the same time the diversification of production, environmental sustainability and the generation of marketable surpluses. The fundamental objective of this work was the design of AFS in areas of the Santa Rita micro-basin, municipality of Palma Soriano, southeastern region of Cuba. To this end, the biophysical characterization of the study area was carried out and in plots with land use conflict; AFSs were designed based on their location within the water network of the micro-basin and the effective depth. Seven AFS alternatives were proposed on 52.91 ha, which contributes to the generation of a source of employment and income for the inhabitants of this agricultural setting; improves the coverage of the protection strips of the riverbeds, increases the forested area and the biodiversity of the Santa Rita micro-basin.

Keywords

Micro-Watershed, Use Conflict, Agroforestry Systems

1. Introduction

The process of intensification of agricultural production activities causes continuous soil degradation and the gradual loss of essential ecosystem services [1-3]. Degradation processes are widespread in hillside ecosystems, causing soil loss and depletion, economic damage, risk conditions and environmental changes [4-6]. Faced with this situation, agroforestry emerges as a productive alternative that contributes to reducing the vulnerability and impact of human activities on these fragile hillside ecosystems. Agroforestry creates an agroecosystem similar to the natural ecosystem before being

*Corresponding author: jchang@uo.edu.cu (Jose Angel Chang Porto)

Received: 15 September 2024; **Accepted:** 31 October 2024; **Published:** 23 December 2024

intervened, protects the soil from heavy rainfall from these slopes, maintains the hydrological cycle and biological diversity and, therefore, guarantees greater sustainability compared to systems such as monoculture [7-9].

Changes in land use in areas of the coffee farm located in the surroundings of the Santa Rita micro-basin, in the Palma Soriano municipality, in the southeastern region of Cuba, with the use of inadequate production systems, have generated a high level of deforestation of native vegetation. This has caused the loss of valuable species of flora and fauna, the deterioration of the protective functions performed by gallery forests in the catchment basins, and low productivity in essential crops. This situation results in economic losses, with a negative socio-environmental impact on producers in the surrounding rural communities, which leads to an increase in environmental degradation in the micro-basin.

The objective of this work was the design of agroforestry systems (AFS) in areas of the Santa Rita micro-basin, to rehabilitate the functions of the ecosystem, with a view to achieving its sustainability and resilience. In this way, it contributes to restoring soil productivity and the conservation of this fragile ecosystem.

2. Materials and Methods

2.1. Location of the Study Area

The micro-basin object of study is called Santa Rita, it is located between the coordinates X1- 579.027,43, X2 – 582.031,14; and Y1 – 167.016,40, Y2 -168.875,15; between the cartographic sheets at a scale of 1:25 000 of Las Cuchillas and Dos Palmas, in the popular council of Caney del Sitio, belonging to the municipality of Palma Soriano. Santiago de Cuba Province [7].

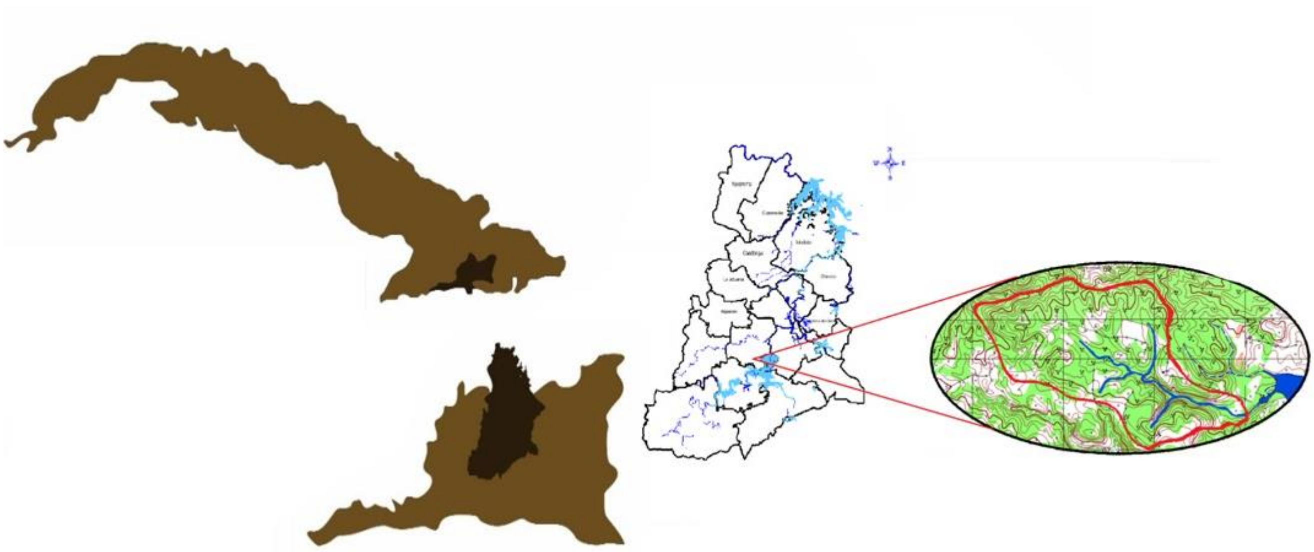

Figure 1. *Location map of the basin under study.*

2.2. Biophysical Characterization of the Study Area

2.2.1. Climate. Precipitation and Temperature

The precipitation and temperature data were taken from measurements made by the instruments located at the hydrometric station of the Gilbert reservoir.

2.2.2. Soil

For the study of the soils, the soil map at a scale of 1:25,000, prepared by the soil institute of the Ministry of Agriculture (MINAGRI), was consulted; the second genetic classification prepared by [10] was used.

2.2.3. Relief

In the study of the relief of the micro-basin, the contour map at a scale of 1:25,000 was used, with intervals of 10 meters. To calculate the average slope, the maximum and minimum elevation of the perimeter of the study basin was taken into account.

2.2.4. Hydrography

The main stream and its tributaries were identified using the cartographic map of the area, and the total length of the streams was calculated using Mapinfo v.12.0 software to determine the drainage network that makes up the micro-basin.

2.2.5. Vegetation

The diagnosis of the existing vegetation was carried out through a field survey, where linear transects were made identifying the tree, shrub and herbaceous species that made up the natural formations. The study carried out by [11] was used to classify the vegetation.

2.3. Survey of the Current Situation by Means of Diagnostic Techniques

Participatory Rural Diagnosis

To gather information, a tour of the agricultural areas of the micro-basin was conducted and, subsequently, a meeting was held with representatives of the cooperatives located in the micro-basin, with whom the fundamental problems affecting the sustainability of this ecosystem were defined by consensus, and the management to be carried out to mitigate the impacts was defined.

2.4. Design of Agroforestry Systems for the Santa Rita Micro-basin

Based on the previous analysis carried out in 304.72 ha of the Santa Rita micro-basin, [12], the plots with land use conflicts were considered to design AFS models that contribute to soil conservation and protect the water network from sedimentation caused by erosion. The AFS proposal was based on 7 indicators that were defined according to the location of the plots within the water network of the micro-basin and the effective depth of the soil.

3. Analysis of the Results

3.1. Biophysical Characterization of the Study Area

3.1.1. Climate: Precipitation and Temperature

In the analysis of climatic factors, it is evident that the months with the highest rainfall coincide with the rainiest months of the spring period (May-October), which is very decisive for coffee crops, as it is the fundamental crop in this agricultural scenario, and also for the planting of short-cycle crops (figure 2). The greatest increase in temperature corresponds to the summer months, where the insolation in the tropics is greater, which suggests that at this time of year, crop protection against solar incidence should be improved and agrotechnical management strategies designed in accordance with the humidity demand of traditional crops [12].

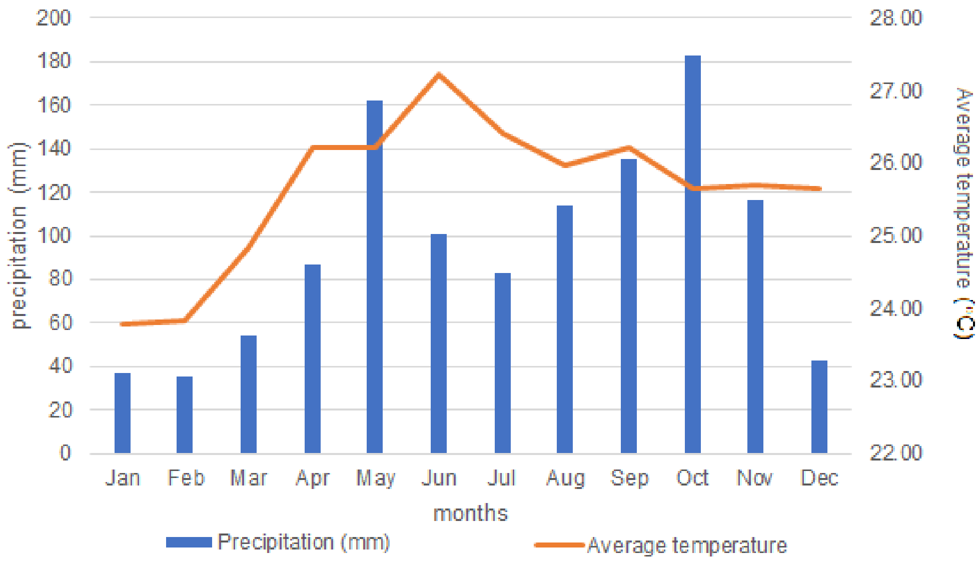

Figure 2. *Average monthly rainfall and temperatures in areas of the Santa Rita micro-basin.*

3.1.2. Soil

The soils in this area are ucric cambisols [10], with a higher degree of erosion in some areas, due to overexploitation without the application of soil conservation measures appropriate to this topography. It is suggested that these soils suffer from the loss of the a+b horizons of 50 to 55 cm; they are moderately productive due to erosion and the slope, which are limiting factors; and they are light to moderately clayey soils, with a sialitic composition.

3.1.3. Relief

The area under study is located between the elevations of 342 (upper part) and 160 (lower part) meters above sea level (masl). The topography is hilly, with intermittent valleys that run only during the rainy season. The slope was classified according to 4 ranges (Table 1), of which 58% of the study area has slopes greater than 12%, which shows a rugged topography with limitations for carrying out agricultural activities in some areas of the micro-basin that can generate erosion.

Table 1. *Slope classification and percentage of study area.*

RANGE(%)	RELIEVE	ÁREA (ha)	(%)
0-2	Plain		
5-12	Soft	76,48	25
12-20	Half	143,03	47
20-40	Medium to trong	85,21	28
Total		304,72	100

3.1.4. Hydrography

The micro-basin occupies an area of 304.72 ha and a perimeter of 8 km, and is located in the middle part of the Cauto River basin. It is a tributary of the Gota Blanca reservoir, classified as a supply to the population residing in the city of Palma Soriano; part of this water is used for irrigation in agriculture. Its drainage network is made up of a stream called El Quemado, with a length of 2.5 km, into which 3 tributaries or dry valleys discharge their waters, which flow only when there is runoff caused by rain. Its drainage density is 0.82 km/km^2, with a concentration time of 2.21 hours, and a slope in the main channel of 9%. These values in a micro-basin are considered medium to high, so the erosive potential and the transport of sediments to the river channels are greater [12].

3.1.5. Vegetation

The characteristic vegetation of this area is mesophytic forests, with semi-deciduous species [11] (Figure 3). There are tall trees with precious wood species such as cedar (*Cedrela odorata*), baria (*Cordia geraschanthus*); hard trees such as the piñon florido (*Gliricidia sepiums*); semi-hard trees such as the algarrobo (*Samanea saman*), and soft trees such as the ayua (*Zanthoxylum elephantiasis*). These forests are also made up of tall fruit species such as mango (*Manguifera indica*), guava (*Psidium guajaba*), anonas fruit (*Annona squamosa*), and mamoncillo (*Melicoccus bijugatus*), all mixed together as part of the coffee semi-forest.

Figure 3. *Natural vegetation in areas of the Santa Rita micro-basin.*

3.2. Design of Agroforestry Systems for the Santa Rita Micro-basin

In studies previously carried out in the Santa Rita micro-basin [12], the current use of the soils was determined. According to the analysis carried out, the authors found that 25 plots within the perimeter of the micro-basin, with an area of 52.91 ha, were located in areas with conflict in use (14 overexploited and 11 underused).

This work took the previous results as a reference and based on the analysis of the plots located in the slope range between 12 and 15%, the location within the water network of the micro-basin, the effective depth of the soil and the content of existing organic matter, served to define 7 criteria that supported the proposal to change the use as an AFS, which are mentioned below.

1. Secondary forest with a predominance of tall fruit trees
2. Cultivated slope at the source of the riverbed
3. Source of the riverbed, with scattered fruit trees in production
4. Cultivated slope with a slope > 12%, in the area of the strip
5. Slope with scrub, with a slope < 6%
6. Cultivated slope with a slope > 6%, in the area of the strip
7. Idle area surrounded by coffee plantations, with semi-shade

Table 2 and Figure 4 show the proposal for land use change for the different AFS to be implemented.

Table 2. *Proposed changes in land use for the different AFS.*

Actual use	Perspective Use (ha)							TOTAL
	Coffee	**temporary crops**	**AFS**	**Fruit Forest**	**AFSs c/fruit**	**Protector forest**	**Hydroregulatory strip**	
Forest	3,58							3,58
Crop			3,53	1,59	6,89		15,03	27,04
Unused	3,18	2,01		12,53		4,57		22,29
TOTAL	6,76	2,01	3,53	14,12	6,89	4,57	15,03	52,91

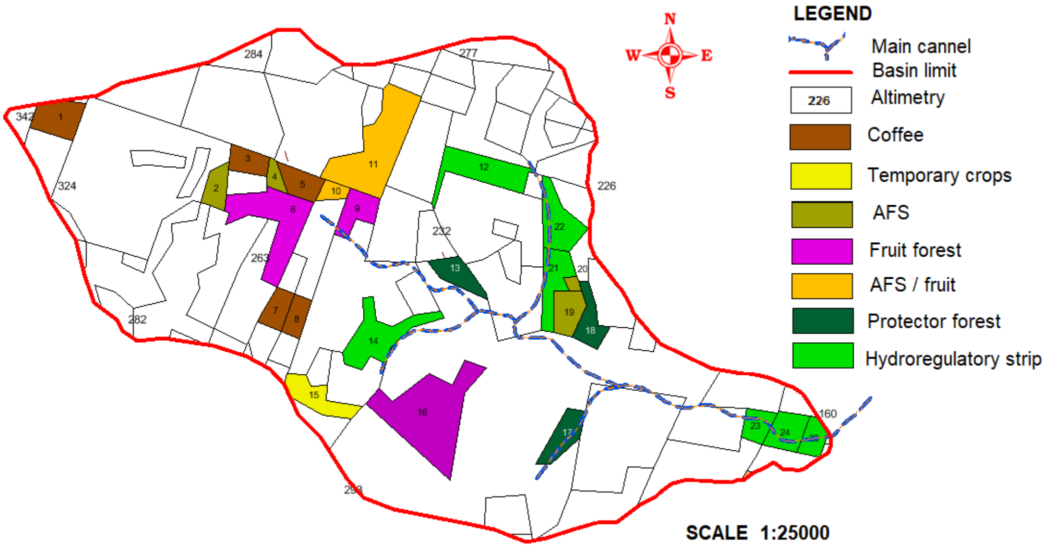

Figure 4. *Proposed map of prospective land use in the Santa Rita micro-basin.*

In a study carried out in the Cauca Valley [13], they proposed indicators for the selection of areas with a vocation to apply SAF with the use of a GIS and socioeconomic diagnosis similar to those proposed in this work, demonstrating the usefulness of the analysis of biophysical and socioeconomic indicators for the design of SAF.

SAF promote biodiversity at the genetic, species (wild, native and non-native) and crop levels, which is crucial for the protection and development of ecosystem services and environmental functions [14, 15].

3.3. Management to Be Applied for Each Proposed Agroforestry System

3.3.1. Proposed Area for Planting Coffee: 6.76 ha

In these areas, which were former coffee plantations, it was proposed to plant coffee after evaluating, according to laboratory analysis results, that the soil properties were similar to those of the surrounding coffee plantations in their environment.

It is suggested as a management for the existing forest formation to thin out from below, to improve the structure of the canopy, with a view to creating semi-shade for the new coffee seedlings.

The planting of the *Coffea canephora* var. Robusta species is recommended, as it is more resistant to the prevailing climatic conditions in this area.

3.3.2. Area Proposed for Planting Various Crops: 2.01 ha

Areas located on the plain of the basin, taking advantage of the fact that the slope in these plots does not exceed 7%, and because the soil has good effective depth.

It is proposed to allocate these plots to the production of short-cycle crops such as: sweet potato (*Ipomoea batatas*), pumpkin (*Cucurbita americana*), corn (*Zea mays*), beans (*Phaseolus vulgaris*); with the objective of producing food for the workers in the coffee harvest.

It is recommended that the preparation of the area be carried out with a silvicultural treatment, which is financed by the State Forest Service (SFS), at a cost of 3845.74 Cuban pesos (CUP)/ha (24 CUP = 1 USD), for the state sector). As for management, it is suggested to maintain developing fruit trees within the area and shrubs with honey-producing characteristics such as the flowering pinon (*Gliricidia sepium*), almacigo (*Bursera simaruba*) and ateje (*Cordia collococca*) within the perimeter of the plots.

3.3.3. Agroforestry System on Slopes: 3.53 ha

In these plots, it was decided to plant a strip of multipurpose forest and fruit species along with the annual agricultural crops, because they are located in areas with a slight slope (10%), which causes sediment to be carried into the riverbeds during the rainy season. It is recommended to plant this strip in 3 sections: upper, middle and lower part (hydroregulatory strip), with a separation of 6 meters.

Figure 5. *Proposed areas for AFS on slopes.*

3.3.4. Proposed Area for Fruit Forest: 14.12 ha

Looking for a strategy of diversification in agricultural production, it is proposed to plant 1.59 ha, which were used for planting crops, and 12.53 ha that were idle, to plant fruit trees, taking advantage of the species existing in these plots such as mango (*Manguifera indica*), caimito (*Chrysophyllum cainito*), loquat (*Manilkara zapotilla*), sapote (*Pouteria sapota*), guava (*Psidium guajava*), and mamoncillo (*Melicoccus bijugatus*), although with low density per species. The production of the fruit trees will serve to feed the workers who will participate in the coffee harvest in this area.

3.3.5. Agroforestry System with Fruit: 6.89 ha

These areas were used for the production of temporary crops, but are located on slopes > 8%, and have some fruit trees in production within the area.

Low-growing fruit trees such as guava (*Psidium guajava*) and pineapple (*Ananas comosus*) were planted at a contour line as shown in Figure 6, at a distance between rows of 5 meters. This plantation has two fundamental objectives: soil conservation by acting as natural barriers, and the production of fresh fruit for marketing.

Figure 6. *Contour pineapple barrier.*

3.3.6. Proposed Area for Protection Forests: 4.57 ha

Taking into account the location of these secondary forest areas in the watercourse recharge zones, and because they have a slope greater than 12%, it is recommended to promote permanent forests for the protection and conservation of the catchment basins. As management, improvement felling should be carried out, eliminating invasive species that form dense masses of little commercial value, such as rubber (*Castilla elastica*).

Figure 7. *Degraded natural forests.*

It is proposed to plant cedar (*Cedrela odorata*) and jobo (*Spondias mombin*) seedlings using the strip enrichment method, 10 meters apart in the row, and on the banks of the yamagua (*Guarea guidonia*), yaba (*Andira inermis*), and ayúa (*Zanthoxylum martinicensis*) riverbeds; seeking to improve the composition and structure of the target forest, with species that may in the future become grain-bearing trees and help in the dissemination of seeds of species of economic and ecological value in this environment.

The system was designed based on the mechanics of erosion retention and the potential of agroforestry practices to conserve soil and its productivity. Thus, in the upper part of the micro-basin, the forest component acts as a cover that reduces the erosive effect of raindrops, thus limiting the possibility of soil erosion.

3.3.7. Hydroregulatory Strip: 15.03 ha

The 7 plots proposed to be used for this system are used for the production of temporary crops in areas of the protection strip of river channels, which causes severe sedimentation.

In the complementary regulations of the Forestry Law in Cuba [16] it is stated that, "In forest strips, the promotion of agricultural crops is prohibited, as well as any movement of land, unless it is carried out as part of compliance with anti-erosion measures." Therefore, the recommended management is to plant strips of evergreen forest and fruit trees in these areas, using the three-loaf method, with a 2x2 meter frame, from the normal water level (Nwl) of the channel, on both banks, in vertical projection towards the top of the slopes.

3.4. Socio-environmental Benefits That Will Be Obtained by Applying the SAF in This Micro-basin

Economic benefit

1. The area of coffee planted for new crops in 3 years increases production and income in both currencies.
2. The new plantations of fruit trees grafted between 3 and 5 years will provide fresh fruit of 5 species that will be marketed and will increase income.
3. The production of root vegetables, grains and vegetables increases

Social benefit

1. Sources of employment are created.
2. Family incomes are increased.
3. The food supply to the communities located in this agricultural setting is improved.
4. Food production is diversified, improving nutritional content.

Ecological benefit

1. It improves the protection of the channels against sedimentation caused by erosion.
2. The biodiversity of the floral resource and the habitat of the fauna is increased.
3. It improves the protection of the soils against erosion.
4. Improves the local climate
5. Increases forest cover.

4. Conclusion

The proposed AFS to mitigate soil degradation in the Santa Rita micro-basin were designed based on 7 indicators based on the location of the plots within the water network of the micro-basin and the effective depth of the soil. Seven AFSs alternatives were proposed in 52.91 ha, which contribute to improving the coverage of the protection strips of the channels, increase the forested area, biodiversity, and generate a source of employment that improves the income of the inhabitants of the Santa Rita micro-basin.

With the implementation of these agroforestry systems, 3 economic benefits, 4 social benefits, and 5 ecological benefits are achieved that will allow the rehabilitation of this fragile mountain ecosystem.

Abbreviations

AFS	Agroforestry System
MINAGRI	Ministry of Agriculture
Nwl	Normal Water Level
SFS	State Forest Service
CUP	Cuban Pesos

Author Contributions

José Ángel Chang Porto: Project administration, Validation

Mercedes Aguilar Castañeda: Investigation

Yisel Rojas Serrano: Investigation

Rolando Arteaga Duran: Investigation, Validation

Rafael Avadi Perez: Investigation

Yaquelin Puchades Izaguirre: Investigation

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Jiang S, Xiong K, Xiao J. Structure and Stability of Agroforestry Ecosystems: Insights into the Improvement of Service Supply Capacity of Agroforestry Ecosystems under the Karst Rocky Desertification Control. Forests. 2022; 13(6): 878. https://doi.org/10.3390/f13060878

[2] Talukder, B. Multi-Criteria Decision Analysis (MCDA) Technique for Evaluating Health Status of Landscape Ecology. In Landscape Ecology for Sustainable Society; Springer: Cham, Switzerland, 2018; pp. 39–49.

[3] Lebuy, R.; Mancilla-Ruiz, D.; Manríquez, H.; De la Barrera, F. Degraded Landscapes in Hillside Systems with Agricultural Use: An Integrated Analysis to Establish Restoration Opportunities in Central Chile. Land 2023, 12, 5. https://doi.org/10.3390/land12010005

[4] Brandolini, P., Pepe, G., Capolongo, D., Cappadonia, C., Cevasco, A., Conoscenti, C., Del Monte, M. Hillslope degradation in representative Italian areas: Just soil erosion risk or opportunity for development? Land Degradation & Development, 2018; 29(9), 3050–3068. https://doi.org/10.1002/ldr.2999

[5] Zhang, W.; Li, H.; Pueppke, S.G.; Diao, Y.; Nie, X.; Geng, J.; Chen, D.; Pang, J. Nutrient loss is sensitive to land cover changes and slope gradients of agricultural hillsides: Evidence from four contrasting pond systems in a hilly catchment. Agric. Water Manag. 2020, 237, 106165.

[6] Yi, J.; Zeng, Q.; Mei, T.; Zhang, S.; Li, Q.; Wang, M.; Tan, W. Disentangling drivers of soil microbial nutrient limitation in intensive agricultural and natural ecosystems. Sci. Total Environ. 2022, 806, 150555.

[7] Marrero Basulto, J. M., Luis Machín, J. A., Novúa Alvarez, O., Rodríguez Hernández, S. V., & Tur Pérez, S. El Atlas Nacional de Cuba "LX Aniversario". Hacia un atlas vivo. Revista Cubana De Geografía, 2020; 2(1). Recuperado de: https://revistasgeotech.com/index.php/rcg/article/view/318

[8] de Mendonça, G.C.; Costa, R.C.A.; Parras, R.; de Oliveira, L.C.M.; Abdo, M.T.V.N.; Pacheco, F.A.L.; Pissarra, T.C.T. Spatial indicator of priority areas for the implementation of agroforestry systems: An optimization strategy for agricultural landscapes restoration. Sci. Total Environ. 2022, 839, 156185.

[9] Rahman MHu, Ahrends HE, Raza A and Gaiser T. Current approaches for modeling ecosystem services and biodi-versity in agroforestry systems: Challenges and ways forward. Front. For. Glob. Change, 2023; 5:1032442. https://doi.org/10.3389/ffgc.2022.1032442

[10] Hernández-Jiménez, A., Pérez-Jiménez, J.M., Bosch-Infante, D. y Castro Speck, N. La clasificación de suelos de Cuba: énfasis en la versión de 2015. Cultivos Tropicales; 2019, vol. 40, no. 1, Disponible en: https://ediciones.inca.edu.cu/index.php/ediciones/article/view/1504

[11] Reyes, O.J. Clasificación de la vegetación de la Región Oriental de Cuba. Revista del Jardín Botánico Nacional, 2011; vol. 32/33, Disponible en: https://www.jstor.org/stable/23725915

[12] Chang Porto, J.A, Aguilar Castañeda, Sánchez Guerra, Y. Arteaga Duran, R. Puchades Izaguirre, Y. Land use planning, in the Santa Rita micro-basin, Palma Soriano municipality. Journal CFORES, enero-abril 2024; 12(1): e811. ISSN: 2310-3469 RNPS: 2347.

[13] Rubiano, J., Rincón Romero, M. & Castro Llanos, F. Identificación de áreas potenciales para la implementación del sistema agroforestal Quesungual en el Valle del Cauca. Perspectiva Geográfica, 2014; 19(2), 201-218.

[14] Kay, S., Rega, C., Moreno, G., den Herder, M., and Palma, J. Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. Land Use Policy, 2019; 83, 581–593. https://doi.org/10.1016/j.landusepol.2019.02.025

[15] Sagastuy, M., and Krause, T. Agroforestry as a biodiversity conservation tool in the atlantic forest? Motivations and limitations for small-scale farmers to implement agroforestry systems in North-Eastern Brazil. Sustainability, 2019; 11, 1–24. doi: 10.3390/su11246932

[16] Garea Alonso, J. M. La Ley Forestal de Cuba: su importancia y repercusión. Estudio legislativo de la FAO. 2001. Disponible en: http://www.fao.org/Legal/default.html