Article

Analysis and prioritization of production systems associated with coffee and avocado

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Abstract

The pressure for the change to avocado monocultures in traditional coffee systems in the state of Veracruz can have consequences, as this crop seeks to maximize financial profitability without considering the sustainability of employment, management, adapting and implementing environmentally friendly technologies, investment capacity and ecosystem services. The objective was to analyze and prioritize different production systems associated with the cultivation of coffee and avocado, through two scenarios: financial (EF) and multicriteria (EMC). EF included monetary measures, which calculated the Cost Benefit Ratio (RBC); at EMC, in addition to RBC, the criteria for the need for investment, employment, management, carbon and nitrogen in plant biomass, biomass and edaphic macrofauna diversity were incorporated, they were analyzed using the PROMETHEE method; through, from which a prioritization order was generated. The analyses were performed on five systems: monoculture avocado (SAM), avocado coffee (SAC), renovated coffee (SCR); coffee plantation with severe cleaning (SCL) and abandoned coffee (SCA), with cycle information 2018-2019. In EF the SAM resulted with RBC far above the others (2.43). EMC prioritized SCR, SAM, and SAC in the top three positions of the ranking. The analyses support the threat of SAM to displace coffee plantations, therefore, the challenge of designing and putting into practice public policies that value social and environmental variables remain, and thus consolidate SAC in a better position that allows to maintain coffee cultivation.

Keywords: agroforestry, multicriteria, productive diversity, PROMETHEE, sustainability.

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Introduction

Currently in Veracruz producers tend to opt for avocado planting, since their production generates net profits up to 4 695.90 $ t^{-1}, with a production of 100 kg per tree and a planting density of 100 plants per hectare (Franco *et al*., 2018), value that exceeded the 2 630.00 $ ha^{-1} net income generated in coffee plantations affected by rust with a yield of 4.5 t ha^{-1}, valued at 5 000.00 $ t^{-1}, considering a maintenance and harvest cost of 19 870.00 $ ha^{-1} (FIRA, 2016).

In Veracruz dominates the production of coffee grown under diversified shade (Sánchez-Hernández *et al*., 2018), these systems are important for: the richness of their floristic composition (Sánchez *et al*., 2017), the low investment in production; and the contribution to the storage of carbon and nitrogen. However, this activity generates low yields for coffee growers in Veracruz. This problem is attributed to the climatic variations that have generated the proliferation of rust, which affects the yield of coffee trees (Granados *et al*., 2014), which makes them vulnerable to the expansion of avocado crop as monoculture.

Changing traditional coffee systems into modern systems, such as avocado crop in Veracruz, can have negative consequences on social and environmental sustainability, as these systems seek to maximize financial profitability without considering other fundamental social factors such as the investment capacity of the small producer and of an environmental nature such as the potential to maintain carbon stores when managing diversified coffee plantations (Ayala *et al*., 2020). The topic of agroforestry systems (SAF) with coffee has been addressed from various approaches, there are studies that use socioeconomic variables to characterize coffee producers and their relationship to their current condition, local resources, access to basic services and management, in order to identify links of value (Aguirre *et al.*, 2016; Leiva *et al*., 2017; Pertuz and Pérez, 2017).

Similarly, Escalante and Somarriba (2001) indicate that the variables that determine the typology of a SAF with coffee are the costs of fertilization, fungicides and maintenance labor, and these are directly proportional to the functional composition of the shade canopy and are therefore important for classifying to the SAF. On the other hand, Dussán *et al*. (2006) identified that the structure of SAF, their production and productivity depend on variables level of education and access to technology. These studies demonstrate the importance of socioeconomic variables in characterizing SAF with coffee, determining their typology, to value the importance of productive diversification and the application and adoption of technology; however, the profitability and variations in socioeconomic and environmental variables of coffee plantations associated with avocado are still unknown.

The integrated analysis of these factors for the coffee systems associated with avocado allows characterizing them under the same comparison pattern and analyze their relationships, helping to develop productive diversification strategies that integrate environmental services with socioeconomic variables and sustainable production. Under this approach, this work aims to analyze and prioritize the production options associated with coffee and avocado crops in Huatusco, Veracruz, Mexico.

Analysis and prioritization are proposed in the light of scenarios that consider, in addition to the private criterion, aspects of public interest with the inclusion of variables that allow to measure the need for investment, employment, management to innovate, carbon and nitrogen content, soil diversity (biomass and diversity of the soil macrofauna), which contribute to social and environmental well-being.

Most problems involving decisions related to prioritization, classification, and choice involve several criteria, which can be addressed in an integrated manner using methods that are grouped into multi-criteria analysis (AMC). The AMC has been widely used in the agricultural sector as a tool to organize the various criteria and alternatives, as well as strategically support a variety of challenging decisions of farmers and policy makers (Berbel *et al*., 2018).

There are multicriteria analysis studies that support the management decision-making of entire agricultural regions (Bournaris *et al*., 2009; Hands *et al*., 2010), impacts and policy scenarios (Hands *et al*., 2006, 2013; Riesgo and Gómez, 2006; Bournaris and Manos, 2012; Bournaris *et al*., 2014), disparities in rural areas (Popescu and Bara, 2015) biomass production (Tziolas *et al*., 2017; Caprara and Martelli, 2016; Kylili *et al*., 2016), biodiversity conservation strategies (Moffett and Sarkar 2006), decision on the location of the agroforestry biomass cogeneration project (Wu *et al*., 2019), among others.

These studies show that the AMC has allowed multiple aspects to be integrated under a holistic approach that contribute to decision-making, since this tool allows to evaluate the impacts, selection of criteria, weighting and aggregation of indicators (Finkbeiner *et al*., 2010). However, the literature does not yet report cases of applications on decisions of agroforestry systems with productive diversification with coffee and avocado that allow the sustainability of coffee plantations affected by rust at the small producer level.

In recent years multicriteria analysis has been used in different scientific branches (Maia *et al*., 2017) due to its practicality and usefulness of methodological integration. Several AMC methods have been implemented to assess environmental, economic and social sustainability in agricultural production. One of the distinctions between the AMC categories is based on the full aggregation approach and the overcoming approach, as the interactive methods (test and error approximation) are not applicable in a multivariate analysis (Benoit and Rousseaux, 2003). Among the most commonly used methods, it is mentioned: multi-attribute utility theory (MAUT) (Lipuscek *et al*., 2010; Myllyviita *et al*., 2012); methods of overcoming (PROMETHEE and ELECTRE) (Kralisch *et al*., 2013; Castellini *et al*., 2012); analytical hierarchy process (AHP) (Dinh *et al*., 2009; De Luca *et al*., 2015); qualification technique for multiple simple attributes (SMART) (Myllyviita *et al*., 2014); visekriterijumska optimization ikompromisno resenje (VIKOR) (Falcone *et al*., 2016); order preference technique similarity with ideal solution (TOPSIS) (Karklina *et al*., 2015).

The advantage of the AMC is that it can integrate subjective economic, environmental and social aspects into evaluation objectively (Myllyviita *et al*., 2014; De Luca *et al*., 2017), since they can be normalized and weighted with the application of various methods such as: ELECTRE, PROMETHEE and TOPSIS. Weighting and standardization through these methods provides transparency for interpretation, as implementation without standardization and weighting substeps could reveal problems for aggregation and comparison of results (Bengtsson and Steen, 2004).

Materials and methods

The study was conducted in Huatusco Veracruz, Mexico, where five cases of studies were selected with the traditional snowball methodology, these cases correspond to the types of management representative of the area: coffee system with abandonment of cultivation for 12 years (SCA), renewed coffee system with varieties of coffee tolerant to rust (SCR), coffee system with severe pruning and cleaning (SCL), avocado system with coffee (SAC) and system with avocado as monoculture (SAM).

Each system was characterized through structured interviews where the economic variables corresponding to the costs of installation, maintenance, inputs, harvest, yield, quality of coffee cherry and quality of avocado fruit in each system were addressed. For social variables, the number of day laborers was considered for each of the activities carried out in the systems, the technologies installed and the number of trainings in which they participate annually, in order to value the capacities of the small producer to maintain and change its production system. Environmental variables were carbon and nitrogen content in plant biomass, biomass and soil macrofauna diversity.

These variables allowed to obtain eight criteria, grouped into three dimensions: (1) financial, which includes the cost benefit ratio (RBC); (2) social, which includes the need for investment (NI), employment (E) and management to innovate (G); and (3) environmental, which considers the carbon content in superior plant biomass (C), nitrogen content in lower plant biomass (N), soil macrofauna biomass (BM) and soil macrofauna diversity (DM). The methodology for determining each criterion is detailed in Table 1.

The analysis of the information collected was developed within of two scenarios

Financial analysis, in which only RBC is considered, based on monetary measures. Multicriteria analysis, in which in addition to the benefit-to-cost ratio, non-monetary aspects considered in the social and environmental dimensions were integrated. In this scenario, each of the three dimensions was assigned the same weight of importance (33.33%), leaving the weights of the different criteria as follows: RBC (33.33%), NI (11. 1%), E (11.1%), G (11.1%), C (8.34%), N (8.34%), BM (8.34%), DM (8.34%). The same weight was considered for all criteria according to the sustainability approach of production systems (Hermann *et al*., 2007; Maia *et al*., 2017).

In the first scenario, the projected cash flow for a 30-year production cycle was analyzed with a discount rate of 10% for each system, and then determined the cost benefit ratio with the revenue information generated by each product in the system and the costs of installation, maintenance, production and harvesting.

All these values were analyzed based on the annual production trend of each crop in the system and with the start of production from the third year of planting. The value of the discount rate was considered according to the methodology proposed by Pérez y Garza (2013) for this type of systems.

For the analysis of the second scenario, multi-criteria analysis, the information collected in each of the criteria was used, for each of the systems (Table 1), which emphasizes that the NI criterion is the only one to be minimized, since less investment need is better. In this scenario, the PROMETHEE II method was applied, whose name comes from its acronym in English (Preference Ranking Organization for Enriched Evaluation). The method is based on the relationship of improvement between the alternatives taking into account the different values that these have in each criterion.

Table 1. Methodologies for determining the values of the criteria

Dimension	Criteria	Methodology
Financial	Cost Benefit Ratio (RBC)	Financial analysis of cash flow, with a discount rate of 10% and a 30-year projection
Social	Investment need (NI)	Amount of capital required to develop the productive project
	Employment (E)	Monitoring the number of day laborers used for handling and production in each system, projected to a 30-year production cycle
	Management to innovate (G)	Accounting for the number of technologies installed in each system
Environmental	Carbon content in plant biomass of the upper stratum (C)	Methodology proposed by Masuhara *et al*. (2015), where allometric equations are considered for each tree and shrub species
	Nitrogen content in lower stratum plant biomass (N)	It was determined by Kjeldahl'smethod
	Edaphic macrofauna biomass (BM)	It was determined based on the total weight of individuals by surface (m^2), expressed in ($g\ m^{-2}$)
	Edaphic macrofauna diversity (DM)	It was determined based on the number of species of organisms found in each of the systems evaluated

Elaboration with information and sampling of the 2018-2019 production cycle.

This version differs from its previous version (PROMETHEE I) in that it generates a complete order in the classification of alternatives. The method provides for the estimation of three basic components resulting from paired comparisons between the different alternatives (Ishizaka and Nemery, 2013): degrees of preference (P_{ij}^{k}), single-criteria flows ($\frac{1}{n\text{-}1}\sum_{j=1}^{n} P_{1n}^{1}$) and global flows.

Degrees of preference(P_{ij}^{k}) express the degree to which the alternative a_i exceeds the alternative a_j in the criterion k. The method allows the possibility to enrich the degrees of preference by using preference functions. Brans and De Simet (2016) propose six functions for expressing preferences. This study uses the function known as usual (Figure 1 and equations (1)), where the values of the indifference and preference thresholds are equal to zero, which means that before the slightest positive difference in $f_k(a_i)\text{-}f_k(a_j)$, the degree of preference is (strong) equal to 1. If the difference is negative or zero, the degree of preference is zero or indifferent.

$$P_{ij}^{k}=\begin{cases}0 \text{ if } & f_k(a_i)\text{-}f_k(a_j)\leq 0\\ 1 \text{ if } & f_k(a_i)\text{-}f_k(a_j)> 0\end{cases} \qquad 1)$$

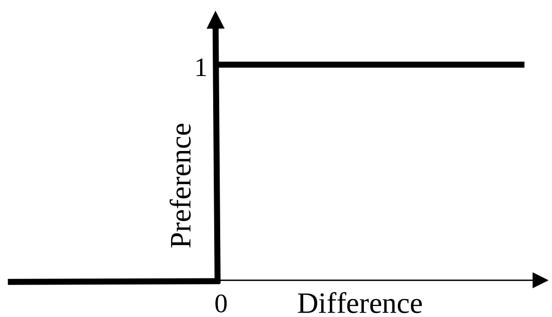

Figure 1. Usual preference function (Brans and De Simet, 2016).

The single-criteria flow is the average of the (P_{ij}^{k}) for each alternative it each criterion. They are estimated in two ways: positive single-criterion flow (FUP= $\frac{1}{n\text{-}1}\sum_{j=1}^{n} P_{1n}^{k}$) and negative single-criterion flow (FUN= $\frac{1}{n\text{-}1}\sum_{i=1}^{n} P_{n1}^{k}$). The FUP expresses how an alternative is preferred over all others in a particular criterion. FUN expresses how the rest of the alternatives are preferred over a particular alternative. Net single-criteria flow (FUNet) is the difference between the FUP and the FUN. The global flow takes into account all the criteria simultaneously, including their weights.

Positive global flow (Φ^{+}), negative global flow (Φ^{-}), and net global flow (Φ), are estimated. The latter determines the classification of the alternatives. This is, $\Phi^{+}= w_1\left(\frac{1}{n\text{-}1}\sum_{j=1}^{n} P_{ij}^{1}\right)+w_2\left(\frac{1}{n\text{-}1}\sum_{j=1}^{n} P_{ij}^{2}\right)++w_n\left(\frac{1}{n\text{-}1}\sum_{j=1}^{n} P_{ij}^{k}\right)$, $\Phi^{-}= w_1\left(\frac{1}{n\text{-}1}\sum_{i=1}^{n} P_{ji}^{1}\right)+w_2\left(\frac{1}{n\text{-}1}\sum_{i=1}^{n} P_{ji}^{2}\right)++w_n\left(\frac{1}{n\text{-}1}\sum_{i=1}^{n} P_{ji}^{k}\right)$, $\Phi=\Phi^{+}\text{-}\Phi^{-}$. Where w_i is the importance weight of the criterion i.

The method application was developed using Smart Picker Pro-version 4.1.0 software. Finally, the stability of the results obtained using the PROMETHE method was analyzed, different changes were made to the criteria values for the first three systems of the resulting classification.

Results and discussion

The results of the financial scenario clearly show that the monoculture avocado (SAM) system has the first position in the system classification, with an RBC of 2.43, followed by the avocado-with-coffee system (SAC) with an RBC of 2.36. The remaining systems are at a greater distance with RBC equal to or less than 1.3 (Table 2). This supports the existing threat that the monoculture of avocado, whose sole decision criterion is based on monetary measures, establishment and replacement by the other systems characterized by including desirable aspects other than strictly financial.

These desirable aspects, such as crops and species diversification, the management of environmentally friendly technologies, the application of vermicompost, and social considerations are characteristic of agroforestry systems with coffee, classified according to Escamilla (1994) as traditional polycultures.

In the analysis of the multicriteria scenario, the determination of the different performances of the systems in the different criteria included configures a decision matrix with the classic characteristics of multicriteria problems, that is, none of the systems has the best performances in all criteria (Table 2). Similarly, neither of them presents the worst values in all criteria. This presents some of the complexity in the prioritization process of this type of alternatives, in addition to showing that the performance values of the criteria will allow identifying the advantages and disadvantages of each evaluated system (Bengtsson and Steen, 2004).

Table 2. System performance matrix at each criterion.

System	RBC	NI	E	G	C	N	BM	DM
SCA	0.96	18 750	6.98	1	41.84	1.61	149.67	8
SCR	1.3	45 660	75.33	2	40.79	1.17	124	5
SCL	1.06	31 740	114.72	1	40.04	1.01	118.11	7
SAC	2.36	41 310	70.99	2	38.94	0.05	1.67	2
SAM	2.43	27 600	38.43	2	26.25	0.03	1	1

Elaboration with information and sampling of the 2018-2019 production cycle.

For the estimation of the classification of this second scenario characterized by the additional inclusion of social and environmental criteria, by applying the PROMETHEE method, the degrees of preference were calculated, from which the net single-criteria flows were computed (Table 3).

Table 3. Net single-criteria flows.

Systems	RBC	NI	E	G	C	N	BM	DM
SCA	-1	1	-1	-0.75	1	1	1	1
SCR	0	-1	0.5	0.5	0.5	0.5	0.5	0
SCL	-0.5	0	1	-0.75	0	0	0	0.5
SAC	0.5	-0.5	0	0.5	-0.5	-0.5	-0.5	-0.5
SAM	1	0.5	-0.5	0.5	-1	-1	-1	-1

The information presented in Table 3 highlights that only the monoculture avocado (SAM) and coffee avocado (SAC) systems have positive net single-criterio flow values in the financial dimension (RBC), in addition, both show negative net unicriteria flow values in all environmental criteria, thereby showing that the intensive agronomic management of the systems negatively affects the maintenance of the resources represented in the environmental criteria.

For their part, the rest of the systems, SCA, SCR and SCL have positive values unique in the criteria related to soil macrofauna, this can be attributed to the recycling of organic waste generated in both systems resulting from high planting density and severe pruning, which generate organic waste and edaphoclimatic conditions that contribute to the activity of soil macrofauna (Paolini, 2018). In addition, it is reported positive flow in the C and N content, it is confirmed that diversified systems use carbon storage and nitrogen availability in the soil (Gallardo, 2017).

Since net single-criteria flows are a measure of the preference that one has for one of the systems in particular, in the criterion in question, over the rest of the systems, this information advances the strengths and weaknesses of each system in each criterion, which will subsequently have to define the priority, depending on the weights of importance assigned to each of the criteria. Subsequently, the net global flows were estimated, which result from the weighted sum of said unicriteria flows for each system, and in turn, these define the classification of the systems (Table 4).

The application of the PROMETHEE method generated a different classification from the financial scenario. The rise to the first position of the renewed coffee system with rust-tolerant varieties (SCR) stands out. The monoculture avocado system (SAM) moved from the first to a second position. The systems, avocado with coffee (SAC) and the coffee system with severe cleaning pruning (SCL), lost a position to occupy the third and fifth position, respectively, in the classification. The 12-year crop-abandoned coffee system (SCA) advanced one place to fourth position (Table 4).

Table 4. Classification of financial and multicriteria scenarios.

Systems	RBC	Classification RBC	Global flow net	Classification PROMETHEE	Variation in position
SAM	2.43	1	0.05534	2	-1
SAC	2.36	2	-0.0001	3	-1
SCR	1.3	3	0.12505	1	+2
SCL	1.06	4	-0.09717	5	-1
SCA	0.96	5	-0.08311	4	+1

Figure 2 graphically presents the classification of the systems for the multicriteria scenario. The order from highest to lowest priority goes from left to right, and the contributions of the criteria are shown in rectangles of different colors that cover a scale between -1 and +1. According to the results, the best evaluated is the rust-tolerant coffee system (SCR). The value of its net global flow (0.125, in Table 4) results from the strength in the employment (E) and management to innovate (G) criteria whose performance values (75.33 jornales and 2 technologies, respectively,

Table 2), allowed comparisons with the rest of the systems to achieve positive net one-criteria flows (0.5 in both, Table 3), which, when multiplied by the respective weights (0.111 in both) generated positive contributions in the sum of the net global flow (0.056 in both, Figure 2).

A similar condition is presented in the performance of criteria C, N and BM, only in this case all three belong to the environmental dimension and the weight of importance assigned to each is 0.0834, so that the positive contribution of each criterion is a little lower (0.042, Figure 2). The case of the RBC criterion has a zero contribution to the Net Global Flow of SCR. This is explained because its performance in this criterion (1.3, in Table 2) corresponds to the midpoint between the five systems.

That is, when compared in paired form with the other systems, it turns out that it dominates two of them and two others dominate it. This means that the unicriteria net flow of the system, in the RBC criterion, is zero (Table 3). The investment need criterion (NI) presents a negative contribution to the global net flow of the system. This is because SCR has a greater investment need than the rest of the systems ($45 660.00, Table 2) and as it is a criterion to be minimized, then the rest of the systems have preferable values that result in a unicriteria net flow of -1 (Table 3), same as when multiplied by their weight (0.111), generates a negative contribution of -0.111 (Figure 2).

A similar analysis can be done on the causes of the ordering in the rest of the systems considered here. In the second position system, monoculture avocado (SAM), the criterion whit the greatest contribution is RBC (0.333), which results because SAM is superior to the rest of the systems in this criterion. However, there are five criteria whose contributions are negative. Therefore, these criteria should be considered to promote the productive diversification of coffee plantations, since the investment capacity of the small producer will influence the programming and decision to implement agronomic management alternatives (Martinelli *et al*., 2019), which will have an impact on the success of the production and entry of the system as an alternative to avocado monoculture.

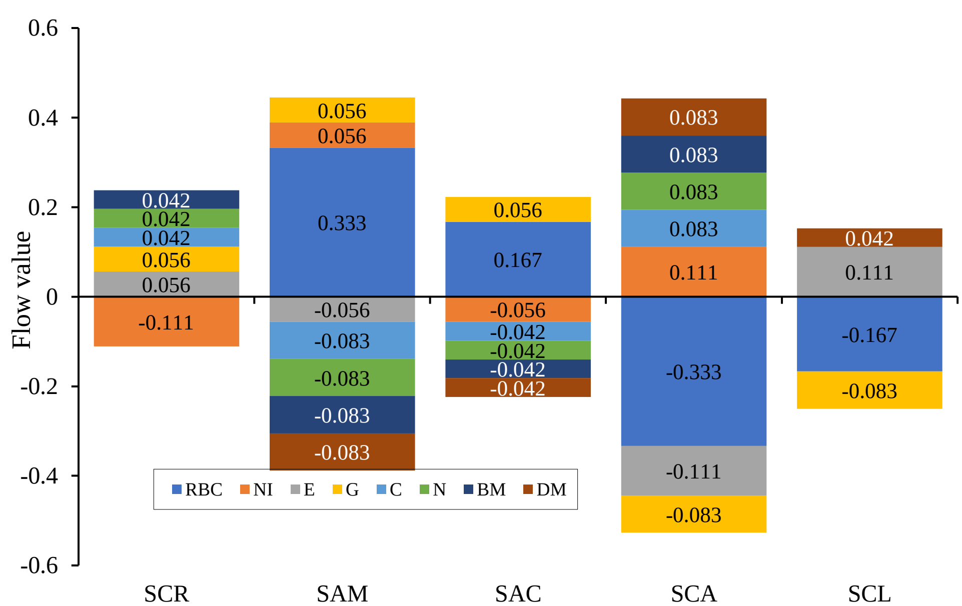

Figure 2. Classification of systems including contributions of the criteria.

Finally, and with the idea of analyzing the stability of these results, changes were made to the performance values of the systems positioned in the top three places of the classification: rust-tolerant coffee system (SCR), monoculture avocado system (SAM) and avocado and coffee system (SAC). The analysis consisted of estimating the critical value of each criterion in the three systems, understood as the minimum change in the criterion, maintaining the other constant values, which causes a change in the position of the system in the classification (Triantaphyllou, 2000), results confirming that the RBC criterion in the SAM is due to the economic income generated by the cultivation of avocado (Franco *et al*., 2018). For the SCR, the variations in the criteria values were made downwards in order to identify the point at which this system lost its first position, for the other two systems (SAM and SAC), the variations were upwards, to observe the point at which their position ascended, except in NI whose variation was down because it was a criterion to minimize.

The results obtained indicate that this ordering generated by the PROMETHEE method is quite stable since in most of the criteria too large variations are required to cause a change in it (Table 5). Although in the case of C in SCR and SAC, the percentages may appear lower, in reality they are not because it should be taken into account that an increase of 1% in carbon content in the system can take several years (Gallardo, 2017).

Table 5. Sensitivity of the resulting classification of the PROMETHE method.

System	Modified criterion	Original performance value	Critical performance value	Percentage of variation	Change in PROMETHEE Classification
	RBC	1.3	1.06	-18.5	-1
	NI	45 660	45 660	0	0
	E	75.33	38.4	-49	-2
SCR	G	2	1	-50	-2
	C	40.79	38.9	-4.6	-1
	N	1.17	0.04	-96.6	-1
	BM	124	1.6	-98.7	-1
	DM	5	1	-80	-1
	RBC	2.43	2.43	0	0
	NI	27 600	18 750	-32.1	0
	E	38.43	75.33	96	1
SAM	G	2	2	0	0
	C	26.25	40.1	52.8	1
	N	0.03	1.02	3 300	1
	BM	1	118.12	11 712	1
	DM	1	5	400	1
	RBC	2.36	2.43	3	1
	NI	41 310	31739	-23.2	1
	E	70.99	75.34	6.1	1

System	Modified criterion	Original performance value	Critical performance value	Percentage of variation	Change in PROMETHEE Classification
SAC	G	2	2	0	0
	C	38.94	40.79	4.8	1
	N	0.05	1.17	2 240	1
	BM	1.67	124	7 325.1	1
	DM	2	7	250	1

In the case of zero variation percentages (NI in SCR, RBC in SAM and G in SAC), no modifications were made because they would not cause the desired effect. NI, as a criterion for minimizing, in SCR is already the worst value among systems, so that no increase in this would change its first position. The cases of RBC and G are similar, but in the opposite direction, both are to maximize and have the maximum value between systems, so there are no increases that improve their position of their systems in the classification. These results show deficiency in the RBC for the SCR system, therefore productive diversification with another crop is necessary to contribute to the prioritization of productive agroforestry systems with better economic income (Jezeer *et al*., 2018).

Conclusions

The analyses carried out give reason to the present threat of displacement of traditional production systems associated with coffee by monoculture avocado systems. On the one hand, the traditional analysis based only on monetary measures, financial analysis, shows that the financial profitability obtained in the SAM is much higher than that obtained in the other systems. In addition, in multicriteria analysis, even though it is considered variables of social and environmental interest, the SAM maintains a second position in the order of priority.

These results, in addition to non-monetary valuations, have an important influence on the importance weights assigned to the different criteria considered, in this way, during a scenario in which public policy decision-makers express greater interest in social and environmental variables, higher weights could be assigned to them and thus consolidate the systems that associate coffee and avocado in better positions in the classification.

Even so, the challenge of designing and putting into practice public policies that incentivize such systems that are evidently more sustainable in social and environmental terms remains.

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