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Tradeoffs between units providing soil ecosystem services in multifunctional landscapes of the Orinoquia

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Ecological assessment of soil ecosystem services was made through indicators of provision of nutrients, amount of organic matter, and cation exchange capacity; and climate regulation, carbon storage, in the Orotoy river basin. As units that provide ecosystem services, mosaics of tropical humid forest cover, oil palm crops and cattle pastures were selected, persistent for 20 years, in windows located in the upper, middle and lower areas of the basin. Soil samples (896) were collected and analyzed in the laboratory for determining physical and chemical properties. The data were processed with the SPAW and R software. Indicators, ranging from 0 to 1, and tradeoffs were represented on a 1: 25.000 scale land cover map. It was found that in the indicator of carbon storage, the low zone obtained the highest average value (0.42); and the indicator of the ecosystem service of nutrient provision obtained close average values in the middle and lower zones, 0.33 and 0.44, correspondingly. In vegetation cover, the tropical humid forest presented the highest average values for the indicator of climate regulation (0,43). The established trade-offs from the valuation are: the upper zone is fundamental for water regulation and climate regulation throughout the basin; forest cover in the entire basin regulates the climate, oil palm crops and cattle pastures *via* fertilization, contribute to the surrounding forests, located in areas of less slope. In the mosaics of the multifunctional landscapes it was found that although the ecosystem services are related to the forming factors of the soil and the vegetation coverage, the influence of cultural practices on the soils is also evident; these determine trade-offs. The importance of including the ecosystem services of the soil in the processes of territorial ordering and management of landscapes like the one of the basin of the Orotoy river is verified, which in the current management scenario presents trade-offs between zones and coverages.

KEYWORDS

socio-ecosystems, valuation, ecosystem service provider units, piedmont, tropical ecosystems

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Introduction

The amount and dynamics of soil organic carbon are the major determinants of the quality and quantity of Ecosystem Service (ES) (Powlson et al., 2011). Soil organic matter is recognized as a key factor controlling the ability of soil resources to provide agricultural and environmental services and sustain human societies, both on a local scale (e.g., maintenance of fertility) and global (e.g., mitigation of atmospheric emissions of C) (Lal, 2004; Marks et al., 2009; Buckingham, 2014; McBratney et al., 2014; Adhikari and Hartemink, 2016). The soil supporting services of nutrient cycling, measured with the storage indicator (t of C ha^{-1} or t N ha^{-1}), is related to soil fertility, soil biodiversity, the capacity to capture, retain and transport water or carbon, or to form or release greenhouse gases from the soil (GHG) and is largely determined by the ability of each soil to form and decompose organic matter (Victoria et al., 2012).

Likewise, soil organic carbon, higher in quantity than the content in the atmosphere, is related to changes in land use, tillage and the incorporation of residues (IPCC, 2006); it is also known that soil can release greenhouse gases into the atmosphere (GHG) as a result of accelerated decomposition due to land use change or unsustainable land management practices (Victoria et al., 2012) and global environmental change (Santacruz, 2010).

For the Orinoquia natural region, there are recent studies on soil ES; among them, Lavelle et al. (2014) studied biodiversity and ecosystem services associated with the soil resource in the Colombian high plains, in large scale production systems, improved grasslands, annual crops (rice, corn and soybeans), oil palm and rubber plantations, contrasting them with the semi-natural savanna; as contributions recorded: the management of chemical fertilization is one of the main drivers of soil processes; Biodiversity and biogeochemical cycles inherited from the original semi-natural savanna (organic matter, nutrient reserves) are essential characteristics to understand the state of the system and understand the current and future trajectories of changes in ecosystems, among others. Sanabria et al. (2014) contribute to the knowledge of biological indicators of ants and the Alexander von Humboldt Biological Resources Research Institute (IAvH), Cormacarena and Corpoica (2015) and Rojas Salazar (2017) advance in the search for sustainability indicators, combining physical properties such as infiltration and water storage to evaluate the ES of provision in the high plain.

On the other hand, at Morinelly plains foothills (2015) the ecological assessment for the Orotoy basin was carried out, at a scale of 1:100,000 and it reported that the highest storage in aerial biomes occurred in gallery forests of the middle zones (1.506.37 t ha^{-1}) and lower zones (980.5 t ha^{-1}). In the same large landscape, Carvajal (2018) found in soils from the "Fluventic Humic Dystrudepts-Typic Fluvaquents" Association, that the gallery forest stored the highest amount of total carbon (139 t ha^{-1}) and that the bushes are also an important total carbon sink (91,7 t ha^{-1}), while soils in different agricultural uses store less. Zárate (2018) reported for a Lithic Eutropept soil, in the Ariari region (municipality of Lejanías), a storage of 291.4–336.8 tons of CO_2 ha^{-1}, with a higher value of soils with natural vegetation cover; suggests that the strategy of using vegetation cover on the ground is a viable measure to help mitigate climate change.

Several authors highlight the importance of spatialization and adequate representation on the scale of the ES in landscape units to answer questions about planning of the soil use, conflicts and opportunities management, support for decision-making on the territory at local, regional and global levels and support of governance processes and institutional strengthening (Syrbe and Walz, 2012; Crossman et al., 2013; Laterra, 2013; Caro-Caro and Torres-Mora, 2015; Malinga et al., 2015; Nahuelhual et al., 2015). In this same line, Andrade et al. (2014), Andrade and Castro (2012) and Andrade-Pérez et al. (2013) postulate the recognition of the territory as a socio-ecological system, a condition applicable to the Orotoy river basin due to its multifunctional landscapes.

They are called multifunctional landscapes because of the perception from experts about the capacity of ecosystems to provide ES to society (García-Llorente et al., 2012). These heterogeneous landscapes with mosaics of agroecosystems and natural systems, with permeable natural and social borders, maintain a flow of genes, water, nutrients, energy, and information (Andrade-Pérez et al., 2013; Mastrangelo et al., 2015). However, it must be kept in mind that the spatial organization of landscapes strongly affects trade-offs, because it affects the capacity of a given landscape to supply ES (Domptail et al., 2013).

In this context, the generation of territorial management processes for the Orotoy river basin is part of the challenges on ES exposed by de Groot et al. (2010), where soil is understood as a complex system and closely linked to ecosystem processes that provide multiple ES to society (Adhikari and Hartemink, 2016). The multifunctional landscape of the Orotoy river basin presents trade-off changes associated with the expansion of intensive oil palm cultivation, especially in the last decade, which would affect the ability of the landscape to maintain its ES.

The use of ecological indicators of soil ecosystem services, in multifunctional landscapes, allows establishing trade-offs between UPSEs, so that their representation supports decisions on planning of soil resources, in a given territory. By this work we wanted to analyze whether the use of ecological indicators of soil ecosystem services of nutrient and carbon storage capacity will support decisions on planning of soil resources in the Orotoy river.

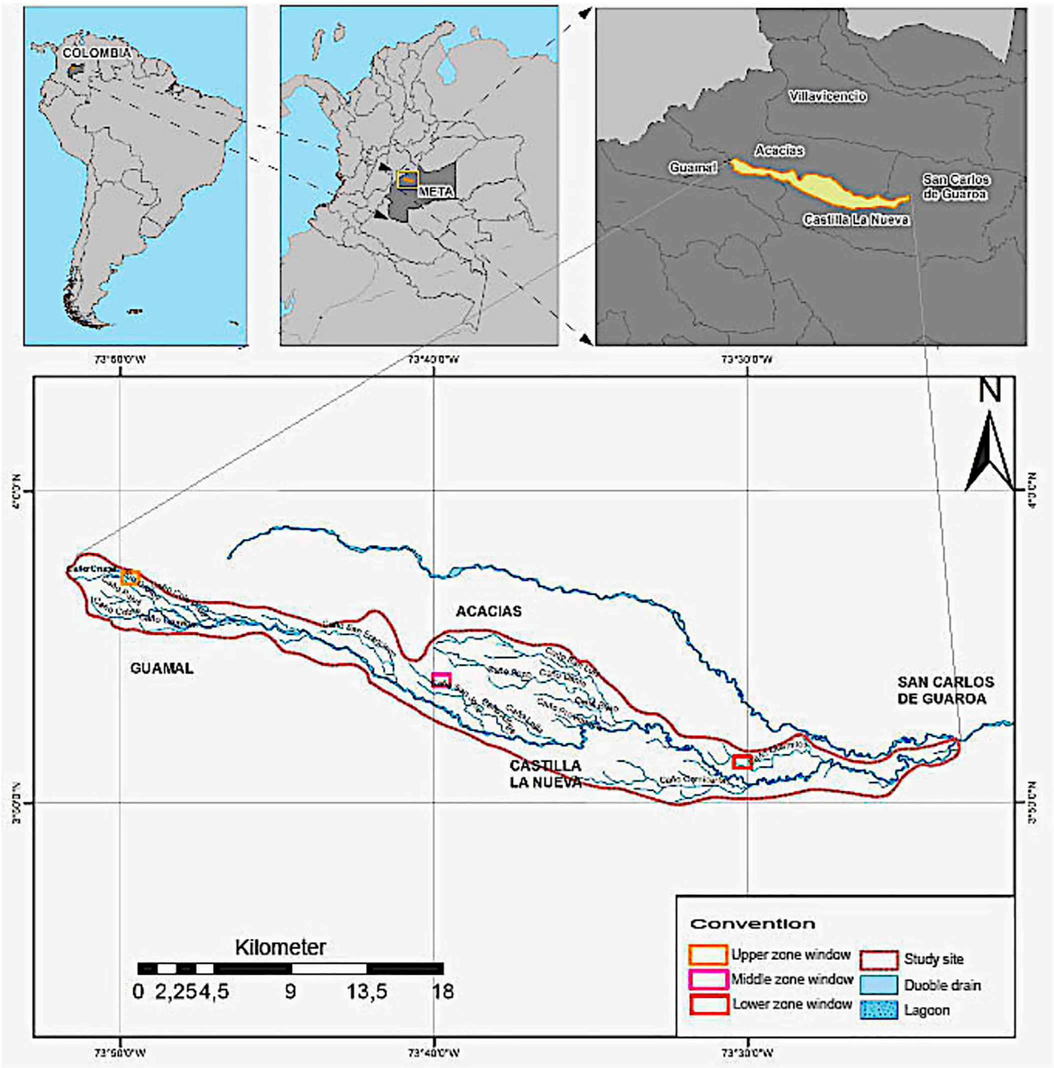

FIGURE 1
Location of the Orotoy river basin and ESPU in upper, middle and lower basin zones windows. Source: Elaborated by the authors.

Material and methods

Study site

The study was carried out in the Orotoy River's drainage basin located at the coordinates 947000 N 1049414 E, 947000 N 1055777 E, 941000 N 1049414 E y 941000 N 1055777 E, at the piedmont of the Eastern Cordillera, and an area extends over approximately 188 km^2. The Orotoy river begins at an elevation of 1,620 m above sea level in the Orotoy hill at the municipalities of Guamal (El Retiro and Recreo rural districts) and Acacías (San Juanito and Fresco Valle rural districts) and proceeds to the Acacías River over a natural course of 54.5 km^2 at an elevation of 250 masl, in the vicinity of the Dinamarca (municipality of Acacías), Barranco Blanco (municipality of Castilla La Nueva) and Patagonia rural districts (municipality of San Carlos de Guaroa).

Research approach

We used the approach of Ecosystem Service Provider Units -ESPU-, discriminating them as follows: ESPU socio-ecosystems, basin zones, called upper, middle and lower; ESPU coverage, corresponding to a natural ecosystem, tropical dense humid forest (DF), or agroecosystems, oil palm plantation (OP) and cattle grassland (GL); and the transect ESPU, assigned to the one carried out in each

TABLE 1 Relationship of ecosystem services with their indicators and previous study sources. Orotoy river basin. Source: Elaborated by the authors.

Process - ecological function	Ecosystem service	Indicator	Soil properties	Study
Nutrient cycling	Nutrients-fertility support	Nutrient availability	Soil Organic Matter (%), pH, Cation exchange capacity (Ca, Mg, K, Na), P availability	Rodríguez et al., 2013, Lavelle et al., 2014, Adhikari and Hartemink, 2016, Rojas Salazar 2017, IAvH, 2015a, IAvH, 2015b. Adhikari and Hartemink, 2016, Carvajal, 2018, Zárate, 2018
Climate regulation	Carbon sequestration	Carbon storage capacity (Soil C stocks)	Soil Organic Carbon (t ha^1)	

vegetation coverage and in the ecotones (transitions between them) (Figure 1).

The ES and indicators selected for this case, from previous thematic studies reported for Orinoquia in general (Osorio, 2014; Lavelle et al., 2014; Rojas Salazar 2017; IAvH et al., 2015; Morinelly, 2015) and from advances in necessary methods for the development of research (Bullock et al., 1985; Jaramillo, 2002) are listed in table 1; For the ecological assessment process, it was started from the ES identified as priority, due to their critical condition and the perception of local stakeholders: determination of the water supply in the soil, carbon storage and water regulation (Caro-Caro et al., 2011, IAvH, 2015a, IAvH, 2015b).

The following criteria for the selection for study windows of 70 ha were applied: the change in land cover from 1986, 2000, and 2014 (Carvajal, 2015) and the analysis of available satellite images based on a Google Earth query in coverage, year 2014 (upper zone) and 2015 (middle and lower zones); the inclusion of the altitudinal gradient from the upper part to the lower part (Caro-Caro et al., 2011); the presence of landscape mosaics made up of tropical humid forest (persistent at least since 1986), Oil Palm Plantation and grasslands (with permanent lots of more than 20 years), and lotic systems; the guarantee of disposition of minimum cartographic units; and the record of access conditions for the collection of primary information and collection of samples. The field work was carried out from May to December 2016, during the rainy season (May to November) and the beginning of the dry season (December). The transects defined for each window and the way in which the 896 soil samples were collected in the field are illustrated in Figure 2. A total amount of 180 soil samples were collected; three replicates came from each transect, at depths of 0–10 cm and 10–20 cm. Seventeen (17) transects defined for the mosaics of each window is illustrated in Figures 2A,B. Samples were collected using a stainless-steel hand auger and stored in labeled polyethylene bags until transport to the Unillanos' soil analysis laboratory. Undisturbed soil samples were also taken with cylinders 5 cm high × 5 cm in diameter at depths of 0–10 cm and 10–20 cm in each transect to determine porosity (real and bulk density). (Grimaldi et al., 2014).

The pH values were measured with a potentiometer in a 1: 1 soil: water mix. Organic matter content (OM) was determined by the Walkley–Black method, as described by Jackson (1967); available phosphorus was determined by the Bray II method; and particle size distributions were determined by the hydrometer method (Bouyoucus, 1951). The exchangeable bases potassium (K+), magnesium (Mg2+), sodium (Na+), and calcium (Ca2+), were analyzed after extraction using 1 M ammonium acetate at pH 7.0; Ca2+ and Mg2+ in the extracts were analyzed using an atomic absorption spectrophotometer, whereas Na+ and K+ were determined by fame photometry. Exchangeable acidity and interchangeable aluminum were determined by the KCl method (extraction with 1 N KCl), and efective cation exchange capacity (eCEC) was determined by mathematical calculations (IGAC, 2006). The quality control chemicals and solutions were of analytical standard book reagent grade and was assured using duplicates at the lab level. Bulk density using the cylinder method (Blake and Hartge, 1986) and then drying at 105°C for 48 h (Doran and Mielke, 1984).

Data analysis

The methods on which this study was based correspond to the estimation of an indicator of an ecosystem service, in this case the indicator of the ecosystem service of fertility, from the physical (clay) chemical variables (pH; interchangeable bases, CEC, P) statistically analyzed using the principal component analysis. Statistical analyses were performed in the R software environment (v.3.6.1; R Development Core Team, 2019) with the ade4 Package. An initial principal component analysis (PCA) allows for identification of the variables that best discriminate among the different windows, land cover and transects. Variables with significant contribution (>50% of the maximum value) to either of the first two principal component axes were selected and their contribution to

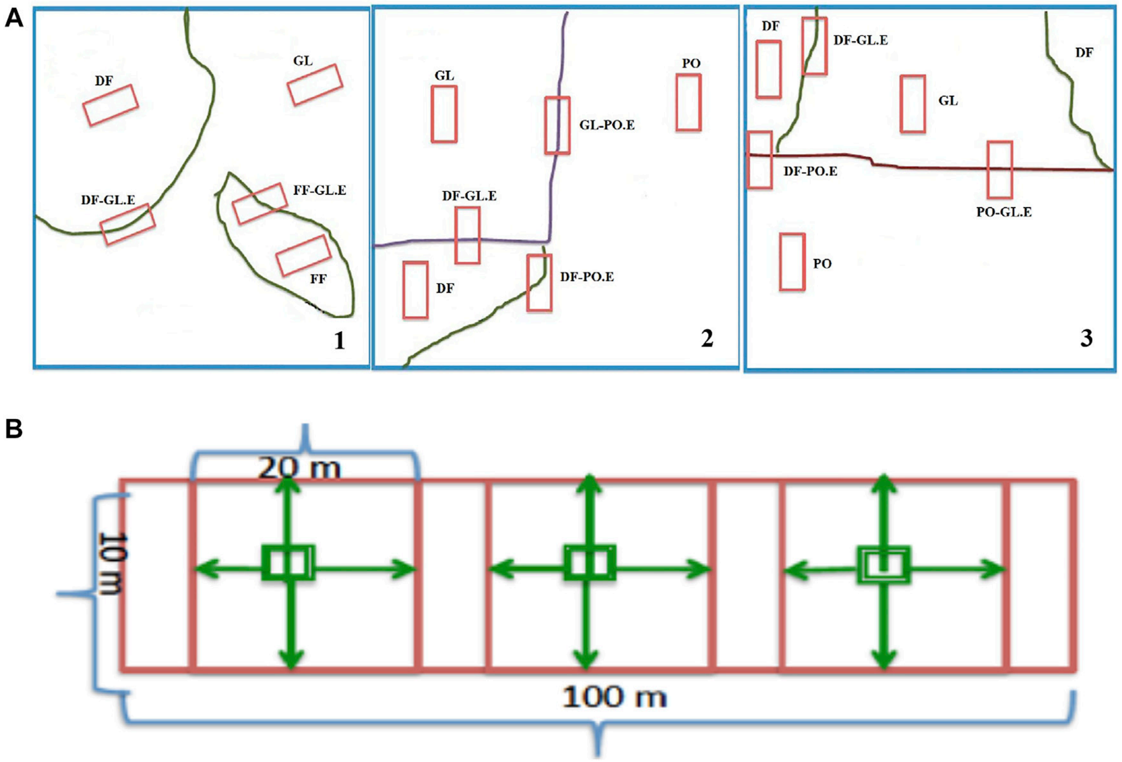

FIGURE 2
(A) Transects location within and between the landscape mosaic in the Orotoy river basin. Red squares represent transect within sampling area ▭. 1) Upper window zone. 2) Middle window zone. 3) Lower window zone. FF, Fragmented Forest; DF, Tropical Dense Humid Forest; GL, Cattle Grassland; OP, Oil Palm Plantation. E, Ecotone transect. Source: Elaborated by the authors. **(B)** Diagram of the sampling units: transect (100 m × 10 m) with three plots (20 m × 10 m). In green the systematic soil sampling is indicated. Orotoy river basin.

PCA axes 1 and 2 multiplied by the overall variability explained by each PCA axis in order to generate a weight factor for each variable. Values for each variable were then multiplied by their corresponding weight factor and summed to generate a raw sub-indicator value using the following formula described by Lavelle et al. (2014).

$$I_{i1} = F_1 \times (\alpha Ia + \beta Ib + \gamma Ic\cdots) + F_2 \times (\alpha IIa + \beta IIb + \gamma IIc\cdots)$$

I_{i1} = value of the ecosystem service indicator at point 1 (window, coverage, transect).

F_1 = % of the value of the variance explained by axis 1 of the PCA.

αI, βI, γI = respective contributions of variables a, b, c to the factor I.

a, b, c = values of the variables measured at the point 1.

Analysis of variance was performed to compare indicators across windows and transects and Tukey´s test was applied with significant level of $\alpha = 0.05$.

Results

Ecosystem Service soil fertility associated with variables of organic matter and cation exchange capacity

From the PCA, the first two components were choose, with weights explaining total variance of 31.4% and 20.4%, respectively (Figure 3). The most important soil properties explaining the variance of the data were the Organic Matter (OM) and Cation Exchange Capacity (CEC), thus they were selected for estimating the nutrient availability indicator, in the ESPU. The PCA allowed to establish that in the windows zone two groups were differentiated: one for the upper zone and another formed by the middle and the lower zones. In terms of transects those corresponded to the Fragmented Forest (FF) and the Fragmented Forest-Grassland Transition (FFGL) ecotone clearly separated, standing out in the whole set the transect of the Oil Palm Dense Forest Transition (OPDF) ecotone (Figure 4).

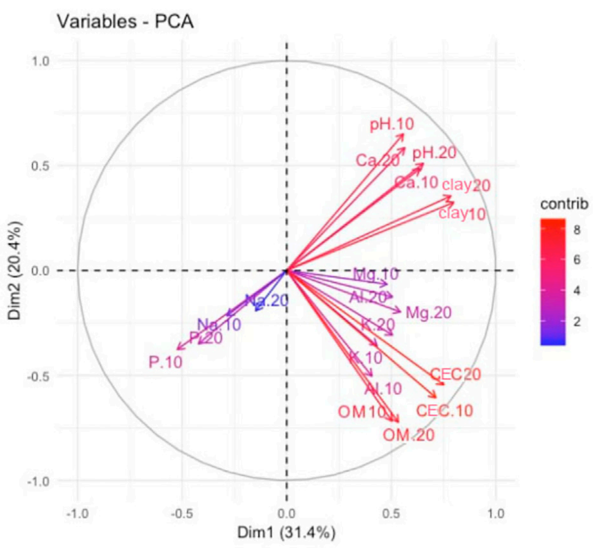

FIGURE 3
Correlation circle with all the chemical variables and clay content to build the soil fertility ES valuation indicator. Orotoy river basin.

The ANOVA showed a highly significant difference between windows (Table 2), where two transects of the remaining group are also separated: the FFGL ecotones (lower value) and the OPDF (highest value). The highest values of the nutrient availability indicator were found in the transects where the oil palm plantation was located, the lowest values in the dense forest and the pastures that have not been fertilized (Figure 5).

Ecosystem service carbon storage in soil associated with organic matter

In the determination of the carbon stock with the variables apparent density and organic matter (%), for the depth of 0–10 cm, the indicator of the ES carbon storage for the ESPU varied significantly between windows, with a more high value for the window of the lower zone, while the land cover with the highest value was that of the OPDF ecotone and the lowest was the FFGL ecotone (Figure 6; Table 3).

Table 3 shows that the highest mean values of the carbon stock indicator were obtained by the forest cover and the transect corresponding to the ecotone between the DF and the Oil Palm- OP. On the other hand, the mean comparison of the soil carbon storage indicator separated the ESPs windows into two groups: upper and medium in one, and in the other hand, lower.

Discussion

Some disadvantages of ecological evaluation focused solely on the condition of the habitat are covered, as Postchin and Haines-Young (2013) expressed. The importance of ecologically valuing soil ES is inferred, an aspect that several authors recently pointed out (Adhikari and Hartemink, 2016; Jónsson and Davíðsdóttir, 2016; Jónsson et al., 2017) at detailed scale (1: 25.000) from the multifunctional approach to the landscape, as a strategy to support land use planning and management in a specific area or object of study. Likewise, Dale and Polanski (2007) expressed that the set of ES, measured by ecological indicators, can increase the value of agricultural lands under alternative management in contrast to the current management.

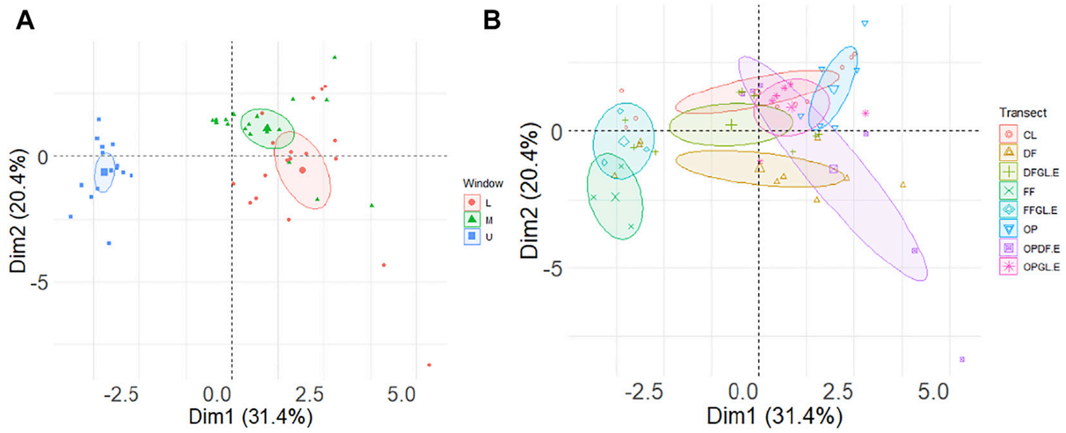

FIGURE 4
Analysis of Principal Components for ESPU, soil ES indicator of nutrient availability. **(A)**. Window. **(B)**. Transect. Orotoy river basin. FF, Fragmented Forest; DF, Tropical Dense Humid Forest; GL, Cattle Grassland; OP, Oil Palm Plantation. DFGL.E, ecotone DF-GL; OPDF.E, ecotone OP-DF; OPGL.E, ecotone OP-GL; FFGL.E, ecotone FF-GL. Source: Elaborated by the authors.

TABLE 2 ANOVA for ESPU of the nutrient availability indicator. α = 0.05. Orotoy river basin. Source: Elaborated by the authors.

ESPU	Degrees of freedom	Sum of squares	Mean squares	F value	Pr (>F)	
Transect	7	0.2827	0.04039	2.175	0.0556	
Residuals	43	0.7986	0.01857			
Window	2	0.5818	0.2909	27.95	8.92E-09	***
Residuals	48	0.4995	0.01041			

*** Statistically significant (p-value < 0.001)

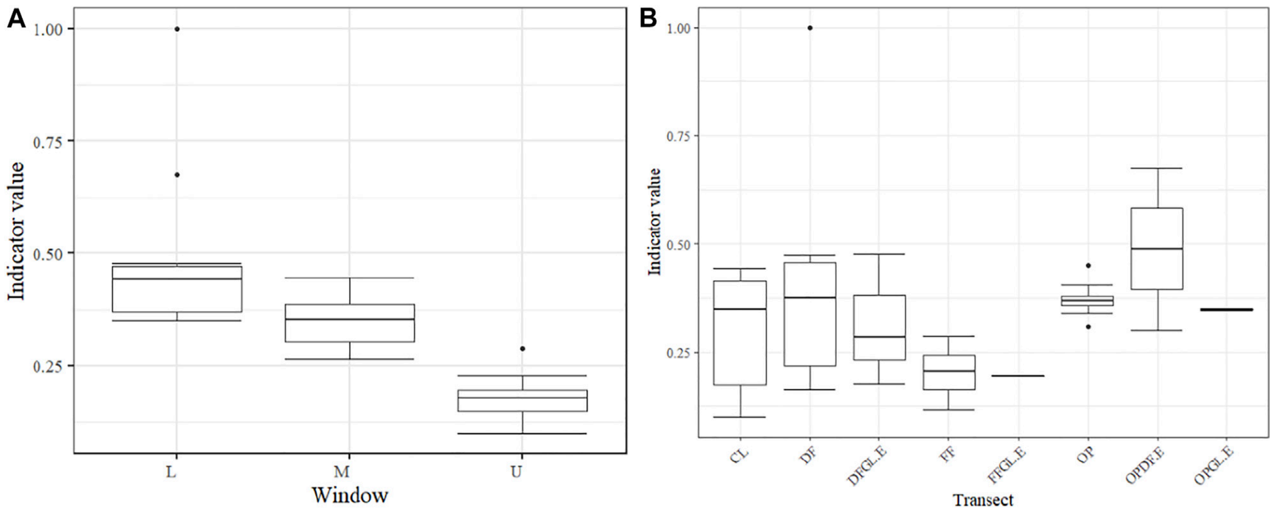

FIGURE 5
Soil ES indicator of fertility ESPU. **(A)**. Window. **(B)**. Transects. Orotoy river basin. FF, Fragmented Forest; DF, Tropical Dense Humid Forest; GL, Cattle Grassland; OP, Oil Palm Plantation. DFGL.E, ecotone DF-GL; OPDF.E, ecotone DF-OP; OPGL.E, ecotone OP-GL; FFGL.E, ecotone FF-GL. Source: Elaborated by the authors.

Ecosystem Service of nutrient supply (fertility): Indicator of nutrient availability

As a general trend, the higher value of the ES fertility indicator, associated with OM, clays and CEC, in the ESPU middle and lower zones of the basin, can be explained by erosive processes that move these particles from the upper zone and concentrate them in the other two zones (Figure 7); in the same way, anthropic contributions fertilization practices in mosaic agroecosystems, especially in OP crops - increase this indicator, due to runoff, by adding bases (Mg^+ y K^+ cations), those that consequently favor accumulation in the lower zone; Added to this is the phenomenon of washing to overflow events of the water courses (channels) that contribute with silts and clays sediments raising the value of the indicator of this ES, mainly in the lower zone.

Anderson-Teixeira and DeLucia (2011) state that the forests that host the greatest amount of carbon are the humid tropical ones that grow on periodically flooded soils. This pattern was registered in the same way in the soils of the forests studied in the Orotoy basin, regardless of its location in the different zones, although with lower values for the upper zone.

The lowest ES of soil fertility was found in the upper zone in the FFGL ecotone and the highest was found in the middle and lower zones in the OPDF ecotone. Those values are explained by how much more organic matter accumulates in the latter. Quantity of organic matter come from two main sources: Forest biomass associated with the processes and functions of soil maintenance and the contributions of the cultural management of OP cultivation: application of bases (K+, Mg++) that come by runoff and are retained, allowing a greater accumulation of organic matter in the soil and therefore an increase in the cation exchange capacity.

Another important factor in understanding soil ES in terms of nutrient provision, *via* organic matter and

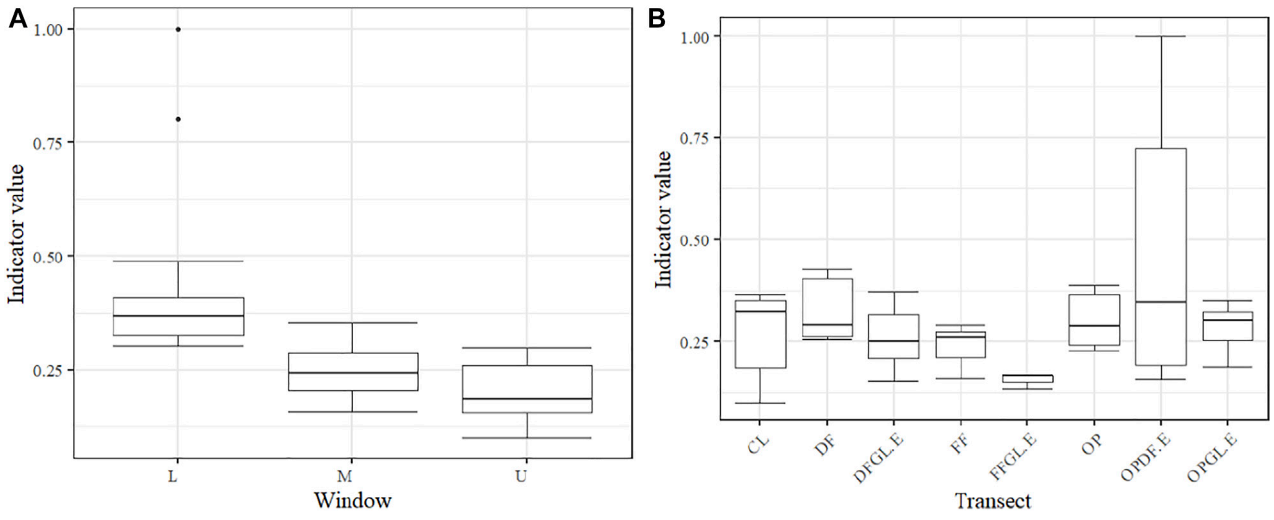

FIGURE 6
Soil ES valuation indicator, Carbon storage, for ESPUs. **(A)**. Window. **(B)**. Transects. Orotoy river. FF, Fragmented Forest; DF, Tropical Dense Humid Forest; GL, Cattle Grassland; OP, Oil Palm Plantation. DFGL.E, ecotone DF-GL; OPDF.E, ecotone DF-OP; OPGL.E, ecotone OP-GL; FFGL.E, ecotone FF-GL basin. Source: Elaborated by the authors.

TABLE 3 ES indicator estimation of the soil carbon storage.

ESPUs	Covers-ESPUs			Transects		
Z/V	**DF**	**GL**	**OP**	**OPGL.E**	**DFGL.E**	**OPDF.E**
U	0.259	0.139				
U	0.254	0.185				
U	0.281	0.1			0.151	0.243
M	0.304	0.348	0.241			
M	0.263	0.354	0.229			
M	0.29	0.343	0.246	0.186	0.204	0.25
L	0.406	0.301	0.389	0.281		
L	0.427	0.364	0.375			
L	0.411	0.322	0.33		0.315	0.342
Aver.	0.321667	0.272889	0.301667	0.2335	0.223333	0.278333
Max.	0.427	0.364	0.389	0.281	0.315	0.243
Min.	0.254	0.1	0.229	0.186	0.151	0.342

ESPUs, ES Provider Unit; Z/V, Zone/Window; U, Upper; M, Middle; B, Lower; DF, Tropical Dense Humid Forest; DFGL.E, Tropical Dense Humid Forest -Cattle Grassland Ecotone; GL, Cattle Grassland; FFGL.E, Fragmented Forest-Cattle Grassland Ecotone; FF, Fragmented Forest; DFGL.E, Tropical Dense Humid Forest-Cattle Grassland Ecotone; OP, Oil Palm Plantation; OPDF.E, Tropical Dense Humid Forest- Oil Palm Plantation Ecotone; OPGL.E, Cattle Grassland- Oil Palm Plantation Ecotone. Orotoy river basin. Source: Elaborated by the authors.

productivity, is the community of soil organisms, since they directly impact cultivation yields and indirectly *via* nutrient cycles - food chains and modification of the soil structure (Barrios, 2007). In the Orotoy basin, Morinelly (2016), reported the Acarí class and the Entomobryidae, Formicidae and Termitidae families, as the most abundant, while the highest values of indices of richness, abundance, diversity and dominance were the ESPs tropical humid forest (gallery forest) of the lower zone and for the fairness index the highest value was from the grassland ESPs (open). Thus, it is possible to highlight the functional importance of biological communities in the soil and in turn, the role of the soil in the

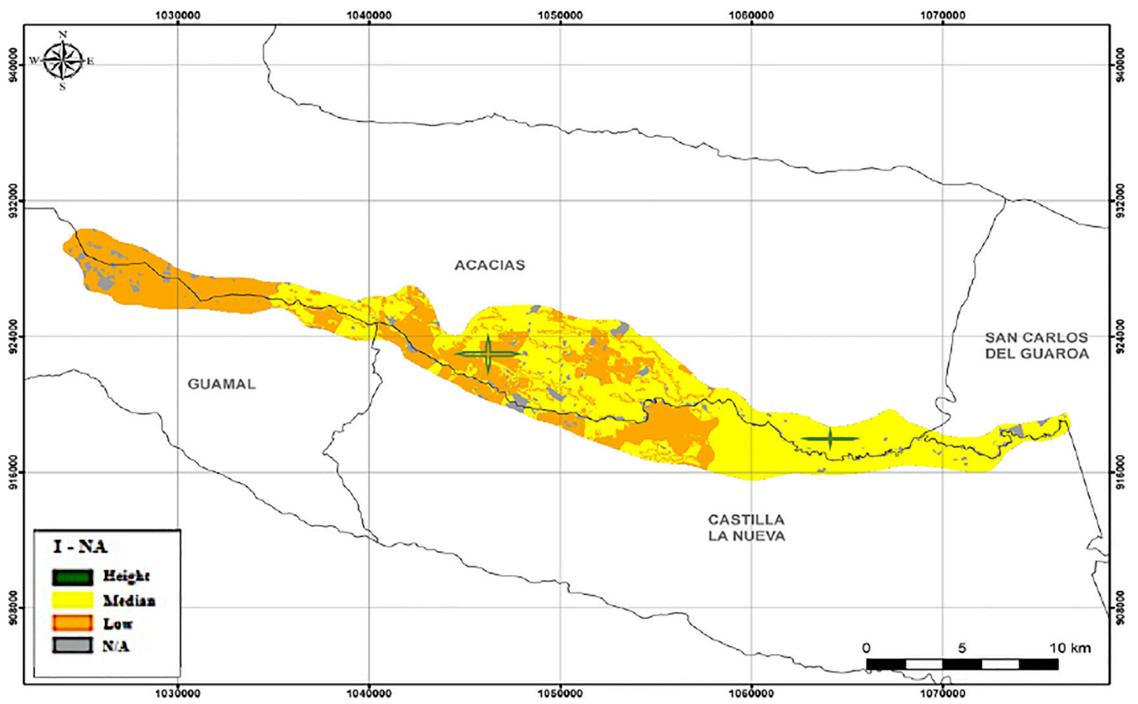

FIGURE 7
Orotoy river basin: 1: 25,000 cartographic representation of the soil ES assessment indicator "storage capacity of nutrients and organic matter." for ESPUs Window and Coverages. Arrows indicate trade-offs and the direction of their flow. Source: Elaborated by the authors.

conservation of biodiversity (Lo-Man-Hung et al., 2011; Pulleman et al., 2012).

The fertility of the landscape mosaic in the Orotoy basin depends on the parental material characterized by a low supply of nutrients, as evidenced in the ES values reported for the forests, mainly in the upper zone; In contrast, in other zones, fertility is improved with the contributions of agroecosystems; trade-offs occur from the ESPUs cultivation of PO and GL towards the DF, *via* runoff (contributions of clays, organic matter increased by cultural management) which appears to increase the ES of water storage and fertility. As Viglizzo and Roberto (1998), Viglizzo et al. (2012) stated, resolving the trade-offs between productivity, stability and sustainability is a central issue in agroecology; in this aspect, Howe et al. (2014) explained the importance of achieving synergies resulting from trade-offs, while Viglizzo et al. (2012) and O´Sullivan et al. (2015) expressed the need to develop agri-environmental policies that recognize ES and trade-offs for the sake of environmental governance.

The ES provision of soil nutrients is related to biodiversity, the capacity to capture, retain and transport water or carbon, and is largely determined by the capacity of each soil to form and decompose organic matter (Victoria et al., 2012), as established in each ESPU.

Regulatory ecosystem service: Soil carbon storage associated with organic matter: Carbon storage capacity indicator

Different studies highlight the role of soils in atmospheric carbon sequestration (Lal, 2004; Franzluebbers, 2005; Buckingham, 2014); carbon sequestration provides benefits to maintain soil quality, such as the aforementioned water storage capacity and fertility, measured as indicators of soil ES; It also allows the soil to become a storehouse of the geological and archaeological heritage of the planet (Marks et al., 2009).

In general, soil scientists recognize the importance of soil organic matter, quantity and dynamics, as a key factor that affects the soil's ability to provide services to agriculture, environment, and human communities at both local scales (maintenance of fertility for example) and global scales (mitigation of carbon emissions into the atmosphere) (Lal, 2004; Marks et al., 2009; Powlson et al., 2011; Buckingham, 2014; McBratney et al., 2014; Adhikari and Hartemink, 2016; Calzolari et al., 2016). The rational management of multifunctional landscapes is important as support in the definition of climate change mitigation strategies based on the evaluation of their ecosystem services, including carbon storage, and the spatio-temporal interactions that characterize them, as stated by, Hao et al. (2017).

In the ESPUs zones of the basin, the highest value of the carbon stock ES indicator was obtained in the lower zone, consistent with the geomorphological conditions of the foothill landscape, with alluvial plain and meander valley at this altitude (300 masl) and Typic Hapludox soil (75%). This zone receives contributions from the runoff (sediments, organic matter) from the upper part, and eventually has effects of flood dynamics due to overflow of channels, in addition to having anthropic input of nutrients by fertilization. As Morison et al. (2012) stated, variables such as forest age, elevation, species composition and soil management can influence the ability of a habitat to store carbon.

In the ESPs coverage (ecosystems), the highest average value of the carbon stock indicator obtained for the tropical humid forest (0.321), coincides as a trend with that reported by Ibrahim et al. (2007) for Colombia in the riparian forests on Andisol-type soils older than 20 years determined at 1 m depth by Moreno and Lara (2003) for intervened primary and secondary forests. While the lowest average value of this indicator for grassland cover (0.27), contrasts with that expressed by Ibrahim et al. (2007), the soil organic carbon storage pattern, in different uses, shows lower amounts in soils of advanced secondary forests and riparian forests than in grassland soils.

The organic carbon storage capacity of soil is related to the use and methods of tillage (DeFries et al., 2004; IgAC, 2006), and with deforestation and selective logging (Asner et al., 2010; Edwards et al., 2014). Regarding the formation of organic matter in Lithic Eutropept soil of foothill plains, Zárate (2018) reported the highest value of fixation, from 291.4 to 336.8 tons of CO_2 ha^{-1}, for the treatment with natural cover, concluding that the strategy of the use of vegetation ground cover is a viable measure to help mitigate climate change.

The higher value of the ES of carbon stock, obtained in the transitional palm-forest cultivation cover in the middle and low zones, can be explained from what is stated by Dale and Polanski (2007): “different forms of carbon sequestration and other environmental benefits accrue to the rows of annuals, perennials or animal husbandry ”and the ES trade-offs that allow the flow of ES from the upper to the lower zone, together with the location of forests in the windows of the basin, since the biophysical conditions in which they are located also contribute to their ability to offer ES (Maass et al., 2002). However, authors like Andrade-Castañeda et al. (2016), did not find significant differences between the ecotones agroecosystems-tropical dry forest, with records of average carbon storage 65.6 t C/ha (rice crop-riparian forest) and 61.3 t C/ha (grassland-riparian forest) at 20 cm depth.

In general for the Orotoy river basin, at a scale of 1: 100,000, local communities have identified trade-offs of the different systems (natural and transformed), from the provision of water and carbon storage in the riparian forests (Caro-Caro et al., 2011) even those provided by productive agroecosystems that generate employment and economic benefits (Osorio and Bogota, 2014; Guzmán, 2016) and cultural services (Zabala-Forero and Victorino, 2019) but they affect the ES provision and quality of the water resource (Rincón-Ruiz et al., 2016a, Rincón-Ruiz et al., 2016b; Lara, 2017; Victorino and Lara, 2017). However, it is important to specify that the dynamics of trade-offs depend on the scale that is the object of research (Laterra et al., 2012; Alarcon et al., 2015), argument that can be demonstrated in this study, where the level of detail makes it possible to establish trade-offs between natural and transformed covers in geormorphological conditions and agricultural management of the basin that favor trade-offs from agroecosystems to tropical humid forests (fertility and carbon stock indicators). Likewise, Budiharta et al. (2018) mention the importance of maintaining tropical forest areas as an alternative for carbon restoration and storage, in zones where there were OP crops, while Harmácková and Vacká (2015) concluded about the importance of “compensation in terms of ES regulation” for decisions in landscapes that need to be conserved.

Conclusion

It was possible to establish that in each ESPU the overall fertility of the landscape mosaic in the Orotoy basin depended on the parental material characterized by a low supply of nutrients.

The ES of the mosaics of multifunctional landscapes were related to the soil forming factors vegetation cover, and cultural practices; these determined trade-offs between ES.

The evaluation of the ES at multifunctional landscape level allowed to understand synergy between the different ESPU and the possible impacts in ES to nutrient provision and sustainability.

The valuation of soil ES allowed to recognize the importance of the mosaics of natural and transformed systems as part of the landscape and the trade-offs that occur between its ESPUs.

The soil ES presented as ecological indicators for nutrient supply and carbon storage in tropical forest, grassland and oil palm agroecosystems provide key information for management alternatives under scenarios of climatic changes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CC-C Question statement, gathering of primary information, processing and analysis of laboratory and data series, preparation of the paper, JB-R selection and analysis of indicators with a landscape approach, analysis and adjustment of the paper, MA-A processing and analysis of indicators, processing and statistical analysis of data, adjustment of paper, MT-M landscape approach, methodological adjustment and adjustment of the paper.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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