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Ecological sustainability evaluation of traditional management in different vineyard systems in Berisso, Argentina

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Abstract

The ecological principles underlying traditional agricultural management practices are not always understood. On the coast of Berisso, Argentina, traditional management practices are applied to ''old'' vineyards located in flood plain areas, subject to periodic floods. Over the last few years, ''new'' vineyards have been planted at slightly higher altitudes, protecting them from river flooding. Despite the ecological differences between the low and high areas, farmers have largely extended traditional management practices to the new vineyards. This study was undertaken to evaluate the risks involved when traditional agricultural management practices are applied to different ecological settings while the underlying ecological principles of those practices are not well understood. The evaluation relies on three distinct sections: (1) assessing the sustainability of a traditional vineyard management system, (2) analyzing its underlying ecological principles and (3) investigating the potential consequences of applying management practices utilized in flood plain zones to higher altitudes. To carry out the evaluation, a methodology based on indicators was used. In particular, an evaluation was developed to examine traditional vineyard management effects on both internal resources, such as soil properties and biodiversity, and external resources, such as nonrenewable energy and water resources. In old vineyards situated within the flood plain, traditional management practices recycle organic matter, preserve biodiversity, provide for an efficient use of nonrenewable energy and ensure a low risk of underground water contamination from pesticides. Furthermore, the soil nutrient balance is maintained via nutrient input from river sediments. In contrast, new vineyards present a negative soil nutrient balance. Our findings thus suggest that traditional management practices are ecologically sound when considered within their original ecological context, but may be inappropriate in new ecological settings.

Keywords: Agroecology; Indicators; Management systems; Vineyards

1. Introduction

Agroecosystems occupy almost one third of the earth's surface (CBD, 1996), which means that agriculture is one of the most important human activities in terms of ecosystem sustainability. Sustainable agriculture (SA) requires the conservation of natural capital (Harte, 1995), i.e., all natural assets capable of producing a flow of useful goods and services for human beings (Daly, 1997). Therefore, agricultural productivity should be consistent with natural resource conservation (Parris, 1999).

A lack of clarity on the concept of sustainability has been identified as a limitation that hinders its attainment (Redclift, 1995). However, consensus does exist around the fact that sustainability involves a wider temporal scale than the one currently used (Daly and Gallo, 1995).

Concern over environmental conservation has led to a search for agricultural systems that have survived over time, systems which fulfill their objective of productivity in harmony with the environment. Traditional agricultural

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systems have raised interest in this context. In the literature, it is acknowledged that traditional agriculture aims to conserve biodiversity and use natural resources in a sustainable way (CBD, 1996; Toledo, 1993, 2001). Traditional systems are considered environmentally sound because they have stood the test of time and exhibit low dependence on external inputs (Altieri, 1992, 1995; Hecht, 1991).

However, the principles upon which traditional systems are based are not always clearly understood (Toledo, 1993). This could lead to the dissemination of traditional management practices as a series of technological recipes, as is seen in conventional agriculture (Paul and Robertson, 1989). In this case, only the practice itself is valued and not the ecological principles it is based on. Thus, the implementation of a practice outside its original environment may imply a risk for ecological sustainability. Traditional management practices that are ecologically sound, preserving natural resources, are a result of the co-evolution of farmers and the environment (Toledo, 1993, 2001; Altieri, 1995). Thus, it is important to analyze and understand the ecological principles upon which these management practices are based (Altieri, 2002), as well as the effects of these management practices on the environment.

On the coast of Berisso, Argentina, at the beginning of the 20th century, vineyards were established in areas of the region that were subject to the periodic flooding of the La Plata River. Local farmers developed a specific agricultural system management that has been passed down from one generation to the next. Recently, new vineyards have been set up, following an economic revitalization of vitiviniculture. Some of these newly established vineyards are located in slightly higher areas, and, as a consequence, they are not subject to the river's periodic flooding. Despite the ecological differences between these two areas, farmers largely extended the type of management used in vineyards at lower areas to the new vineyards at higher altitudes. Even though these new systems appear relatively independent of external inputs, the implementation of such traditional management practices outside of their original ecological setting might affect ecological sustainability.

Evaluating sustainability is not simple, given the concept's complexity and the disagreement over its definition; hence, different methodologies have been proposed, many of which are based on the use of indicators (Torquebiau, 1992; Smyth and Dumansky, 1995; Gómez et al., 1996; Masera et al., 1999; Sarandón, 2002; Zhen et al., 2005). Indicators have also been used to evaluate the environmental impact of agriculture at the farm level (Van der Werf and Petit, 2002; Halberg et al., 2005) and can therefore be used to study the ecological principles underlying agricultural management practices. Research aimed at evaluating agricultural sustainability usually compares the sustainability of different management systems (Clermont-Dauphin et al., 2005; Lefroy et al., 2000; Pacini et al., 2003; Masera et al., 1999; Rasul and Thapa, 2004). Nonetheless, analyses of the effects of a specific management system under different ecological conditions should be studied.

The objective of this study was to evaluate the risk of applying traditional management practices in different ecological settings without first understanding their underlying ecological principles. This evaluation was carried out by assessing the sustainability of a traditional vineyard management system, analyzing its underlying ecological principles and investigating the possible consequences of applying management practices that originated in flood plains to higher altitudes.

2. Methodology

2.1. Study area

Berisso is located in Buenos Aires province, Argentina (latitude 34°53′ South, longitude 57°54′ West). The region is classified as subtropical and humid, with average temperatures between 14 and 18 °C and an annual rainfall of 910 mm. The area consists of coastal plains, with altitudes between 0 and 5 m. The prevailing natural vegetation in this wetland zone (Malvárez, 1999) is coastal forest. Old vineyards are located in the alluvial plain of the La Plata River, which is a modern unit of fluvial accumulation. Soils are Fluvisols (FAO, 1998), with a horizon sequence of (Oi)-A-Cg1-2Cg2-3Cg3-; they evolved under hydromorphism conditions, accentuated by a water table close to surface level (Martínez et al., 2000). The newly established vineyards are located on a shelly ridge composed of accumulations of mollusk valves, both whole and broken up. Soils are Rendzic Leptosol (FAO, 1998) with an A-horizon of 20–40 cm and a high content of well-humified organic matter, under which there exists an AC or C-horizon made up of layers of small shells (Martínez et al., 2000).

2.2. Description of vineyards

Old vineyards situated at lower altitudes have a drainage system composed of small channels called *zanjillos*. These channels drain surplus water after floods. Other larger channels, named *collectors*, collect water from the zanjillos. Farmers clean zanjillos annually and place the sediment at the base of vine plants. In contrast, newly established vineyards do not have a drainage system, since they are protected from floods.

In the two vineyard systems studied, the cultivated species is *Vitis labrusca* L., which is adapted to temporal flooding conditions. In both systems vines are grown on an arbor, which prevents floodwater from reaching the grapes. Vineyards have a permanent soil cover of spontaneous vegetation, which is periodically mowed to facilitate crop management activities such as pruning and shoot-tying. Little to no chemical inputs (e.g. herbicides, fungicides and pesticides) are used. Nevertheless, these systems do not show pest or disease problems. The vineyards are also surrounded by areas with low, disturbed vegetation.

To evaluate the ecological sustainability of traditional management, two ‘‘old’’ systems, O1 and O2, and two ‘‘new’’ systems, N1 and N2, were selected as case studies. These vineyards were selected using two criteria: they had to be representative of their management system and accessible.

2.3. Evaluation of ecological sustainability

For the evaluation of sustainability, a conceptual framework was identified and indicators were defined. It is commonly held that sustainable agriculture preserves the set of basic natural resources and prevents degradation. In addition, SA must preserve natural resources that are both internal to the system, such as soil and biodiversity, and external to the system, such as water and nonrenewable energy resources.

For each resource, relevant characteristics according to the attributes of agroecosystem sustainability (descriptors) (Torquebiau, 1992) were selected. Then, an indicator was designed for each descriptor. Furthermore, some indicators included subindicators and variables (Table 1). Thus, the indicator is a measurement of the effect of the system on the descriptor (Torquebiau, 1992). For soil resources, biological (soil life), chemical and physical properties were selected as descriptors because they are the main characteristics of soil sustainability. For biodiversity, autotrophic (vegetal) and heterotrophic (animal) diversity were taken into account. Fossil fuel inputs were monitored to evaluate nonrenewable energy use, because they are considered the most relevant for agriculture sustainability (Gajaseni, 1995; Gliessman, 2001). Finally, the relevant characteristic for water resources was the effect of management on underground water (Table 1).

In defining indicators, the methodology proposed by Sarandón (2002) was adopted as follows: (I) the farm level was set for the analysis and (II) pressure indicators (Winograd et al., 1998) were developed and justified to assess the effect of system management on resource conservation. State environmental conditions were evaluated as subindicators and variables, (III) a relative weight was given to each variable, subindicator or indicator, according to its influence on sustainability (Table 1). This weight was based on the following criteria. Soil indicators were weighted considering the criterion of irreversible deterioration of soil properties: the highest weight was given

Table 1
Conceptual framework and indicators used to evaluate the ecological sustainability of vineyard systems in Berisso, Argentina

Resource	Descriptor	Indicator	WV[a]	Subindicator	WV	Variables	WV
Internal							
Soil	Biological property (soil life)	Contribution to soil organic matter	3	Cover biomass recycling	3		1
				Cover management	4	Cover growth regulation	
						Cover biomass final condition	1
				Frequency of the cover biomass contribution to the soil	2		
				Vine biomass recycling	1		
				Vine biomass management	2		
	Chemical property	Partial nutrient balance	1	Nitrogen balance	1		
				Phosphorus balance	3		
				Potassium balance	2		
	Physical property	Erosion risk	2	Seasonal variation of the soil cover percentage	3		
				Flood frequency	1		
Biodiversity	Autotrophic diversity	Autotrophic diversity management	3	Natural area/cultivated area ratio	3		1
				Spontaneous vegetation diversity	1	Shannon index	1
						Equity index	
				Spontaneous vegetation management	4		
	Heterotrophic diversity	Heterotrophic diversity management	1				
External							
Nonrenewable energy	Energy from fossil fuels	Energy efficiency					
Water	Underground water	Pesticide pollution risk		Pesticide leaching risk	1		
				Pesticide dose, toxicity and frequency of use	1		

[a] WV, weight values.

to biological properties, followed by physical and chemical ones. Biological property subindicators related to spontaneous vegetation were weighted more heavily than those related to crop biomass because cover is permanent on the farms. Because of their influence on organic matter quality for heterotrophic organisms, those subindicators relating to biomass management were weighted more heavily than recycling ones. Nutrient abundance and restoration facility were the chosen criterion for partial nutrient balance subindicators (phosphorus > potassium > nitrogen). Seasonal soil cover percentage variation was also chosen as a subindicator and received a higher weight than flood frequency, as it is sensitive to farmer management. For biodiversity indicators, the functional dependence between the two types of diversity (autotrophic and heterotrophic) was considered: more weight was given to autotrophic diversity as it influences heterotrophic diversity. Spontaneous vegetation management influences spatial and temporal diversity in perennial cultivation systems, therefore, spontaneous vegetation management received the greatest weight between autotrophic diversity management subindicators. Lower weight was given to spontaneous vegetation diversity, as it is a state subindicator. The same weight was given to pesticide leaching risk subindicators and to all the selected variables. Finally, to permit comparisons, variable, subindicator and indicator values were standardized on a 0–4 scale, with 0 indicating low sustainability and 4 high sustainability.

2.4. Data collection

Data collection involving farmer interviews and field data was carried out between September 2002 and April 2003 (Table 2).

Partial nutrient balance was calculated as the difference between the input and output of nitrogen (N), phosphorus (P) and potassium (K). To calculate system inputs, both fertilizers directly applied by farmers and also nutrients carried away by floodwater and fluvial sediments were taken into account. An average of 12 floods per year was assumed. Nutrient contribution from the river was estimated based on the field observation that one fourth of the zanjillo's volume is retained in each flood. The content of N, P and K in river water was calculated using data from the Consejo Permanente para el Monitoreo de la Calidad de las Aguas de la Franja Costera Sur del Río de la Plata (1997). Annual contribution of fluvial sediment in the 'zanjillos' was estimated to be 1.5 cm thick. Sediment density was 1.2 g cm^{-3} and nutrient composition was determined by chemical analysis (Table 2).

For nutrient output calculations, crop yield and grape clusters' chemical composition were considered (Table 2).

Energy efficiency (EE) was calculated as energy outputs to inputs ratio (EE = harvested E/supplied E) and only nonrenewable energy sources were considered. In each system, information was obtained about the type and amount of the input and machinery used. Total energy input was calculated by adding direct energy (the amount of energy in terms of fuel used during the crop cycle) and indirect energy (the energy required for industrial production of machinery and inputs). For each input, an equivalent energy value was obtained from the literature (see Table 4). To estimate *energy output*, crop yield (grape clusters) as well as energy content were taken into consideration.

Autotrophic diversity, the proportion of natural (or low disturbed) area to cultivated area on each farm was measured. In addition, Shannon and equity's indexes of vegetal cover were calculated comparing samples taken from two vineyard zones: between vine rows and within each row (Table 2). The indexes of each plot were weighted according to the area covered by the two zones (68% between rows, 32% within each row).

Heterotrophic diversity management and pesticide pollution risk, information about pest and disease management and pesticide use was collected via farmer interviews. The toxicological category and recommended application dose were obtained from the CASAFE database (2003), while leaching risk was obtained from the Extension Toxicology Network (EXTOXNET, 2004).

Table 2
Field data collection

Indicator	Field data collection	
	Interview	Other
Contribution to soil organic matter	X	
Partial nutrient balance	X	In each system subject to flooding (O1 and O2), one compound sample from 10 sediment subsamples was obtained. The percentages of total N, P and K were determined. Total N, P and K percentage was measured on a compound sample taken from 20 grape clusters.
Erosion risk	X	In each farm, the percentage of total coverage was calculated through 10 samples of 0.25 m^2.
Autotrophic diversity management	X	In each farm, cultivated and natural area was measured. In addition, 10 samples of 0.25 m^2 were carried out (five between vine rows and five within each row). The different plant species were identified and the percentage of total coverage and coverage by individual species was calculated.
Heterotrophic diversity management	X	
Energy efficiency	X	
Pesticide pollution risk	X	

Table 3
Balance of nitrogen, phosphorus and potassium (kg ha^{-1} year^{-1}) for old (O1 and O2) and new (N1 and N2) vineyard systems in Berisso, Argentina

Nutrient	Agroecosystems			
	N1	N2	O1	O2
Nitrogen				
Input	0	0	39.1[a]	39.1[a]
Output	2.9	13.5	7.7	5.4
Balance	−2.9	−13.5	31.4	33.6
Phosphorus				
Input	0	0	90.1[a]	90.1[a]
Output	0.7	3.2	1.8	1.3
Balance	−0.7	−3.2	88.3	88.8
Potassium				
Input	0	0	55.1[a]	55.1[a]
Output	3.5	16.4	9.2	6.5
Balance	−3.5	−16.4	45.9	48.6

[a] It includes the contribution from water and the fluvial sediment.

The pesticide leaching risk subindicator was obtained in each plot using the following equation:

$$\mathrm{PLR} = \frac{\sum_{i=1}^{n} A_i \cdot B_i}{\sum_{i=1}^{n} B_i}$$

where PLR is the pesticide leaching risk, A_i the value assigned to the pesticide i leaching risk and B_i is the number of applications of pesticide i.

Assigned pesticide leaching risk values were: low (4); unknown, but permitted in organic agriculture legislation (3); unknown and not permitted in organic agriculture legislation (1); high leaching risk (0).

The dose, toxicity and frequency of pesticide application subindicator were composed of two terms: toxicity and dose. The former evaluates high or low toxicity pesticide use and was determined with the following equation:

$$T = \frac{\sum_{i=1}^{n} C_i \cdot B_i}{\sum_{i=1}^{n} B_i}$$

where T is the toxicity, C_i the value assigned to the pesticide i toxicological category and B_i is the number of applications of pesticide i.

Toxicological categories I and II were given a value of 2, while categories III and IV received a value of 4. A threshold value of 3 was set; above this value, low toxicity products were considered prevalent, while below, those of high toxicity would be prevalent. The second term evaluates the application dose: a value of 4 was given to applications that were equal or lower than the recommended dose, while a value of 2 was assigned to higher than recommended doses. A threshold value of 3 was established to separate high (below) or low (above) doses.

3. Results

The balance of N, P and K varied between the two vineyard systems. In old systems (O1 and O2, located in areas affected by flooding), the balance of N, P and K was positive, with a balance of P > K > N (Table 3). Nutrients originating from floodwater and fluvial sediment accounted for 3.5 and 96.5% of total input, respectively, thereby buffering the harvest effect on nutrient balance. In contrast,

Table 4
Energy efficiency for old (O1 and O2) and new (N1 and N2) vineyard systems in Berisso, Argentina

	Equivalent energy (MJ unit^{-1})	Agroecosystems							
		N1		N2		O1		O2	
		Amount	Total	Amount	Total	Amount	Total	Amount	Total
Inputs (*I*)									
Gasoline (l)	42.3[a]	20	846	94	3976.2	66	2791.8	70	2961
Diesel (l)	47.8[a]	20	956	0	0	0	0	0	0
Tools (kg)	90[b]	1	90	1	90	1	90	1	90
Synthetic fungicide (kg)	271.9[a]	3	815.7	7	1903.3	3.6	978.84	0	0
Herbicide (l)	450[c]	0	0	0	0	0	0	0.5	225
Copper sulfate (kg)[f]	4[d]	0	0	21	84	0	0	20	80
Lime (kg)[f]	1.3[a]	0	0	11	14.3	0	0	20	26
Insecticide (kg)	327.3[a]	0.1	32.73	0.2	65.46	0.2	65.46	0	0
Total inputs			2740.43		6133.26		3926.1		3382
Outputs (*O*)									
Grapes (kg)	3.4[e]	3200	10880	15000	51000	8500	28900	6000	20400
Energy efficiency (*O*/*I*)			4.0		8.3		7.4		6.0

[a] Pimentel et al. (1991).
[b] Gajaseni (1995). The use of a strimmer of 7 kg was considered (estimated to last 7 years) (depreciation 1 kg year^{-1}).
[c] Hernánz et al. (1995). The energy value of glyphosate was used.
[d] Calculated as of the values of lime obtained by Pimentel et al. (1991). A three to one energy to lime proportion was given.
[e] Valor Calórico de alimentos (2004). http://www.csalto.net/control%20peso/calorías_alimentos.htm.
[f] These are components of Bordeaux mixture.

Table 5
Pesticides used in old (O1 and O2) and new (N1 and N2) vineyard systems of Berisso, Argentina, action taken, toxicological category, leaching risk, dose and number of applications

Systems	Pesticides used	Action	Toxicological category	Leaching risk	Application dose	Number of applications
N1	Mancozeb	Fungicide	IV	Low	Recommended	4
	Deltamethrin	Insecticide	II	Low	Recommended	1
	Emulsifiable oil	Insecticide	IV	p.o.a	Recommended	1
N2	Mancozeb	Fungicide	IV	Low	Recommended	2
	Bordeaux mixture[a]	Fungicide	p.o.a	p.o.a	Recommended	2
	Folpet + aluminum phosethyl	Fungicide	IV	Low	Recommended	2
	Cypermethrin	Insecticide	II	Unknown	High	1
O1	Mancozeb	Fungicide	IV	Low	Recommended	4
	Deltamethrin	Insecticide	II	Low	Recommended	1
	Emulsifiable oil	Insecticide	IV	p.o.a	Recommended	1
O2	Glyphosate	Herbicide	IV	Low	Recommended	1
	Bordeaux mixture	Fungicide	p.o.a	p.o.a	Recommended	4

p.o.a, permitted in organic agriculture.
[a] The Bordeaux mixture, because it is a homemade product, does not have toxicological information for each active principle in the Phytosanitary Guide (CASAFE, 2003). Since it is a product authorized in Argentine organic agriculture (Resolution SAGyP No. 423/92; Resolution, IASCAV No. 116/94; Resolution, IASCAV No. 188/95), it was considered of low toxicity.

the newly established vineyards (N1 and N2, situated in higher areas) had a slightly negative nutrient balance for all three nutrients, with an imbalance of K > N > P (Table 3).

Vineyard energy efficiency was similar in the two analyzed systems (Table 4), ranging from 4 to 8.3, with no clear pattern of energy efficiency observed between old and new systems. Fuel was found to make up the largest portion of the energy input, ranging from 65 to 86% of total energy input. Approximately 80% of fuel was used to mow spontaneous vegetation. The portion of energy input made up of fungicides was higher than that for insecticides and herbicides. Compared to old systems, new ones applied more synthetic fungicides, which implies a higher energy cost than traditional fungicides such as Bordeaux mixture (Table 4).

In general, the two systems used similar agrochemicals with low toxicity and low risk of leaching (Table 5). Fungicides and herbicides showed a lower toxicity than insecticides, and they were all usually applied at an adequate dose (Table 5).

Sustainability indicators show that management practices were more sustainable in old floodplain systems than in newly established vineyards located at higher altitudes (Table 6). Generally, management of old and new vineyards had a low impact on both internal (soil and diversity) and external resources (nonrenewable energy and water) (Table 7). Indicators' values were mostly high, suggesting a low risk for system sustainability (Fig. 1a and b). In terms of sustainability, the most substantial difference between old and new systems emerged when soil fertility management was examined (Fig. 1a and b).

In old systems, N, P and K management reached high values of sustainability (Table 6) through the conservation of soil chemical properties (Fig. 1a). On the other hand, an unsustainable management of nutrients was observed in new systems (Table 6), which suggests that the conservation of soil chemical properties may be impacted in the long run (Fig. 1b).

Soil organic matter parameters showed similar values for both old and new systems (Table 6) and indicated that soil biological properties were conserved in both systems (Fig. 1a and b). Even though soil cover, which plays a key role in erosion prevention, was similar in both systems, old ones demonstrated a higher risk of erosion, which can be explained by the impact of river flooding.

In old and new vineyards a good natural/cultivated area ratio was found: 0.26, 0.21, 0.21 and 0.21 for N1, N2, O1 and O2 systems, respectively, which translated into high sustainability indicator values associated with biodiversity management (Table 6). Spontaneous vegetation showed high diversity and even species distribution (Table 6), indicating autotrophic diversity conservation (Fig. 1a and b). On the other hand, due to the use of agrochemicals, neither old nor new systems performed well in terms of heterotrophic diversity preservation (Table 6). Nevertheless, the harmful influence of agrochemicals was not very strong as most of those used were not very toxic. Energy use was satisfactory (Fig. 1a and b), especially in N2, O1 and O2 systems. Pesticide parameters (dose, toxicity, application frequency and leaching risk) showed a low risk of underground water contamination in old and new vineyards (Table 6 and Fig. 1a and b).

4. Discussion

Measuring sustainability is very difficult due to the multidimensionality of the concept. However, efforts have been made to translate general principles of sustainability into operational definitions and methodologies (Masera et al., 1999; López-Ridaura et al., 2002). These include the development of different indicator-based methods, most strongly ecological (Pacini et al., 2003), which can be used to evaluate the environmental impacts of agriculture (Van der Werf and Petit, 2002).

Table 6
Standardization and results of subindicators and variables employed in the evaluation of ecological sustainability of old (O1 and O2) and new vineyards (N1 and N2) in Berisso, Argentina

Subindicators and variables	Standardized scale	Agroecosystems			
		N1	N2	O1	O2
Cover biomass recycling	4: Returns between 81 and 100% 3: Returns between 61 and 80% 2: Returns between 41 and 60% 1: Returns between 21 and 40% 0: Returns less than 20%	4	4	4	4
Cover management		3	3.5	3.5	3.4
Cover growth regulation	4: Cut with strimmer 3: Mechanically cut with tractor 2: Use of specific herbicide 1: Use of total herbicide 0: Burned	3	4	4	3.8
Cover biomass final condition	4: Buried close to the surface 3: Left on the surface 2: 1: Buried deep 0: Burned	3	3	3	3
Frequency of cover biomass contribution to the soil	4: Cut four or more times in the year, during at least three seasons 3: Cut at least three times during two seasons 2: Cut two times in the year 1: Cut one time in the year 0: Not cut	4	4	4	4
Vine biomass recycling	4: Returns between 81 and 100% 3: Returns between 61 and 80% 2: Returns between 41 and 60% 1: Returns between 21 and 40% 0: Returns less than 20%	4	4	4	4
Vine biomass management	4: Buried close to the surface 3: Left on the surface 2: 1: Buried deep 0: Burned	3	3	3.3	3.3
Nitrogen balance	4: Positive or even balance 3: Deficit $<33\%$ in extraction per harvest 2: 34–65% deficit in extraction per harvest 1: 66–99% deficit in extraction per harvest 0: 100% deficit in extraction per harvest	0	0	4	4
Phosphorus balance	Idem nitrogen	0	0	4	4
Potassium balance	Idem nitrogen	0	0	4	4
Seasonal variation of the soil cover percentage	4: Average above 80% 3: Average between 60 and 80% 2: Average between 40 and 60% 1: Average between 20 and 40% 0: Average below 20%	4	3	4	4
Flood frequency	4: No flooding throughout the year 3: Flooding three times a year 2: Flooding six times a year 1: Flooding nine times a year 0: Flooding ≥ 12 times a year	4	4	0	0
Natural area/cultivated area ratio	4: Above 25% 3: Between 21 and 25% 2: Between 16 and 20% 1: Between 10 and 15% 0: Below 10%	4	3	3	3

Table 6 (*Continued*)

Subindicators and variables	Standardized scale	Agroecosystems			
		N1	N2	O1	O2
Spontaneous vegetation diversity		3.5	4	4	4
Shannon index (ShI)	4: ShI between 80 and 100% of the highest calculated 3: ShI between 60 and 80% of the highest calculated 2: ShI between 40 and 60% of the highest calculated 1: ShI between 20 and 40% of the highest calculated 0: ShI below 20% of the highest calculated	3	4	4	4
Equity index (Ei)	4: Ei between 80 and 100% of the highest calculated 3: Ei between 60 and 80% of the highest calculated 2: Ei between 40 and 60% of the highest calculated 1: Ei between 20 and 40% of the highest calculated 0: Ei below 20% of the highest calculated	4	4	4	4
Spontaneous vegetation management	4: Only weeded by cutting 3: Weeded by cutting combined with the use of herbicide 2: Controlled only with specific herbicide 1: Only mechanical control with tractor (with harrow or weeding hoe) 0: Controlled only with herbicide	4	4	4	3
Heterotrophic diversity management (indicator)	4: Only biological control 3: Integrated management of plagues 2: Only chemical control, with low toxicity products 1: Only chemical control, with high toxicity products, low dose 0: Only chemical control, with high toxicity products, high dose		(See Fig. 1)		
Pesticide leaching risk	4: Use of pesticides of very low leaching risk 3: Pesticides of low leaching risk and/or permitted by organic legislation 2: Pesticides of moderate leaching risk 1: Pesticides of unknown leaching risk 0: Pesticides of high leaching risk	3.8	3.2	3.8	3.2
Pesticide dose, toxicity and frequency of use	4: Use only of biological or natural products in adequate doses 3: Low toxicity pesticides and/or permitted by organic legislation, in adequate doses and frequencies 2: Low toxicity pesticides in high doses and frequencies 1: High toxicity pesticides in adequate doses and frequencies 0: High toxicity pesticides in high doses and frequencies	3	3	3	3
Energy efficiency (indicator)	4: Energy efficiency ≥ 5 3: Energy efficiency between 3.7 and 4.9 2: Energy efficiency between 2.4 and 3.6 1: Energy efficiency between 1.1 and 2.3 0: Energy efficiency ≤ 1		(See Fig. 1)		

The conservation of natural capital has been indicated as a necessary requirement for sustainable agriculture (Harte, 1995). According to the present sustainability analysis, old flooded systems maintain natural capital as they preserve soil, biodiversity, nonrenewable energy and water resources. The ecological rationality of traditional systems that has been recognized by various authors (Altieri, 1995, 2002; Hecht, 1991; Toledo, 1993) suggests that it is possible to reconcile agricultural system productivity with natural resource preservation (Parris, 1999).

Traditional management of old vineyard systems minimized losses of solar radiation, showed a balanced flow of nutrients and exhibited a high level of organic matter cycling and conservation. These ecological principles have been discussed by Reijntjes et al. (1995) and Gliessman (2001) as being necessary for the design of sustainable systems: this suggests the existence of an ecological rationality in the traditional management of vineyards.

Biodiversity conservation is relevant to the functioning of agroecosystems (Swift et al., 2004; Altieri, 1999). Diverse

Table 7
Values of sustainability for internal and external resources of old (O1 and O2) and new (N1 and N2) vineyard systems, in Berisso, Argentina

Resources	Agroecosystems			
	N1	N2	O1	O2
Internal				
Soil	3.1	2.9	3.5	3.5
Biodiversity	3.4	3.2	3.2	2.8
External				
Nonrenewable energy	See Fig. 1			
Water	See Fig. 1			

vegetation presence within and around crops has been proposed as a strategy to increase diversity (spatial and temporal) in perennial cultivation systems (Altieri, 1999; Nicholls, 2001) and would explain the low incidence of pests in the vineyard systems studied (Gliessman, 2001). In addition, vegetative cover achieves greater ecological efficiency by optimizing resource use and loss of solar radiation, among other things. In this way, vineyard agroecosystems push towards a more advanced successional stage, which is a sustainable management strategy proposed by Agroecology Theory (Gliessman, 2001).

Energy efficiency, especially where fossil fuels (non-renewable) are concerned, has been proposed as an acceptable indicator of agroecosystem sustainability (Pimentel et al., 1991; Halberg et al., 2005; Ozkan et al., 2004). The energy efficiency of these vineyards was greater than that indicated by Gliessman (2001) for modern fruit crop systems. Both old and new vineyard systems show an efficient use of nonrenewable energy, as a result of their low dependence on external inputs.

In old vineyard systems, the nutrient balance was sustained through fluvial sediment influx, confirming that farmers can make an appropriate use of natural environmental potential (Toledo, 1993). This nutrient management is similar to that developed in the ‘‘chinampas’’ of Mexico (Altieri, 1995), where farmers use the sediment obtained from ponds with fish and aquatic plants to fertilize crops.

Analysis of indicators suggests that old vineyards stood the test of time because their management practices have been ecologically sound and result from the co-evolution of farmers and the environment (Toledo, 1993, 2001; Altieri, 1995). The current management of vineyards is the result of the transfer of techniques between generations of farmers. In contrast, newly established vineyards registered a negative nutrient balance as a result of the absence of fluvial sediment. Eventually, this will lead to soil nutrient depletion (Stoorvogel, 2001), and subsequently will impact natural capital conservation. Vineyard farmers have extended management practices that were successful in one agroecosystem into another, resulting in non-sustainable systems. This suggests that the transfer of information from one generation to the next should include knowledge about the coherence of agricultural production systems and the environment rather than just transmission of a series of ‘‘successful’’ techniques. When the purpose is to rescue traditional management practices of farmers (CBD, 1996), it is necessary to go beyond the simple description of techniques: the underlying ecological principles must be analyzed and understood (Altieri, 2002) in order to understand the impact they might have on natural resources. This becomes essential when expanding agricultural management practices to other ecological conditions.

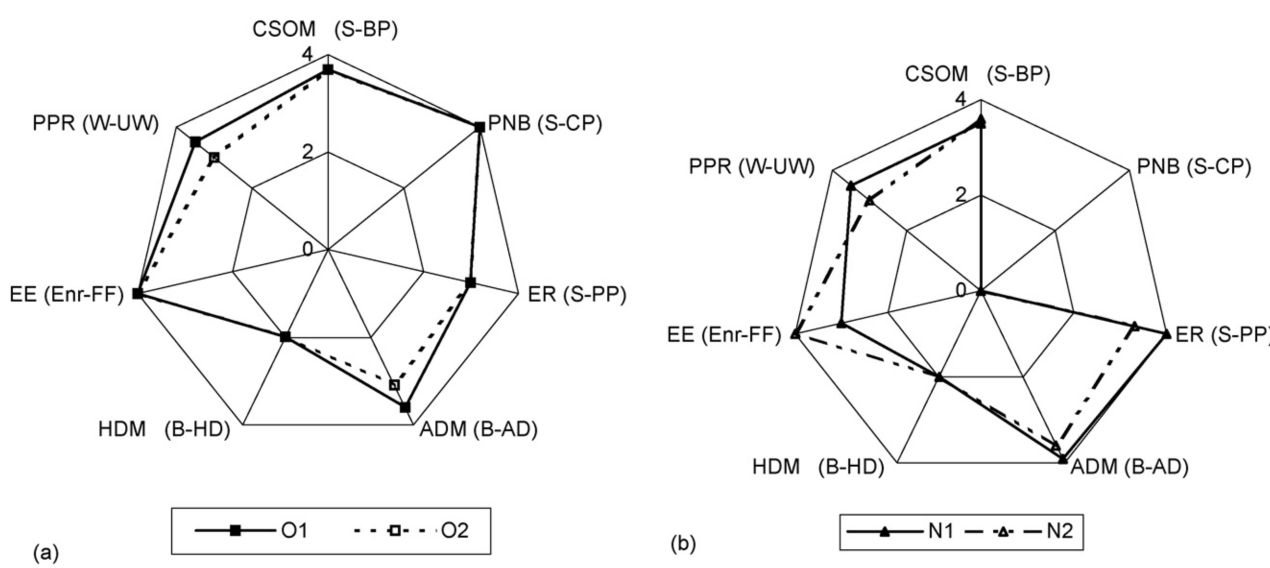

Fig. 1. Amoeba representing the ecological sustainability of old (a) and new (b) vineyard systems in Berisso, Argentina. CSOM, contribution to soil organic matter; PNB, partial nutrient balance; ER, erosion risk; ADM, autotrophic diversity management; HDM, heterotrophic diversity management; EE, energy efficiency; PPR, pesticide pollution risk. In brackets, first term resources: S, soil; B, biodiversity; Enr, nonrenewable energy resources; W, water resources; second term descriptors: BP, biological property; CP, chemical property; PP, physical property; AD, autotrophic diversity; HD, heterotrophic diversity; FF, energy from fossil fuels; UW, underground water.

5. Conclusions

It is possible to evaluate the risks involved when traditional management practices are applied to different ecological settings, as well as to understand the underlying ecological principles of this management system by using sustainability indicators. The management used in old floodplain vineyards preserves internal resources, soil and biodiversity, as well as external, nonrenewable energy and water resources. In contrast, traditional management practices applied to new systems can affect soil chemical properties, making these systems unsustainable.

This research suggests that traditional management practices are ecologically sound when considered within their original ecological conditions but not in different conditions. The ecological principles underlying different management practices must be understood in order to predict the impact they might have on natural resources. This is a key step towards an agriculture system that reconciles productivity with environmental conservation.

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