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Sustainability of lemon (*Citrus aurantifolia* Swingle) farms in the province of Santa Elena, Ecuador

Sustentabilidad de fincas productoras de limon (*Citrus aurantifolia* Swingle) en la provincia de Santa Elena, Ecuador

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Abstract

The objective was to evaluate the sustainability of lemon farms (*Citrus aurantifolia* Swingle) in Santa Elena, Ecuador. Surveys were applied to a sample of 83 lemon producers from this province, with structured questions about economic, ecological and socio-cultural dimensions. The sustainability was determined with techniques of multicriteria analysis to calculate the Economic Indicator (IK), Ecological Indicator (IE) and Socio-Cultural Indicator (ISC), to estimate the General Sustainability Indicator (IS Gen) of each farm. The 25.3% of the farms had an IK> 2; 60.24% an IE> 2 and 55.4% an ISC> 2. The 74.7% of the farms had an IS Gen <2, which indicates that the farms are not sustainable.

Key words: dimensions, survey, multicriteria, ecological.

Resumen

El objetivo fue evaluar la sustentabilidad de fincas productoras de limón (*Citrus aurantifolia* Swingle) en Santa Elena, Ecuador. Se aplicaron encuestas a una muestra de 83 productores de limón de esta provincia, con preguntas estructuradas sobre dimensiones económicas, ecológicas y socio culturales. La sustentabilidad se determinó con técnicas de análisis multicriterio y se calcularon el Indicador Económico (IK), Indicador Ecológico (IE) e Indicador Socio cultural (ISC), para estimar el Indicador de Sustentabilidad General (IS Gen) de cada finca. El 25.3 % de las fincas tuvieron un IK > 2; el 60.24 % un IE > 2 y el 55.4 % un ISC > 2. El 74.7 % del sistema de producción de limón en Santa Elena tuvieron un IS Gen < 2, lo que indica que las fincas no son sustentables.

Palabras clave: dimensiones, encuesta, multicriterio, ecológico.

Introduction

Lemons represent approximately 10% of the world citrus production with more than 120 billion tons per year (USDA, 2018). Ecuador produced 28 000 t annual (FAO, 2018), with some provinces as the economic base for the production and commercialization of citrus, especially *Citrus aurantifolia* Swingle, known as "lime" or "key lime" or "lemon". This lemon is the most cultivated species and, with the lemon Tahiti (*Citrus latifolia* Tan), it amounts to approximately 4 965 ha. In Santa Elena province, there are 500 hectares of lemon, cultivated by approximately 400 farmers (PIDAASSE, 2011). Deficiencies in management and technological improvement are crucial for the development of the citrus sector, which must be considered with sustainability criteria (Santistevan *et al.*, 2017). Gómez-Limón & Arriaza (2011), define sustainable agriculture as one that promotes food sufficiency, conserves natural resources, protects the environment and is economically viable. In addition, agricultural farms should not only generate an economic rent, should also maintain the appropriate conditions of the environment so that the crop develops successfully, minimizing disturbances to the natural environment, but above all that allows to improve the quality of life of the agricultural producers. In Ecuador, in recent years, there have been some studies related to the evaluation of sustainability in different agricultural production systems (García, 2015;

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Palomeque, 2016; Reina, 2016; Santistevan et al., 2016), using the multicriteria analysis with indicators (Sarandón & Flores, 2009; Sarandón *et al.*, 2016). These studies suggest a different and innovative vision in the analysis of agricultural systems and also in the design of future plans for the agricultural development of this country. In this sense, the present study had the objective of evaluate the sustainability of lemon farms (*Citrus aurantifolia*) in the Province of Santa Elena, Ecuador.

Materials and methods

The study was carried out in two rural parroquia of the Santa Elena Canton of the province of Santa Elena, which is located in the Litoral Region, in the extreme west of the Ecuadorian territory (Figure 1) at 2°13'36''LS and 80°51'29''LO, with an area of 3,762.8 km^2, which represents approximately 1.46% of the Ecuadorian territory (SAMBITO, 2014).

Figure 1. Location of the Province of Santa Elena in Ecuador

From a finite population of 400 lemon producers a random sample of 83 was taken (Scheaffer *et al*., 1987). To evaluate sustainability, a multicriteria analysis method proposed by Sarandón *et al*. (2006) was used; the indicators were selected and constructed according to the methodology and conceptual framework proposed by Sarandón (2002) and Sarandón & Flores (2009) adapted for a perennial crop such as lemon. These were integrated by indicators and sub-indicators and whose definition was consulted with technicians and farmers in the area of study (Márquez & Julca, 2015).

The information was obtained from a structured survey, which considered closed questions of the dimensions: economic, sociocultural and environmental. Then we made the comparisons between farms, the data obtained for each variable was standardized on a scale of 0 to 4. The value 4 represents the highest sustainability and 0 the lowest sustainability (Table 1). The values obtained for each sub-indicator were weighted multiplying it by a coefficient according to the relative importance of each variable with respect to sustainability. The weighting of sub-indicators and variables was valided with technicians and farmers in the area (Márquez & Julca, 2015).

The formulas used to calculate the indicators of sustainability were:

Economic indicator (IK) =

$$\frac{2\left(\frac{A1+A2+A3+A4+A5}{5}\right)+B+\frac{C1+C2+C3}{3}}{4}$$

Ecological indicator (IE) =

$$\frac{\frac{A1+A2}{2}+\frac{B1+B2}{2}+C}{3}$$

Sociocultural indicator (ISC) =

$$\frac{2\left(\frac{A1+A2+A3+A4}{4}\right)+B+C}{4}$$

With economic (IK), environmental (IA) and social (ISC) indicators values found, the general sustainability index (ISGen) was calculated, weighting the three dimensions equally, according to the definition of sustainability. It was considered that to be sustainable a farm must have an ISGen greater to 2 and, in addition, none of the three dimensions individually, should have an indicator with a value less to 2.

Table 1.- Sub-indicators and indicators used to evaluate the sustainability of lemon producing farms in Santa Elena, Ecuador.

Economic dimensión									
	Profitability of the farm (A)					***Net income (B)***	***Economic risk (C)***		
Value	**A1**	**A2**	**A3**	**A4**	**A5**	**B**	**C1**	**C2**	**C3**
4	>20	>60	<5	100	340-350	>610	>4	0-20	4
3	15-20	60-50	5.1-10	75	330-339	550-600	4	21-40	3
2	11-14	45-49	10.1-15	50	320-329	500-549	3	41-60	2
1	9-10	40-44	15.1-25	25	310-319	450-499	2	61-80	1
0	<9	<40	>25	<25	<310	<450	1	81-100	0

Ecological dimensión					
	Soil life conservation (A)		***Risk of soil erosion (B)***		***Management of the BD (C)***
Value	**A1**	**A2**	**B1**	**B2**	**AZC**
4	100	Total	0-5	B2-1	>1
3	75-99	Alta	6-15	B2-2	0.5-1
2	50-74	Media	16-30	B2-3	0.25-0.5
1	25-49	Baja	31-45	B2-4	<0.25
0	<25	MNC	>45	B2-5	0

Sociocultural dimensión						
Value	***Satisfaction of basic needs (A)***				***Social integration (B)***	***C&CE (C)***
	A1	A2	A3	A4	B	C
4	A1-1	A2-1	A3-1	A4-1	Very high	C1-1
3	A1-2	A2-2	A3-2	A4-2	High	C1-2
2	A1-3	A2-3	A3-3	A4-3	Media	C1-3
1	A1-4	A2-4	A3-4	A4-4	Low	C1-4
0	A1-5	A2-5	A3-5	A4-5	Null	C1-5

Legend: **In Economic Dimension**: A1: Productivity t ha-1; A2: Physical quality of the lemon (mm); A3: Incidence of pests and diseases (%); A4: Use of rootstock for lemon Subtle (%); A5: Density of plantation (plants ha-1). B: Net income (Dollars); C: Economic risk; C1: Diversification in production (number of products); C2: Dependence of external inputs (%); C3: Numbers of commercialization routes for lemon. **In Ecological Dimension**: A1: Management of vegetation cover (%); A2: Crop diversification; MNC: Monoculture; B: Risk of soil erosion; B1: Predominant slope (%); B2: Soil conservation; B2-1: Level curves or terraces; B2-2: Live and dead barriers; B2-3: Borderlines; B2-4: Staggered against the slope; B2-5: Sowing in favor of the slope; C: Biodiversity management (BD); AZC: Areas of conservation area (ha). **In Sociocultural Dimension**: A1: Housing (material); A1-1: Concrete; A1-2: Mixed; A1-3: Wood; A1-4: Reed; A1-5: Do not have your own home. A2: Access to education. A2-1: University or Institute. A2-2: High school. A2-3: Elementary and secondary school. A2-4: Elementary and secondary school. A2-5: Without access to education. A3: Access to health and health coverage. A3-1: Adequate infrastructure and permanence of doctors. A3-2: Medically equipped and temporary doctors. A3-3: Badly equipped and temporary doctors. A3-4: Badly equipped and without qualified personnel. A3-5: Without health center. A4: Basic services. A4-1: Installation of all services. A4-2: Installation of water and energy. A4-3: Installation of light and well water. A4-4: No installation of light and well water. A4-5: Without light and without water. B: Social Integration; C: Ecological knowledge and awareness (C & CE). C1-1: Wide view on ecology, beyond your farm. C1-2: Knowledge of ecology from everyday practice. No use of agrochemicals, conservation practices. C1-3: Partialized view of ecology. Awareness about some practices that affect the environment. C1-4: They do not present an ecological knowledge. But it uses low input practices. C1-5: No kind of ecological awareness.

The mathematic formula to calculate the ISGen was:

$$\text{General Sustainability Index (ISGen)} = \frac{IK+IA+ISC}{3}$$

The sustainability analysis was carried out individually for the 86 farms. Cluster multivariate analisis technique was used to select four "type farms" and the critical points of the three dimensions of sustainability to be compared were analysed. The "type farms" are those that represent a group of farmers or production systems with similar characteristics (Salazar, 2012; Tuesta *et al*., 2014; Santistevan *et al*., 2015; Collantes, 2016).

Table 2.- Most important characteristics of "type farms" producing lemon in Santa Elena, Ecuador (Santistevan *et al*., 2015).

Characteristic	Type I	Type II	Type III	Type IV
Number of farms (%)	44.6	15.7	26.5	13.3
Average total area of farmland (ha)	2.3	4.3	4.5	16.5
Average area with lemon (ha)	1.2	1.2	2.5	4.5
Average N° plants/ha	250	275	260	280
Investment/ha/year (US$)	325	400	625	1450
Monthly income (US$)	450	540	675	700
Location	Manglaralto	Colonche	Colonche	Manglaralto

Table 3.- Scores obtained in each of the sub-indicators in the evaluation of the sustainability of lemon producing farms, in Santa Elena, Ecuador.

Economic dimension									
	Profitability of the farm (A)					***Net income (B)***	***Economic risk (C)***		
	A1	A2	A3	A4	A5	B	C1	C2	C3
Value	1.6	1.9	1.1	3.2	2	0.8	0.8	1.2	0.7
Ecological dimension									
	Soil life conservation (A)			***Risk of soil erosion (B)***			***Management of the BD (C)***		
	A1		A2	B1		B2	AZC		
Value	1.4		0.6	3.6		3.2	1.6		
Sociocultural dimension									
	Satisfaction of basic needs (A)					***Social integration (B)***	***Knowledge and EC (C)***		
	A1	A2	A3	A4		B	C		
Value	3.6	1.8	1.9	2.7		1.4	1.9		

Legend: **In Economic Dimension**: A1: Productivity; A2: Physical quality of the lemon; A3: Incidence of pests and diseases; A4: Use of rootstock for lemon Subtle; A5: Planting density. B: Net income: C1: Diversification in production; C2: Dependence of external inputs; C3: Numbers of commercialization routes for lemon. **In Ecological Dimension:** A1: Management of vegetation cover; A2: Crop diversification; CD: Monoculture; B1: Predominant slope; B2: Soil conservation. Management of BD: Management of biodiversity. MB: Areas of conservation. **In Sociocultural Dimension**: A1: Housing (type of material); A2: Access to education; A3: Access to health and health coverage; A4: Basic services; B: Social integration; C: Knowledge and ecological conscience

Results

The lemon farms in Santa Elena can be organized into four groups (Santistevan *et al*., 2015) and the most important characteristics of the "type farms" of each group are presented in Table 2.

Table 3 shows that when assessing economic sustainability, for most variables, lemon farms had average values far from four, ranging from zero to four. For example, in the sub-indicator of profitability sub-indicator (A), the variable *Use of rootstock for lemon* (A4) had a value close to four, with the mandarin Cleopatra as the most frequent rootstock; the variables A1, A2, A3 and A5 values less than 2. The indicator of *Net Income* (B) the value was 0.8, i.e. between 200 and 300 US$/month. The sub-indicator *Economic Risk* (C) has the highest value in *Dependence on external inputs* (C2=1.2); but in all cases the values were less than two. The economic indicator (IK) was greater than two in only 25.30% of the farms evaluated, a result that indicates that most of the farms were not economically sustainable (Figure 2).

Table 3 also presents the results of the ecological sustainability assessment. For the sub-indicator *Conservation of soil life* (A), variables *Management of vegetation cover (A1)* and *Crop diversification (A2)* have values less than two. For *Risk of soil erosion* (B), subindicators *Predominant slope variable* (B1) and *Soil conservation* (B2) haved values greater than two, the farmes use land with slopes less than 5% and the crop is installed using contour lines or terraces, repectively. The

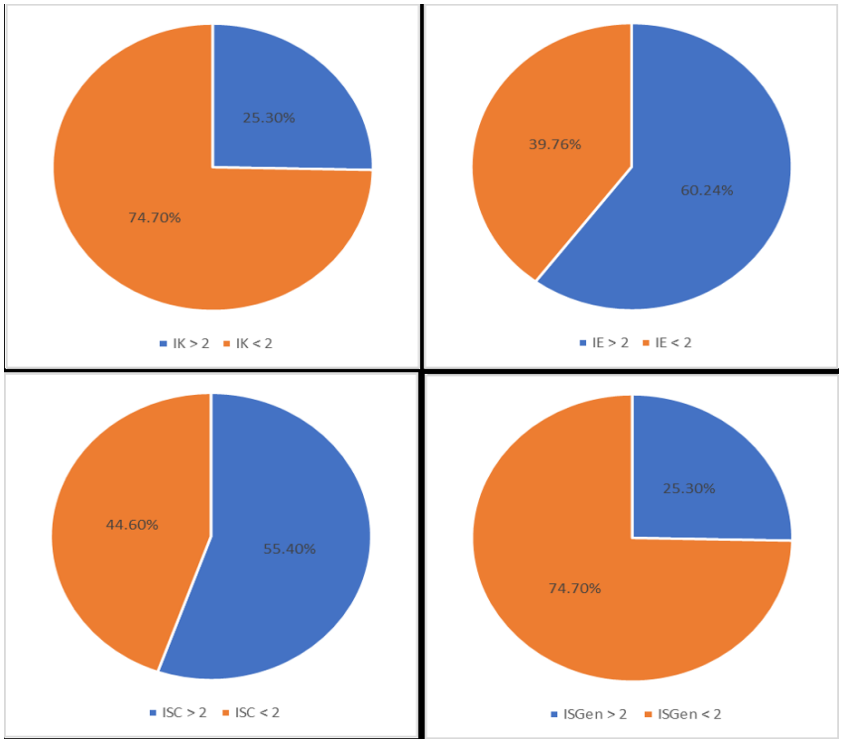

Figure 2. Evaluation of sociocultural sustainability (ISC), ecological (IE), economic (IK) and General Sustainability Index (ISG) of lemon producing farms, in Santa Elena, Ecuador.

Biodiversity Management sub-indicator has the variables Areas of Conservation Zones (AZC) with a value less than two. The ecological indicator (IE) is greater than two in the 60.24% of the farms evaluated, a result that indicates that most of the farms are ecologically sustainable (Figure 2).

As for socio-cultural sustainability, Table 3 shows that, for most variables, lemon farms had average values of less than four also ranging from zero to four. For the sub-indicator *Satisfaction of basic needs* (A), both variables *Housing material* (A1) and *Basic services* (A4) had values greater than two, i.e. the houses are made of concrete and have water, drainage and telephone installations. The sub-indicator *Social Integration* (B) had a value less than two and the same was found for the sub-indicator *Ecological Knowledge and Awareness* (C). The sociocultural indicator (ISC) was greater than two in 55.4% of the farms evaluated, a result that indicates that most of the farms were socioculturally sustainable (Figure 2). In general, 74.7% of the farms evaluated had an ISGen less than 2 (Figure 2), i.e. only 25.3% of lemon farms are currently sustainable.

Discussion

Dimensions of sustainability

Economic sustainability is understood as the set of strategies that allow the agricultural business to remain financially viable over time and provide an acceptable livelihood for the rural family (Lien *et al*., 2007). In this study, only 25.3% of farms are economically sustainable (Figure 2), while 74.7% do not, because lemon production is affecte by low productivity and low fruit quality. The incidence of pests and diseases is high, and although the use of patterns for lemon cultivation is an adequate and widespread technique among producers in this area, it is not enough to obtain high yields or to improve the quality of lemon (Table 3). The values of productivity and plantation density indicate that there is potential for increasing productivity, with densities of 312 plants ha^{-1}, productivity values of up to 42.1 t ha^{-1} have been reported (Medina *et al*., 2004). Likewise, there may be other factors that would affect the production of *Citrus aurantifolia* such as the inappropriate use of fertilizers, use of unimproved cultivars, lack of weed control and others. This would indicate the need for comprehensive improvement in crop management, including agronomic practices such as pest, disease and weed management (Lardizabal & Medlicott, 2013). The monthly net income is low, below $300, which is related to low productivity and fruit quality. In addition, having only one marketing channel and a high dependence on external inputs shows the high financial risk assumed by lemon farmers in the Santa Elena area. However, Santa Elena farmers have chosen to specialize in this crop; this is probably because the farmer cannot diversify or because alternative crops that can be grown in their area do not have the profitability they seek. A high dependence on external inputs carries a danger for farmers as they can increase in price regardless of the price of the product (in this case the lemon). This would cause an increase in production costs and a crisis of economic resources that would result in this small producer being expelled from the market (Altieri

& Nicholls, 2010). The low social integration (Table 3) shows that small farmers are not organized, do not have bargaining power and are highly dependent on wholesalers who determine the final price of the product.

Ecological sustainability seeks to improve the well-being of the farmer by protecting the resources used to meet human needs and by ensuring that the production of waste does not cause harm to the farmer himself (Goodland, 1995). Only 60.24% of lemon farms are ecologically sustainable, while 39.76% did not reach acceptable levels of sustainability (Figure 2); Producers who achieved positive levels of sustainability implement practices that reduce the risk of soil erosion, such as the use of soils with little slope and soil conservation practices (Table 3). In this regard, Peña *et al*., 2016; Sanclemente & Patiño, 2015 and Murillo *et al*., 2016, indicate that the good vegetation cover not only conserves the soil, but also improves its characteristics which in turn can have positive effects on the growth and development of the cultivated plants. Although the implementation of this agricultural practice should be well studied, otherwise it could cause a decrease in crop yields (Salazar *et al*., 2012). On the other hand, crop diversification not only helps to increase the conservation of tropical soils, but also has an important effect on the biology of soils, favoring the growth and development of different species within the agroecosystem and generating extra income for farmers (Fernández *et al*., 2015). Work to improve ecological sustainability must be done on the management of low vegetation cover and diversification, for example, with the implementation of other crops or other citrus species as oranges or mandarins. The management of biodiversity on lemon farms can bring great benefits to farmers, such as a decrease in the use of external inputs (Blanco, 2016; Paleologos *et al*., 2017).

Socio-cultural sustainability refers to agriculture that provides meaningful and equitable employment for farmers, workers and their families and produces food for a broad group of consumers (Pilgeram, 2011). In this study, 55.4% of farms are socio-culturally sustainable (Figure 2). In Santa Elena, a majority group of lemon farmers live in houses built with concrete material or are of mixed type, have basic education or have no formal education and the community has a medical center that has neither the adequate infrastructure nor the trained personnel to maintain the health of lemon farmers. On the other hand, the farmers in this area have electricity in their homes and get their water from wells. Various authors use the education factor as a socioeconomic index within sustainable agriculture (Machado & Ríos, 2016) and access to drinking water as a key indicator of environmental sustainability (Fausto & Justo, 2006). Obtaining water from wells can be a risk for the inhabitants of Santa Elena, since it can have high concentrations of microorganisms and other agents harmful to human health (Méndez *et al*., 2015; Zegarra, 2017), so more in-depth studies are needed on the type of water that is consumed by these populations in order to ensure that it meets all standards for consumption. The low access to education and health services (Table 3), shows that the work of the government in the study area is deficient and that it is necessary to reverse this situation to improve the socio-cultural sustainability of lemon production in this area. While low social integration and ecological knowledge and awareness, suggest the need for greater dissemination of the advantages that have the producer organization and ecological awareness for the improvement of this dimension of sustainability.

Critical points of sustainability

The concept of sustainability is complex because it implies simultaneously fulfilling several objectives: productives, ecologicals or environmentals, social, culturals, economics and temporal (Sarandón & Flores, 2009). Therefore, the "critical points" can change from one production system to another and it is logical to find some differences between the four types of farms evaluated (Table 2). The analysis of the economic dimension (Figure 3) shows that, in the short term, pest and disease control should be improved, which, added to an increase in plantation density, will have a favorable impact on higher farm productivity and an improvement in the quality of the lemon, which would improve family income. In the medium term, access to new markets should be explored, which would help to improve family income. In the environmental dimension (Figure 3, DA), in the short term, the management of vegetation cover and the increase in the area dedicated to conservation zones could be improved. In the medium term, the task could be achieving a greater diversification of crops, focusing on associated crops accompanied by natural vegetation which would favor the beginning of certification processes for the lemon as organic, sustainable production and others. The certification of agricultural

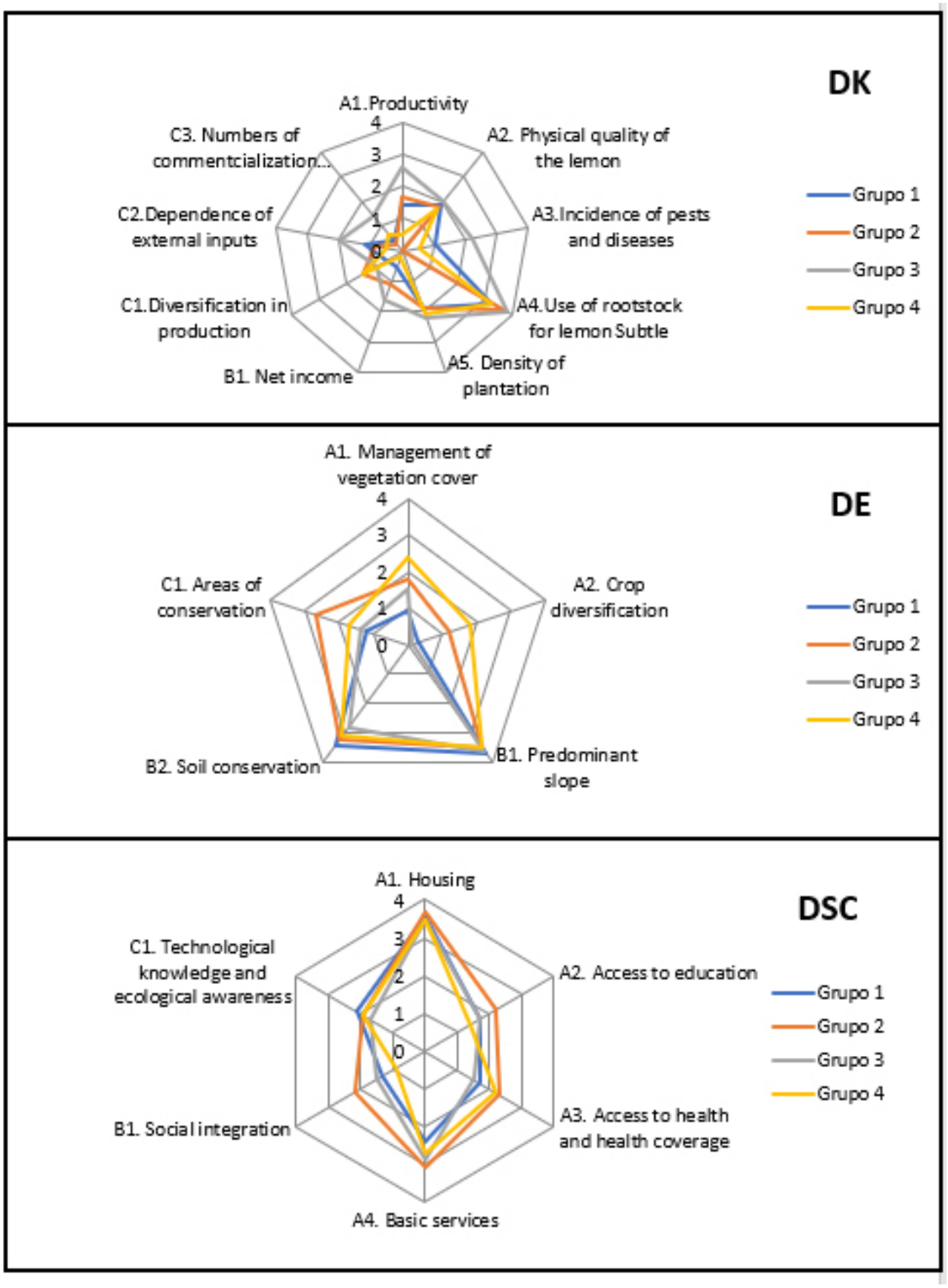

Figure 3. Critical points of sustainability in the economic (IK), environmental (IE) and sociocultural (ISC) dimensions in "lemon-producing" type farms in Santa Elena, Ecuador.

products allows to enter other types of market that in some cases could mean improvements in price up to 30%. In the analysis of the socio-cultural dimension (Figure 3) the need for improvements in the variables of access to education, social integration and technological knowledge and ecological awareness is evident.

Finally, for a farm to be considered sustainable, the General Index (IS Gen) must be greater than two and none of the three indicators must have a value less than two (Sarandón *et al*., 2006). With these criteria, only 25.3% of lemon farms are currently sustainable. These results show that achieving sustainability of agricultural production systems is a complex task, where improvement is not always the same in each of the three dimensions of sustainability. The results obtained in this study are consistent with other studies carried out in Ecuador in recent years, where sustainability has been evaluated in various agricultural production systems (Santistevan *et al*., 2015; García, 2015; Palomeque, 2016; Reina, 2016), which suggest a different vision for the future design of agricultural development plans for the country. However, at the present time a low number of sustainable farms is observed, which is mainly explained by the results obtained in the variables related to the economic and socio-cultural dimensions, which shows the low level and quality of life of agricultural producers. Changing this situation is not always in the hands of the farmers because it depends mainly on other instances such as local, regional and national government that must invest in infrastructure and services to improve the competitiveness of this productive sector (Santistevan *et al*., 2016).

Conclusion

The majority (74.7%) of the lemon producing farms in Santa Elena (Ecuador) are not sustainable, however adequate techniques are presented such as soil conservation, predominant slope, use of rootstock and planting density that could be replicated in other systems of production.

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