# Use of indicators as a tool to measure sustainability in agroecosystems of arid land, San Juan, Argentina

## Uso de indicadores como herramienta para medir la sustentabilidad en agroecosistemas de tierras áridas, San Juan, Argentina

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**Abstract**

The main objective of this study was to determine the sustainability status of three agroecosystems in arid areas, and to identify the critical aspects that limit it, through the use of economic, ecological and socio-cultural indicators. Three agroecosystems (AE) were selected from the Department of 25 de Mayo, San Juan. Its main economic activity is goat farming and, to a lesser extent, cultivation of orchards, as well as subsistence economic activities. To determine the state of sustainability, the indicators were selected and subsequently standardized and weighted according to their relative importance with respect to sustainability. The results indicated that none of the dryland AE achieves sustainability simultaneously in its three dimensions. The systemic analysis through indicators showed that the critical variables are food self-sufficiency, water access, livestock survival, and technical assistance, among others. The methodology used is simple, allowing to detect the sustainability status of the three EAs, and to identify the critical variables that jeopardize the permanence of the AE over time.

**Keywords**

multidimensional • analysis agroecology • dryland • non-irrigated land

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### Resumen

El objetivo principal de este estudio fue determinar el estado de sustentabilidad de tres agroecosistemas en tierras áridas, e identificar los aspectos críticos que la limitan, mediante el uso de indicadores económicos, ecológicos y socioculturales. Se seleccionaron tres agroecosistemas (AE) del departamento de 25 de Mayo, San Juan. Su principal actividad productiva es la producción caprina y en menor medida la producción de huerta, ambas orientadas a una economía de subsistencia. Los indicadores seleccionados se estandarizaron y ponderaron de acuerdo a su importancia relativa con respecto a la sustentabilidad. Los resultados indican que ninguno de los AE alcanza la sustentabilidad en sus tres dimensiones simultáneamente. El análisis sistémico a través de indicadores mostró que las variables críticas son la autosuficiencia alimentaria, el acceso al recurso hídrico, la supervivencia del ganado y la asistencia técnica, entre otras. La metodología utilizada fue fácil de usar, permitió detectar el estado de la sustentabilidad de los tres AE e identificar las variables críticas que ponen en peligro la permanencia de los AE en el tiempo.



**Palabras clave**

analisis multidimensional • agroecología • tierras secas • tierra no irrigada


## Introduction

One of the subjects addressed by agroecology is the evaluation of agroecosystems (AE) in terms of their state of sustainability. This responds to certain concerns expressed by scientists and technicians, given the environmental and social crisis in rural production systems, as a consequence of the "modern" agriculture imposed by the Green Revolution (10, 42, 47). The "sustainable development" concept was officialized in 1987 by the World Commission on Environment and Development, and it was defined as that which "meets the needs of the present without compromising the ability of future generation to fulfill theirs". In that context, the term "sustainable agriculture" was raised in response to the decreasing quality of natural resources, or of the productive base of modern agriculture (7). The concept is linked to the objectives of sustainable development launched by the UN in 2015 aiming to eradicate poverty, ensure food security, stop land degradation, and biodiversity loss, among other aspects (54). Although the sustainability of a production system is a controversial concept under permanent construction, there is broad consensus on the fact that agriculture production has gone from purely technical to a much complex issue, requiring consideration of ecological, economic, and sociocultural aspects for its assessment (19, 42, 58).

Agroecology postulates that, in order to understand the reality of AE, an integrative, holistic and systemic perspective is required, leaving aside the reductionist vision usually held by agrarian sciences when analyzing production systems. The agroecosystem approach has commonly been simplified to one or few of its components, without addressing their interactions or including the man as one of its main components (44, 49). In this sense, the agroecology approach must be put into practice through research that allows understanding the socio-ecological relationships within agroecosystems; accounting for the complex phenomena that result from these interactions; and making a diagnosis of such realities from a systemic approach (40, 52, 58). Also, agroecology acknowledges and values traditional indigenous and rural agriculture knowledge wisdoms (9, 13, 35, 48). This way of understanding nature has reached its objectives of productivity accounting for biodiversity and using the natural resources in a sustainable fashion (1, 22, 56), where techniques are adapted to the local socioeconomic and ecological conditions. Although some of these systems, mainly developed by farmers for food self-sufficiency are considered as sustainable a priori, publications operationalizing the concept by using tools to effectively evaluate the condition of these systems are scarce (18), or only consider one dimension (21, 25). Since the evaluation of AE sustainability involves the analysis of multiple dimensions, the use of indicators as tools for such end is proposed. This methodology has been tested by several authors that evaluated the sustainability of traditional production systems (1, 11, 19, 35, 39, 57). For example, commonly used indicators are food self-sufficiency (46), soil cover (10), biodiversity (45), water quality (5, 43), and basic needs satisfaction (24). An indicator is defined as a variable selected according to an adopted criterion, which responds to social, ecological and economic local characteristics, and is in agreement with the selected scale of analysis. In consequence, a group of indicators measured in a given AE inform about its state of sustainability in a given moment, and allow detecting the critical variables that jeopardize the permanence of AE in time.

On the other hand, experiences evaluating sustainability of AE in drylands, more specifically in non-irrigated lands, are scarce compared to those in AE of oases or irrigated lands (3, 39, 58). In general, non-irrigated AE are characterized by being of difficult access and isolated from the main urban cores, not presenting well-defined property boundaries. Also, their access to water comes from different sources (20). San Juan province is located in the arid strip of center-west Argentina. Here, territory is sectorized in oases, occupying 3% of the area, and where most urban and rural-urban centers merge with majorly intensive production systems. The rest of the territory is comprised by mountain chains and drylands. In these areas, the rural communities and indigenous descendants are strategically and sparsely distributed within extensive production systems based on a subsistence economy. Their main economic activity is goat farming, and to a lesser extent, orchard cultivation for self-sufficiency. In this context, we ask: 1- which is the state of these AE in the economic, ecological and sociocultural fields? 2- Are these systems sustainable?

To answer these questions, sustainability was considered as an historical, dynamic and situated concept, subjected to constant reconceptualization and change (18). An AE is considered sustainable if it meets the following sustainability criteria (46): economically viability, sociocultural acceptance, and productive and ecological suitability. Each of these objectives are measured by a group of indicators.

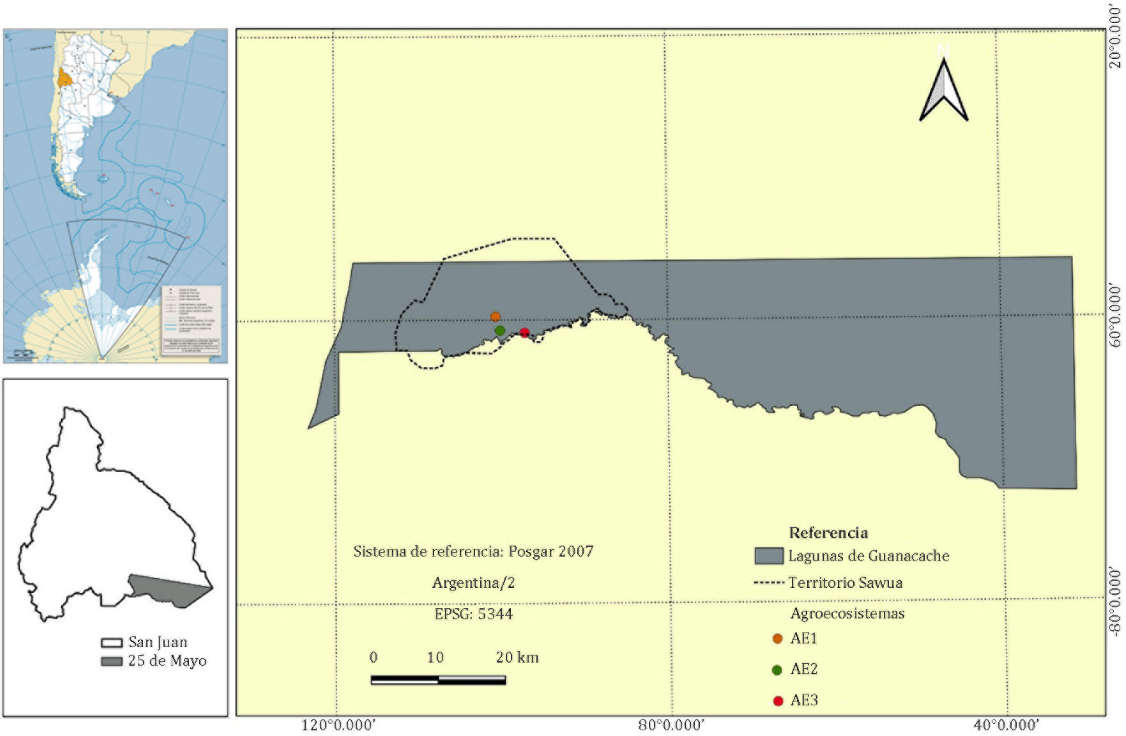
Our hypothesis was that local economic, ecological and sociocultural indicators determine critical points of sustainability in the production systems of the arid communities established in the

Central Mountain. The objective of this study was to determine the state of sustainability of three agroecosystems of arid lands, and to identify the critical aspects that limit this sustainability, using economic, ecological and sociocultural indicators.

## Materials and methods

### Study area

The study area is located towards the South of San Juan province, in 25 de Mayo department, which corresponds to the former wetland Lagunas de Guanacache, declared as a Ramsar Site in 1999 (figure 1).




The polygon towards the the right corresponds to the Wuarpe Sawa Community area, within the Ramsar Lagunas de Guanacache Site (gray polygon). The color points correspond to the studied agroecosystems.

El polígono de puntos ubicado a la derecha corresponde con el área de la Comunidad Wuarpe Sawa, dentro del Sitio Ramsar Lagunas de Guanacache (polígono gris). Los puntos de color corresponden con los agroecosistemas en estudio.

**Figure 1.** Study area, in 25 de Mayo, San Juan, Argentina.

**Figura 1.** Área de estudio, departamento de 25 de Mayo, San Juan, Argentina.

It is the seventh wetland of Argentina and the first in extension (980000 hectares including the Guanacache, Desaguadero and Bebedero lacoons (www.ramsar.org.ar) (33, 50, 51). The Ramsar Site is located in the center-west of Argentina, in the Cuyo Region, and it belongs to the Desaguadero - Salado basin. These wetlands form a system of lagoons and chained marshes, fed by the Mendoza and San Juan rivers, which discharge into the Desaguadero river. At the present, this system behaves like an endorheic basin, due to the great use of its waters from the main tributaries in the upper and middle parts of its routes. It is a continental wetland system of natural origin composed of rivers, lagoons and marshes, and of historical, archaeological and cultural value.

Regarding relief, Guanacache is a plain called "Gran llanura de la travesía". It is a deep sedimentary basin formed by a great depression slightly tilted towards the east, filled by sandy, silty and clayey sediments of lacustrine, fluvial, and wind origin (2, 4, 26).

From a biogeographic point of view, the area corresponds to the Monte province, which is characterized by a dry, warm climate, with summer, torrential rainfall that varies between 80 and 200 annual mm, and wide thermal amplitude (17). Physiognomically, the Monte is a mosaic of three types of vegetation: a) shrub steppes, dominated by species of the family Zygophyllaceae; b) edaphic steppes of halophyte shrubs, such as *Suaeda divaricata*, Atriplex spp., *Allenrolfea vaginata*; and c) forests, mostly dominated by species of the genus Prosopis.

**Description of the production systems**

Three AE located on the south section of the San Juan river were selected. The 3 AE belong to the Wuarpe Sawa community, acknowledged as descendants of indigenous peoples by the Instituto Nacional de Asuntos Indígenas (INAI) in the year 2000 (figure 1, page 193). The AE were selected using the snowball method (15). The average extension of these production systems is 560 hectares, but they do not present defined boundaries, and the parcels are delimited by the foraging resources of the herds of each AE (20). The most common productive activities are cattle breeding (with an average of 80 heads per AE), and, to a lesser extent, orchard production (vegetables and seasonal fruits) for self-consumption. Goats are one of the few resources that provide income to the families, and their breeding takes place traditionally, with animals foraging extensively in the open field. In the recent past, the productive landscape was much different, and the farmers called themselves "dwellers", due to their tight relationship with activities related to the presence of lagoons (29). Other activities that provide income to the AE families are temporary pruning and harvest in the nearby vine and pistachio settlements, as well as craft making with wool, leather and ceramic.

Water access is a key point for the development of productive activities, and the quantity and quality of water varies according to the four available sources: the San Juan river, water wells, perforations, or water transported through a municipal tank truck (the only way of access to drinking water). It should be highlighted that the water well and perforation technologies (present in AE1 and AE2, and absent in AE3) do not provide quality water for animal or people consumption, or to be used in the orchard (55); thus, not used by the farmers. For that reason, such sources were not considered when performing the sustainability analyses, and only sources with permanent use were addressed.

The marketing routes of young and adult goats take place through a "cabritera", which buys the animals from the community to resell them in the nearby urban center. Other marketing routes include the landowners of the region and particular customers who go to the farms. Certain farm products are directly sold to the individual customers by personal delivery, and crafts are made on request and sold to individual customers or craft centers in Mendoza.

**Data collection**

To collect agroecological information regarding ecological, economic and sociocultural aspects of the production systems, as well as information about the perception and knowledge of the AE, the following methods were used: participant observation (14), semi-structured interviews to each familiar unit (AE1: a couple, a son, a daughter and a granddaughter, AE2: a couple and two sons, AE3: two people), and visits around the AEs with a family member.

To address water quality (whether it is suitable for different uses; *e. g.* human and animal consumption, orchard irrigation, other uses) water samples were taken from each surveyed source of each AE according to the protocol proposed by INTA (27). Samples were placed in 1-liter aseptic plastic containers for physical-chemical determinations, and 250 ml were used for bacteriological measures. The samples were analyzed by the INA-CRAS (National Institute of Water-Regional Center for Groundwater), and by the Institute of Technological Research.

To address the offer of forage resources, 3 physio-structural transects within the farm area of each AE were established during the forage supply period, using the Point Quadrat method adapted for the Monte area. At each transect, the frequency of forage species, their specific contribution, and specific contribution by contact (considered as a relative expression of biomass) were determined (23, 34, 36).

**Sustainability indicators**

Sustainability indicators were built, standardized and weighted according to the methodology proposed by Sarandón (44). The threshold value of sustainability (TVS), defined as the mean value of the adopted scale of values (0 to 4, in this case) corresponded to 2. Weighting was performed by multiplying the value from the scale by a coefficient according to the relative importance of each of the sustainability variables. The economic, ecological and sociocultural indicators were calculated as the algebraic sum of their components, multiplied by their weight, to finally estimate the General Sustainability Index (GSI).

**Description and weight of the indicators**

The methodology applied to build the indicators allowed obtaining a series of standardized and weighted indicators and sub indicators for each analyzed sustainability dimension (economic, ecological and sociocultural, table 1, page 196). Below, the way in which each indicator and sub indicator were measured, the categories adopted by each indicator within the standardized scale, and their subsequent weighting are shown.

**Table 1.** Summary of the indicators, sub-indicators, their estimation methodology, and weighing adopted in the estimated indexes (IE, IEC, ISC).

**Tabla 1.** Resumen de los indicadores, subindicadores, metodología utilizada para calcular cada uno y la ponderación que adoptó cada uno en el cálculo de los indices (IE, IEC, ISC).

| **Economic Indicators** | **Economic subindicators** | **Method** | **Weighing** |
|---|---|---|---|
| Food Self-sufficiency (FS) | Number of products for self-consumption (NPSC) | Interview, participant observation | 2 |
| | Area destined to Self-Consumption (ASC) | *In situ* measurement | 2 |
| Economic Risk (ER) | Number of Marketing Channels (NMC) | Interview | |
| | Diversification of Sale Products (DSP) | Interview, participant observation | |
| | Dependence on external inputs (DI) | Interview | |
| | Productive Activities (PA) | Interview, participant observation | 2 |
| Extraproperty Work (EPW) | | Interview | 2 |
| **Ecological Indicators** | **Ecological Subindicators** | | |
| Access to Water (AW) | Water - Quantity (QUAN) | Interview | 2 |
| | Water - Quality (QUAL) | Water analysis | 4 |
| Livestock Survival (LS) | | Interview | 2 |
| Foraging Resources (FR) | Quality of the Foraging Resources (QUALFR) | Transects | 2 |
| | Quantity of the Foraging Resource (QUANFR) | Interview, Transects | |
| **Social Indicators** | **Social Subindicators** | | |
| Basic Needs Met (BNM) | Household (H) | Interview, participant observation | |
| | Health (HE) | Interview | |
| | Education (ED) | Interview | |
| Technical Assistance (TA) | | Interview | 2 |
| Satisfaction of the Production System (SPS) | | Interview | 2 |

The economic dimension was measured through three indicators:

1-Food Self-sufficiency (FS). A self-sufficient AE, in terms of the food produced within its limits, is considered sustainable. This indicator is composed by two sub indicators:

-Number of products for self-consumption (NPSC). Measured as the N° of products aimed at family consumption, including animal and plant products.

0: 1 product is produced.
1: 2-3 products are produced.
2: 4-5 products are produced.
3: 5-6 products are produced.
4: More than 7 products are produced.

-Area destined to Self-Consumption (ASC). Measured as the area destined for the cultivation of vegetables and fruits for family consumption.

0: less than 15 $m^2$.

1: between 15-30 $m^2$.

2: between 30-40 $m^2$ .

3: between 40 - 50 $m^2$.

4: Higher than 50 $m^2$.

2-Economic Risk (ER). An AE that reduces the economic risk and insures the productive-economic capital for the future generations is considered sustainable. This indicator is composed by four sub indicators:

-Number of Marketing Channels (NMC). Measured as the N° of channels through which each AE commercializes goats and/or other products.

0: no marketing channel.

1: 1-2 marketing channels.

2: 3 marketing channels.

3: 4 marketing channels.

4: more than 5 marketing channels.

- Diversification of Sale Products (DSP).

Measured as the N° of products destined to market, either from the orchard, livestock, craft, fabric, and/or processed products.

0: 1 product for sale.

1: 2 products for sale.

2: 3 products for sale.

3: 4 products for sale.

4: More than 5 products for sale.

-Dependence on external inputs (DI).

Measured as the % of inputs that an AE must destine in order to guarantee livestock and/or orchard production.

0: 80 - 100% of dependence.

1: 60 -80% of dependence.

2: 40 -60% of dependence.

3: 20 al 40% of dependence.

4: 0 al 20% of dependence.

-Productive Activities (PA). Measured as the N° of productive activities carried out within the limits of the AE.

0: No productive activities.

1: 1-2 productive activities are carried out.

2: 3 productive activities are carried out.

3: 4 productive activities are carried out.

4: More than 5 productive activities are carried out.

3-Extraproperty Work (EPW). An AE in which its members use labor to enhance or maintain the intra property production is considered sustainable. This indicator was measured as the participation of the members of the family within each AE in extraproperty work throughout the year.

0: extraproperty work during the whole year.

1: extraproperty work during three seasons.

2: extraproperty work during half of the year.

3: occasional extraproperty work.

4: no need of extraproperty work.

Since AEs respond to a self-sufficiency economic model, the indicators of food self-sufficiency and extraproperty work; along with the sub indicator of number of productive activities were assigned twice the weight of the rest of the indicators for the economic dimension. For the calculation of the economic dimension index, the following formula was used:

$$IE = \frac{(2*NPSC + 2*ASC)/4 + (NMC + DSP + DI + 2*AP)/5 + (2*EPW)/2}{3}$$

The ecological dimension was measured through 3 indicators:

1-Access to Water (AW). An AE with free access to quality water quality resources, for all the activities that depend on this resource, is considered sustainable. This indicator is composed by two sub indicators:

-Water - Quantity (QUAN). Measured as the % of activities (that depend on water resources) covered within the AE, as a function of the quantity of water within that AE.

0: Covers 0-20% of its needs.

1: Covers 20-40%.

2: Covers 40-60%.

3: Covers 60-80%.

4: Covers 80-100%.

-Water - Quality (QUAL). Measured through the analysis of water samples from the sources, as the quality of the resource for different uses (water for human and animal consumption, for irrigation, and other uses).

0: Unsuitable.

1: Suitable for two uses.

2: Suitable for three uses, including human consumption.

3: Suitable for four uses.

4: Suitable for multiple uses.

2-Livestock Survival (LS). An AE that minimizes livestock losses through time is considered sustainable. This indicator is measured as goat losses in % of mortality/ year, and acknowledges the multiple causes that can derive in livestock death.

0: More than 20% of mortality.

1: Between 15-20% of mortality.

2: Between 10-15% of mortality.

3: Between 5-10% of mortality.

4: Between 0-5% of mortality.

3-Foraging Resources (FR). An AE with enough foraging resources to meet livestock demands, is considered sustainable. This indicator is composed by two sub indicators:

-Quality of the Foraging Resources (QUALFR). Measured as a function of the specific quality of the species with higher contribution of forage biomass within the AE.

0: Bad.

1: Regular.

2: Good.

3: Very Good.

4: Excellent.

- Quantity of the Foraging Resource (QUANFR). Measured as the percentage of food needs that the foraging resource of the AE is able to fulfill.

0: Covers up to 20% of the diet.

1: Covers between 20-40% of the diet.

2: Covers between 40- 60% of the diet.

3: Covers between 60 - 80% of the diet.

4: Covers between 80 - 100% of the diet.

The calculation of the ecological dimension index assigned double weight to the water access indicators, especially water quality, as well as to livestock survival, since it is the main productive activity within the AE. Also, double weight was assigned to forage quality, given its importance in the nutritional intake of the herd. The following formula was used:

$$IEC = \frac{2*((W - QUAN + 2*W - QUAL)/3) + 2*LS + (2*QUALFR + QUANRF)/3}{5}$$

The sociocultural dimension was measured through 3 indicators:

1-Basic Needs Met (BNM): An AE in which the farmers have insured housing with services, permanent access to health service and to the different educational levels is considered sustainable. This indicator is composed by three sub indicators:

-Household (H). Measured as the state of the household, including water and electricity services.

0: Without household and services.

1: Incomplete household/ no service.

2: Incomplete household/one service.

3: Complete household/two services.

4: Complete household/all the services.

-Health (HE). Measured as the access to a health center (the possibility of arriving or having access to the health center without inconveniences) with medical staff and adequate equipment/ infrastructure for medical assistance.

0: Without access to health center.

1: Access to health center/ no equipment/ temporary medical staff.

2: Access to health center/ scarce equipment/ temporary medical staff.

3: Access to health center/ moderately equipped/ temporary medical staff.

4: Access to health center/ adequate equipment/ permanent medical staff.

-Education (ED). Measured as the access to the different education levels (the possibility of arriving or having access to the educational center).

0: No access to education.

1: Access to primary level.

2: Access to primary and secondary levels/ with restrictions.

3: Access to primary and secondary levels/ without restrictions.

4: Access to primary, secondary and higher level.

2-Technical Assistance (TA). A system is sustainable if it is reachable to technicians that can improve the production status. It is measured as the presence of technical assistances in the field, and the feasibility of carrying out technical measures that improve the production status.

0: No technical assistance.

1: Eventual technical assistance/ no proposals.

2: Eventual technical assistance/ undone proposals.

3: Frequent technical assistance/ developing proposals.

4: Frequent technical asssistance/ completed proposals.

3-Satisfaction of the Production System (SPS). An AE is considered sustainable and able to support itself in time if its farmers are satisfied with the productive activities, measured as the degree of satisfaction in relation to the productive activities carried out.

0: Discontent, would not do it anymore.

1: Not at all satisfied, would live somewhere else.

2: Moderately satisfied, would keep producing.

3: Satisfied, did better before.

4: Satisfied, would not do anything else.

The sociocultural dimension index was calculated giving double weight to the satisfaction of the production system, since a discontent farmer has higher probabilities of abandoning the activity. Also, the technical assistance was weighted with the following formula, since AE have few resources and are isolated from urban centers and roads:

$$ISC = \frac{(H + HE + ED)/3 + 2*SPS + 2*TA}{5}$$

Finally, the General Sustainability Index was calculated as the algebraic sum of all the indexes that compose the sustainability dimensions:

$$ISG = (IE + IEC + ISC)/3$$

## Results

### Sustainability analysis

The use of indicators allowed detecting the state of sustainability of the three analyzed AE. Broadly, the only AE with a general sustainability index (GSI) higher than the threshold value was AE 1 (GSI= 2.3), while AE2 and AE3 were below that threshold (table 2 and figure 2, page 200). Figure 3 (page 201) and table 1 (page 196) show the individual analysis of the economic (EI), ecological (ECI) and sociocultural indexes (SCI) for each AE. The results indicate that the three studied AE varied according to the addressed dimensions, and that neither of them reached the TSV in the three dimensions.

**Table 2.** Values of the set of indicators with their respective economic (IE), ecological (IEC), and sociocultural (ISC) indexes; and the general sustainability index (ISG) for the three agroecosystems in drylands of San Juan, Argentina.

**Tabla 2.** Valores del conjunto de los indicadores con sus respectivos índices económico (IE), ecológico (IEC), sociocultural (ISC) y el índice de sustentabilidad general (ISG) para los tres agroecosistemas de zonas áridas, San Juan, Argentina.

| | FS | ER | EPW | IE | AW | FR | LS | IEC | BNM | SPS | TA | ISC | ISG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AE1 | 4 | 3.2 | 3 | 3.44 | 1.33 | 2.00 | 1 | 1.07 | 1. 67 | 3 | 2 | 2.33 | 2.3 |
| AE2 | 0.5 | 1.4 | 1 | 0.88 | 1.33 | 2.00 | 1 | 1.07 | 1. 67 | 3 | 2 | 2.33 | 1.4 |
| AE3 | 0.5 | 1.2 | 4 | 2.04 | 1 | 2.00 | 1 | 1.00 | 1.33 | 3 | 0 | 1.47 | 1.5 |

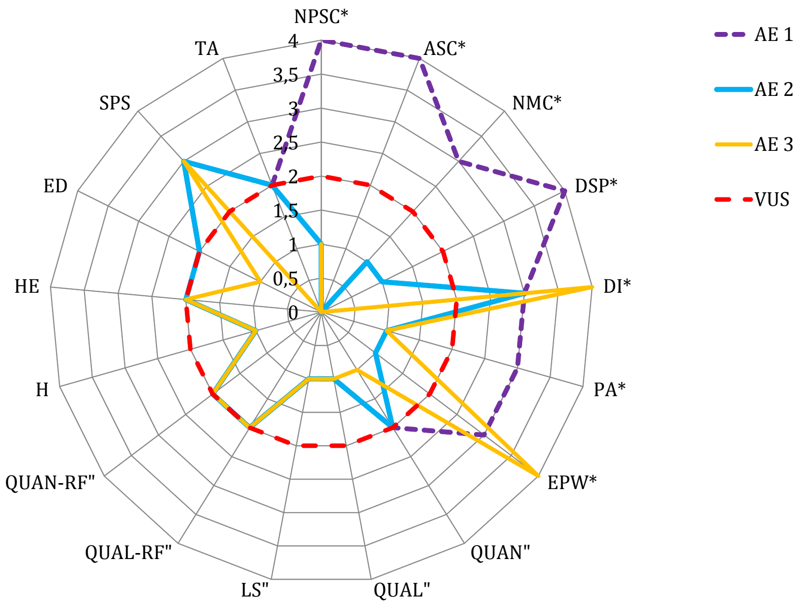



**Figure 2.** Spider web chart of the sustainability indicators in the three agroecosystems in drylands of San Juan, Argentina. The outer limits represent the ideal value of sustainability (4), and the intermediate limit the threshold value (2). In asterisk: economic (E), ecological (EC) and Sociocultural (SC) indicators are indicated with asterisks, quotes, and normal text, respectively.

**Figura 2.** Representación gráfica en un diseño en tela de araña, de los indicadores de sustentabilidad en tres agroecosistemas de tierras áridas, San Juan, Argentina. Los límites exteriores representan el valor ideal de sustentabilidad (4) y el intermedio el valor umbral (2). Con asterisco: económicos (E); con comillas: ecológicos (EC) y los que no tienen marca socioculturales (SC).

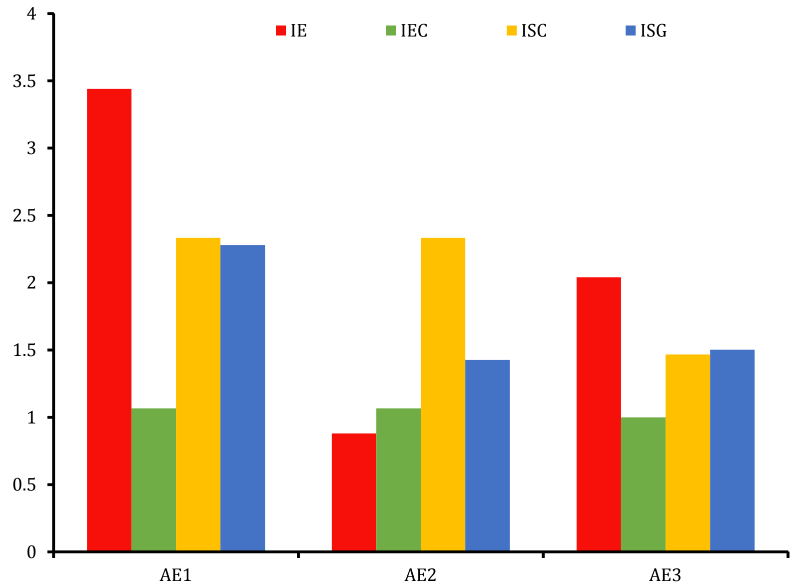



**Figure 3.** Values of the three dimensions of sustainability indexes: economic (EI), ecological (ECI) and sociocultural (SCI) dimensions. The bar on the far right indicates the value of the general sustainability index (GSI).

**Figura 3.** Valores de los índices de las tres dimensiones de la sustentabilidad: índice de la dimensión económica (IE), de la dimensión ecológica (IEC) y de la dimensión sociocultural (ISC). La última barra a la derecha indica el valor del índice de sustentabilidad general (ISG).

In the case of EI, AE1 widely exceeded the other AE within the established scale (EI= 3.44), while AE2 did not reach sustainability in this dimension (EI= 0.88) and AE3 reached the TSV.

However, for the ECI the situation was similar in the three agroecosystems, with none reaching the TSV; while for SCI, AE1 and AE2 obtained the same value (SCI= 2.33), reaching the threshold sustainability value. On the other hand, AE3 reached a lower to the TSV value (SCI= 1.47).

When analyzing the indicators for each dimension, it was observed that AE3 reached food self-sufficiency with a high number of foods produced in the area, enough to cover the whole family needs (figure 2, page 200). Also, AE3 reduced the economic risk by diversifying production and increasing the number of products for sale and the marketing channels. In the other AE, food self-sufficiency was not reached (both with FS= 0.5, table 2, page 200), nor did they reduce the economic risk (ER= 1.4 and 1.2 in AE2 and AE3, respectively). These two AE did not exhibit diversification of productive activities and had none to 1 or 2 marketing channels. The only indicator within economic risk that was similar among the three AE was the low dependence of external inputs.

On the other hand, the indicator extra-property work exceeded the TSV in AE1 and AE3 (figure 2, page 200), but not in AE2, since this system is mainly sustained by such incomes (EPW= 1).

For the ecological dimension, a critical situation was found in the three analyzed systems. For the indicator access to quality water, the resource was partially available in AE1 and AE2 (for example, human consumption was only partially satisfied), while AE3 showed an even worse situation (AW= 1), since it only counts with one water source. The San Juan river is shared by the three AE, but its flow varies throughout the year, and its quality is only suitable for animal consumption and orchard. Regarding goat survival, the three AE showed 15-20% losses due to mortality (LS= 1 in the three AE, table 2; figure 2, page 200), with the following causes mentioned in the interviews: illness, attacks by wild dogs and malnutrition. The latter was related with foraging resource availability in the area, which did not cover 60% of the diet, although its quality (*i.e.*, the nutritional status of the available foraging species) was good in the three systems. The species that provide the higher foraging biomass for livestock are *Prosopis alpataco* and Lycium spp. (figure 4).

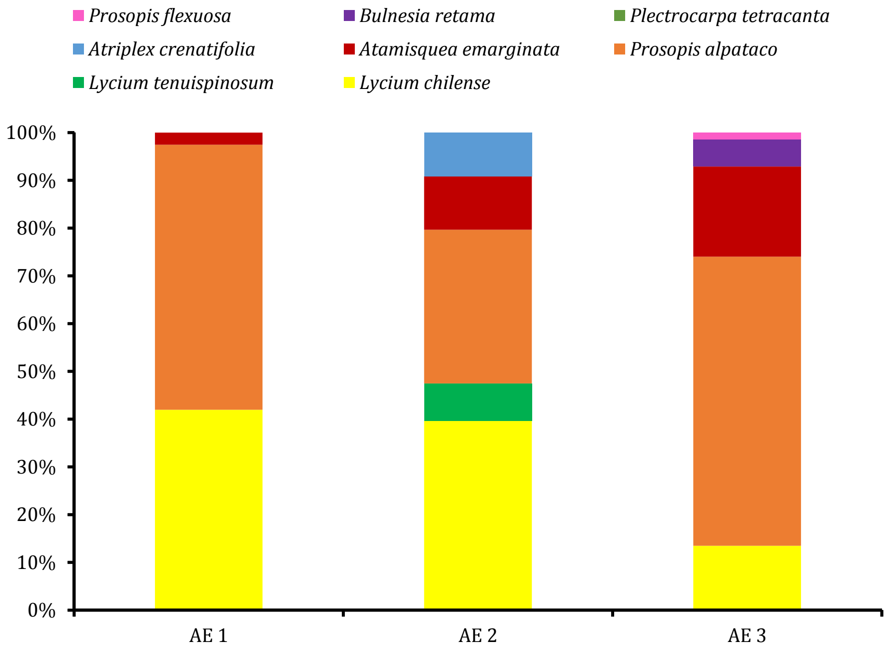



**Figure 4.** Specific contribution by contact (CSC), expressed as percentage of the foraging species to the forage supply season.

**Figura 4.** Contribución específica por contacto (CSC) expresada en porcentaje de las especies forrajeras para la época de oferta forrajera.

Regarding the social dimension indicators, they showed that the basic needs were not satisfied in neither of the AE, with AE3 showing the lowest values (BNS= 1.33, table 2, page 200).

Despite this, farmers were satisfied with the productive activities, and did not express they would rather perform other activities. Regarding the technical assistance indicator, AE3 did not present any type of assistance, while in the other two systems technicians reached the area and made suggestions, yet, not carried out.

## Discussion

Our results confirm the former hypothesis of this research: the indicators for the three dimensions (economic, ecological and sociocultural) used at the local scale, determine the critical points that jeopardizes the sustainability of the AEs over time. Sustainability is a multidimensional concept, that should thus be understood and evaluated in a systemic and holistic fashion. The obtained results suggest that the analyzed AE do not reach sustainability, since it is not achieved in its three dimensions. Furthermore, considering the objectives that sustainable agriculture should meet (46), and that were proposed as a framework for this study, none of the analyzed systems meets them all simultaneously. Instead, differences in the values of the economic, ecological and sociocultural dimension indices were found. This situation agrees with that found in other studies that have evaluated sustainability at the farm scale, although in those studies the systems did reach sustainability (3, 46). The dimensions were composed by indicators that reflected their state. The economic dimension was found to be the most variable for the three systems, while the ecological dimension was very similar, and the sociocultural dimension resulted similar between AE1 and AE3, but differed for AE3.

The variability in the economic dimension indicators of the three AE might be due to the fact that each AE adopts diverse strategies that define the economy of each system. Although AE1 and AE3 are economically sustainable, substantial differences were found between these systems. AE1 is held due to the diversification of its productive activities, products for self-consumption and sale, and the relation established with the diverse consumers. Also, this AE is sustained through family labor, which occurs exclusively within its limits, and which might explain why the members of this AE do not participate in extraproperty jobs. On the other hand, AE3 is not sustained by a diversification of productive activities, therefore it does not present a diversity of products for consumption, while livestock production is lower and occurs only to sustain domestic demand. This might be due to the fact that this AE is composed by elderly members that have retired from market-oriented production and that cannot carry out extraproperty work as another possible strategy for the economic growth of the system. Their main objective is to keep the productive capital needed to subsist. On the other hand, AE2 did not reach sustainability in the economic dimension, and a different life strategy than that of AE1 and AE3 was detected. In this system, there is no diversity of productive activities, since it dedicates exclusively to goat breeding, such as AE3. However, AE2 commercializes livestock, ensuring an influx of money for family needs or for buying livestock forage. In contrast to the other AE, this system is largely sustained by extraproperty work, for which the family invests time, leaving aside diversification within the farm.

As in this study, a study performed in Salinas Grandes, Catamarca addressing economic diversification in multiple-use systems (28) found a diversity of life strategies within the community members, with some people carrying out diversified productive activities while others dedicated almost exclusively to a certain activity (cattle ranching in that case) and others had extraproperty jobs. Several agroecology publications promote the diversification strategy, and it is usually referred to as that one of the bases to reach sustainable agroecosystems. Furthermore, it is recognized that polycultures, agroforestry and other diversification methods imitate natural ecological processes (8, 12, 16, 30, 35, 45, 53). On the other hand, extraproperty jobs reduce the use of natural resources within the farm, and gives independence of the climatic and economic uncertainties to the people who adopt this strategy (28).

The analysis of the ecological dimension was similar for the three AE, but certain differences regarding the components of this dimension were detected in AE3, mainly due to the lack of water resources in this system, compared to the other two. This could be explained by the fact that this AE is more isolated, (figure 1, page 193) impeding the municipal tanker truck to and provide drinking water. "Not even the technicians with technical proposals can reach the farm" (information from one of the interviews). In AE1 and AE2, the water extracted through the wells and perforations has very high salt content, and thus cannot be used for productive activities. These sources are virtually voided, despite being functional (55). The San Juan river is the common water source for all the AE, through which the herd water needs of the three AE, the orchard water needs of AE1, and the consumption needs through filtration in AE3 are provided. To this respect, a study by Tapia *et al.* (2017) about water source quality in the study area, found that the water provided by the San Juan river is suitable for the different activities. It is worth mentioning that this source does not have a permanent water course, and water is scarce in the seasons where it is most needed, due to its utilization in the upstream oasis.

In response to this situation, the members of the AE develop different strategies to provide water to the herds, such as the fabrication of pastures inside the river, where they extract water through excavation. These kind of subsistence strategies, together with solid the strong roots, might explain that the AE still remain in the area, even under critical conditions.

In the Lavalle desert, towards the south of the study area, the situation regarding water resources is similar to that from our study area, where the surface flows that supply water to the area are scarce and discontinuous, and subterranean waters have high salinity levels, even exhibiting high levels of hydroarsenism (59).

Regarding foraging resources, the indicators reflect that its quality is good for the three AE, while its quantity is not enough to meet goat demands. The latter explains why these systems have to buy extra foraging inputs for the herds, although they are still insufficient and usually destined to cover feeding needs of horses (mean of transport). On the other hand, goat survival is critical in the three systems. The most common identified causes of goat death are starvation, attacks by dogs, and diseases due to lack of sanitary control, among others. Although this is the main productive activity and farmers would not dedicate to anything else, it is deteriorating. To this respect, a study case with goat farmers in the Lavalle desert (59), next to the study area, showed that goat production is strongly compromised because ranching is held in degraded areas with low foraging availability, due to a lack of calving planification, a high percentage of animals with brucellosis (chronic infectious contagious disease produced by *Brucella melitensis*), and a lack of adequate management practices, among other factors. The analysis of the ecological dimension could deepen, through the consideration of variables related to orchard development, such as soil management or crop rotation, among others. They were left aside in this study due to orchard being a secondary activity.

Sustainability of the socioeconomic dimension was reached in AE1 and AE2, while AE3 did not exceed the STV. Although livelihood and health access conditions are similar among the three systems, access to education and technical assistance is not. The members of AE3 claimed not having the opportunity to go to school, thus they dedicated to farming activities since childhood. On the other hand, technical assistance for this AE does not have continuity in time, and technical proposals are only partially achieved, for which resources (such as vaccines) are only guaranteed at certain seasons or times of the year. The situation is more critical in AE3, where technical assistance is null. Once more, this could be due to this farm being isolated. Finally, farmers are satisfied with the activity, to the point that they do not do anything else. Such satisfaction, their roots, and the "hope that the lagoons will appear again", justify why these systems remain in the site despite the critical sustainability conditions identified in this study.

The results of this study confirm the utility of indicators for multidimensional evaluations, through which an analysis of the state of the productive systems can be held at different levels. Addressing both general issues, such as the GSI, to more specific situations, allow detecting economic, ecological and sociocultural-factors under critical states, that might jeopardize sustainability at the farm level. In turn, this methodology allows detecting how the different values interrelate among each other, and explains the functioning of each system. Also, the weight of the indicators came out through consensus within the working group, and has been used in other studies (46). Undoubtedly, results can vary according to the criteria used to weight the indicators, including the participation of the farmers in this decision, as suggested by Roming *et al.* (1996), and Lefroy *et al.* (2000). Since this study is a synchronic evaluation, it has certain limitations that can be overcome through an evaluation in time (diachronic), addressing the trends of the system, analyzing whether the compromising reality of these AE might change if, for example, all the AE had unrestricted access to quality water.

Although sustainability is a situated concept, the local indicators used in this study can be applied in other rainfed agroecosystems with similar characteristics. The analysis performed can be deepened by measuring other variables. For example, in the ecological dimension, goat production can be evaluated through technical-productive parameters, such as flock structure, or pregnancy and birth rates (37, 38). In the social dimension, community interaction and land tenure could be measured (32); while in the economic sphere, other indicators can be addressed, such as family income composition (6).

Ultimately, the decision about the variables chosen to assess sustainability is determined by the objective of the study, the scale of analysis (farm, land, region), the type of establishment, productive activity, farmer characteristics, and the possibilities of carrying out the effective measurement of the mentioned variables.

## Conclusions

The indicators used to measure sustainability in dryland agroecosystems allow identifying critical points that might jeopardize the sustainability of the different dimensions analyzed. In our study, no agroecosystem exceeds the threshold sustainability value simultaneously in all three dimensions, even when the general sustainability index does reach this value. In general, the indicators with a critical state were food self-sufficiency in the economic dimension; access to water resources and livestock survival in the ecological dimension; and technical assistance in the field, and satisfaction of basic needs in the socio-cultural dimension. In this sense, the multidimensional analysis of sustainability showed that these indicators should be taken into account when seeking intervention alternatives in the agroecosystems, and when making decisions regarding their sustainable development.

The development and use of indicators, even with their limitations, is an adequate and flexible tool to evaluate trends, establish differences among productive systems, and detect critical variables that hinder the achievement of sustainable agriculture. In turn, the detection of these variables can derive in the implementation of management and self-governance measures by the technicians and local actors, aiming at improving sustainability in the AE. The indicators used are easy to measure, inexpensive, and reflect the reality in the different dimensions addressed.

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