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ENVIRONMENTAL MANAGEMENT & CONSERVATION | RESEARCH ARTICLE

Heterogeneity in agricultural land use decisions in Argentine Rolling Pampas: The effects on environmental and economic indicators

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Abstract: Argentine Pampas are one of the major regions in the world for agricultural production. There is a trend towards system simplification in this area, with soybeans being the predominant crop. One major concern of "soybeanization" is its long-term effect on productivity. There is an increasing interest in more diverse and intensive cropping sequences in order to mitigate environmental concerns related to agricultural simplification, while increasing or maintaining crop production. The aims of this study were to assess the heterogeneity of agricultural land use schemes in Pergamino, Buenos Aires, and to determine environmental and economic indicators for the different land uses. Data were collected through surveys to a sample of farmers for three cropping years. For each farm, three environmental indicators (soil organic carbon, nitrogen and phosphorus balances) and two economic indicators (crop revenue and on-farm environmental cost associated to negative soil organic carbon and nutrient balances) were computed. Under current land use and crop

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PUBLIC INTEREST STATEMENT

The growing demands for a transformation of the current agricultural systems are based on the aspiration that these systems generate sufficient quality food for the world population, with a low impact on the environment, making positive social and cultural contributions.

Argentine Pampas are one of the major regions in the world for agricultural production. While there is nowadays a trend towards system simplification in this area, with soybeans being the predominant crop or the only one in most land-use schemes, there is also an increasing interest in alternatives for sustainable intensification, based on more diverse and intensive cropping sequences.

The aim of this study was to assess the heterogeneity of land use schemes in Pergamino, located in the most productive agricultural region in Argentina, in terms of economic and environmental indicators. The characterization of different farming systems provides valuable information in the search of sustainable intensification alternatives for Argentina's Pampas.

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management practices, soil nutrients and organic carbon tend to decrease. The estimated on-farm environmental cost from soil organic carbon and nutrients losses represents a 6% of crop revenue, on average. Farm size is related to land-use schemes and environmental and economic indicators. Smaller farms are associated with a lower proportion of full-season soybeans in crop rotations, lower nutrients and carbon losses, and lower environmental costs. There are farms in the sample with diverse and intensive rotation schemes and low environmental cost. The characterization of farming systems provides valuable information in the search of sustainable intensification alternatives.

**Subjects: Agriculture & Environmental Sciences; Agriculture; Environment & Economics**

Keywords: agricultural systems; sustainability; Argentinean farmers

1. Introduction

Favorable soil fertility and climatic conditions for growing annual crops, along with farmers' predisposition towards technology adoption, determine that the Argentine Pampas are one of the major regions in the world for agricultural production. Since the 70s, this region has increased land allocated to annual crops, replacing pastures and grasslands. While corn and wheat are still important crops, there has been a strong increase in soybean area, which has tripled in the last 20 years (Figure 1). Soybean production is a key activity in Argentina's economy, in 2017 soybean products accounted for 27% of total exports (INDEC, 2018).

Since the 90s, the spread of genetically modified glyphosate-resistant soybean, under no-till, changed dramatically the production systems. Planting glyphosate-resistant soybean has several advantages for farmers. In the first place, this crop has the highest economic return compared to other crops (Cabrini & Calcaterra, 2016). Secondly, this technology strongly simplified crop management practices, particularly weed control. These factors determine that soybean is now the predominant or the only crop in the rotations. In Pergamino district, which is located in the core area of the Rolling Pampas, soybean occupied approximately 80% of the arable land during the 2017/2018 crop year. This phenomenon is locally called "soybeanization".

Figure 1. Corn, soybeans and wheat planted area, Argentina, 1970–2017.
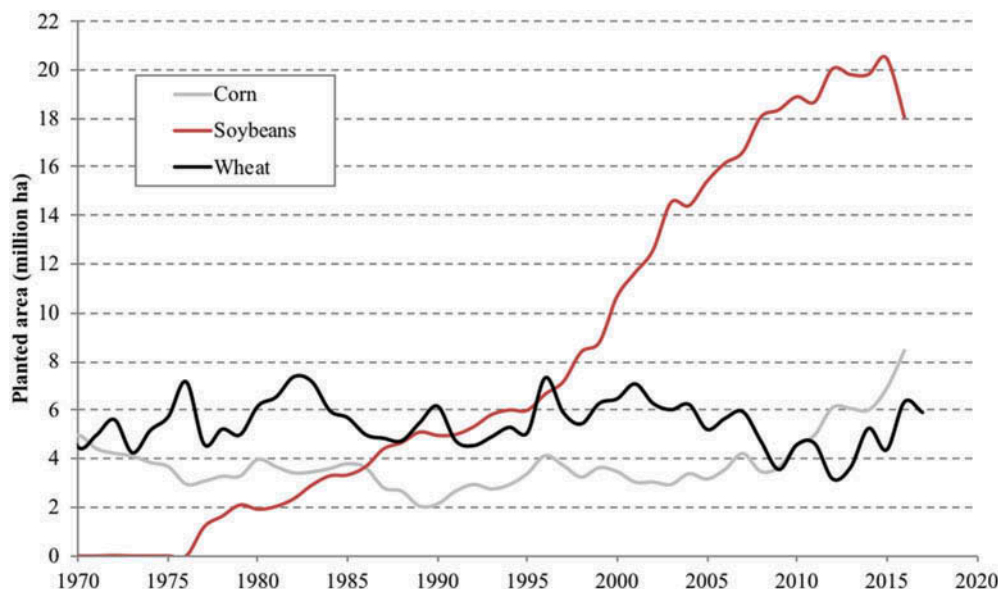
These simplified production systems present strong economies of scale, being an incentive to extend the size of the farming operation and the practice of tenant farming, driving small-scale producers out of agriculture. About half of the planted area in Pergamino is rented (Cabrini & Calcaterra, 2008). There is mixed evidence of the effect of land tenancy on crop choices and management practices in this region (Arora, Bert, Podesta, & Krantz, 2015; Cabrini, Calcaterra, & Lema, 2013).

While the expansion and intensification of agriculture in Argentina are directly related to economic growth, it has raised concerns about its social and environment impacts, and long-term sustainability of current production systems is questioned (e.g., Cabrini et al., 2018; Flores & Sarandón, 2002; Viglizzo, Frank, Bernardos, Buschiazzo, & Cabo, 2006; Wingeyer et al., 2015). Environmental problems associated with soybeanization include the emergence of glyphosate-resistant weeds, soil and water pollution and soil fertility loss.

One major concern of soybeanization is its long-term effect on productivity. Several studies have assessed the evolution of soil organic carbon (SOC) and nutrient balances, two key indicators of soil "health", under different production systems. Most soils under agriculture have lower SOC than their natural counterparts. Depending on crop rotations and management practices, cultivated soils may contain 50–75% of the original SOC pool.

In the Argentine Pampas, SOC loss is mainly attributed to the large proportion of full-season soybean in crop rotations (Berhongaray, Alvarez, De Paepe, Caride, & Cantet, 2013; Caride, Piñeiro, & Paruelo, 2012; Milesi Delaye, Irizar, Andriulo, & Mary, 2013). In addition, crop rotations with a high proportion of soybean may decrease soil pH, due to products derived from biological N fixation, presumably enhancing microbial decomposition of soil organic matter (Huggins, Allmaras, Lamb, & Randall, 2007). In this regard, several studies have demonstrated that soybean monoculture decreases SOC stocks, macroaggregation (Caride et al., 2012) and water infiltration (Sasal, Andriulo, & Taboada, 2006) and exposes soil to erosion during fallow (Sasal, Castiglioni, & Wilson, 2010).

Soil organic carbon level is related to both off-farm and on-farm environmental impacts. Soil organic carbon is associated with land productivity, since an adequate level of soil organic matter is related to better air and water circulation and nutrient availability (Loveland & Webb, 2003). Also, SOC has a role in reduction of groundwater contamination since it reduces pesticides leaching.

Moreover, carbon sequestration contributes to climate change mitigation (Bolinder, Janzen, Gregorich, Angers, & VandenBygaart, 2007; Stockmann et al., 2013). Therefore, carbon sequestration in agricultural soils is often mentioned as a win-win strategy with multiple benefits (Lal, 2004).

Nutrient balances are also key indicators in the assessment of environmental performance of agricultural systems, mainly because of the concerns about soil and water contamination associated to nutrient excess (Austin et al., 2013; Berge, Ittersum, Van, & Rossing, 2000). However, the mining of natural N and P is creating deficits rather than excesses in some regions of Latin America (Díaz de Astarloa & Pengue, 2018). Several authors have expressed concerns about negative nutrient balances in the Pampas and the importance of considering these deficits in land management and fertilization decisions. Persistent nutrient deficits can decrease land productivity, increase future fertilization requirements, and decrease farmers' profits (Alvarez, Steinbach, & De Paepe, 2014; Cabrini et al., 2013; Flores & Sarandón, 2002; Garcia & Vázquez, 2012). Several studies argue that the large proportion of soybean in crop rotations is responsible for more negative balances of nitrogen (N) and phosphorus (P) in Argentina's Pampas (Díaz de Astarloa & Pengue, 2018). Even when a large proportion of N in soybean grain comes from biological fixation (Collino et al., 2015), there are big N exports in harvested grain and lixiviation associated with this crop (Cabrini & Calcaterra, 2016; Zazo, Flores, & Sarandon, 2011).

There is an increasing interest in more diverse and intensive cropping sequences in order to mitigate environmental concerns related to agricultural simplification and monocultures, while increasing or maintaining crop production. In this search for more favorable scenarios, the effects of intensifying the use of land by sequencing two crops in a season have been evaluated. Recent publications focus on agronomic impacts of increasing the frequency of double crops and including cover crops in crop rotations (Andrade, Poggio, Ermácora, & Satorre, 2015, 2017; Pinto, Fernandez-long, & Piñeiro, 2017). These studies make emphasis on water and energy use efficiencies, and results support the idea that it is possible to improve performance of agricultural production by implementing more intensive and diverse production systems.

Most studies that have assessed productivity and environmental impacts of crop rotations in the Argentine Pampas are based on satellite images, aggregated or plot-level data. Only very few studies have considered both environmental and economic performance of farming systems, using farm-level data. The aim of this study was to assess the heterogeneity of land-use decisions based on farm level data, characterizing crop rotations and crop management of 19 farms of Pergamino river basin. Data were collected through surveys to farmers for three cropping years. For each farm, three environmental indicators (soil organic carbon, nitrogen and phosphorus balances) and two economic indicators (crop revenue and on-farm environmental cost associated to negative soil organic carbon and nutrient balances) were computed.

2. Methodology

2.1. Site description
The study area comprises 4000 ha and lies between latitudes 33°51′ and 33°53′ S and longitudes 60°45′ and 60°47′ W (North Buenos Aires province, Argentina) on the NW section of the Pergamino Creek basin. The area presents a smoothly undulating sedimentary landscape with a general slope of 0.5% towards the creek. The climate is temperate humid without a dry season and mean annual temperature is 17°C. Mean temperatures for the coldest (July) and warmest (January) months were 9.6°C and 23.4°C for the 1910–2017 period, respectively (Agro-climatological network database, INTA). Mean annual rainfall for this period was 987 mm, with rainfall annual totals displaying a coefficient of variation of 27% for the same period.

The dominant upland soil (24% of the sub-basin area) is a Typic Argiudoll of the Pergamino Series; the long smooth slopes towards the Pergamino Creek have soil complexes (43% of the sub-basin area) containing upland soil intermingled with varying proportions of an Argiudoll with an incipient A2 horizon and an alkaline soil (a Typic Natralboll of La Faustina Series). Flood plain soils (23% of the sub-basin area) form a heterogeneous association of poorly drained alkaline and saline soils of the creek sides. The area is representative of the Rolling Pampas in Argentina (Figure 2).

2.2. Farmers' survey and farming system characterization
A survey was conducted on a sample of 19 farms which represented 70% of the study area. The survey inquired about land use (crop rotation, pastures and grassland used for cattle rearing), grain and oilseed yield and fertilization rates, for three cropping years (2009/2010, 2010/2011 and 2011/2012). While the questionnaire inquired about both agriculture and cattle rearing productions included in the farm, only the data related to agricultural production on arable land were considered in this study. Rainfall for the three crop years was on average 976 mm (1301, 877 and 755 mm, for cropping years 2009/2010, 2010/2011 and 2011/2012, respectively).

Table 1 presents the variables used to describe each farming system. Three variables are used as farms characteristics: operated land, land tenancy and professional advice. Three variables are used to describe agricultural land use: crop diversity index, proportion of land assigned to full-season soybeans and proportion of land assigned to double crops. The crop diversity index is computed as the inverse of the Herfindahl-Hirschman coefficient (1/HH*100). The HH is computed

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Figure 2. Study area: Pergamino, Buenos Aires, Argentina, changes in land use between 1995 and 2015.

Source: GIS group INTA— Pergamino, Argentina.
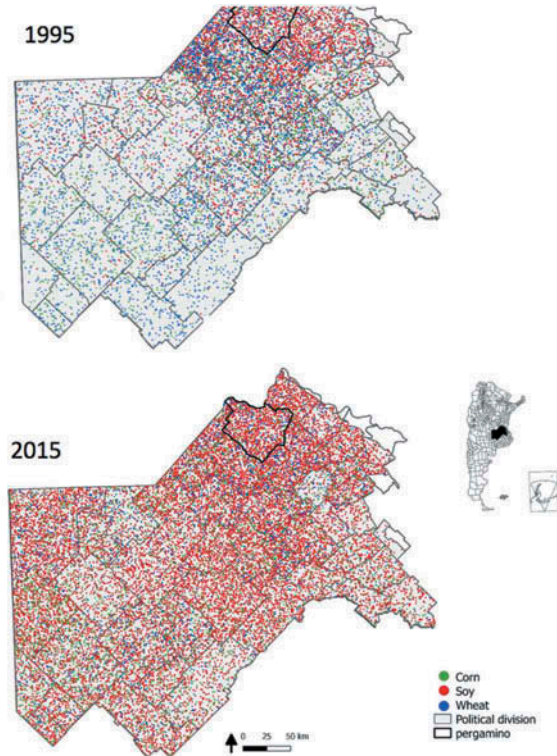
for each farm as the sum of the squared percentage of land assigned to each crop. Also, for each farm, three environmental indicators (soil organic carbon, nitrogen and phosphorus balances) and two economic indicators (crop revenue and on-farm environmental cost associated to negative soil organic carbon and nutrient balances) were computed. These indicators are described in the following sections.

2.3. Carbon balance

A simulation model for soil organic carbon (SOC) balance was employed to analyze the SOC dynamics (Andriulo, Mary, & Guerif, 1999; Milesi Delaye et al., 2013). The model considers three compartments: crop residues, active SOC (Ca) and stable SOC (Cs) (Figure 3). The annual C input to soil (m) is the sum of the carbon in stubble, roots and rhizodepositions. These variables were estimated at farm level based on proportion of land assigned to each crop, crop yields for each farm, harvest index and the aerial/root ratio. In the case of cover crops, data for dry matter production were not available from farmers and estimated dry matter production was obtained from plot trials (Restovich, Andriulo, & Portela, 2012). Carbon input to the active SOC compartment is computed as m*k1, where k1 is the humification coefficient, which depends on the type of residue and tillage system (Table 2). SOC losses as mineralization of the active fraction are estimated as the active SOC pool (Ca)* k, where k is the mineralization parameter, which depends also on crop tillage. An average initial SOC content of 42,8 tn ha^{-1} (0–20 cm soil depth was considered for all farms) (Milesi Delaye et al., 2013). This SOC level is equilante to 2.84% of soil organic matter (SOM), since SOM es computed as 1.72 * SOC. Based on the model, the SOC in the long-run equilibrium is computed as:

$$Ceq = Cs + m*k1/k \tag{eq.1}$$

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Table 1. List of variables considered to characterize the farming systems, Pergamino District, Buenos Aires, Argentina		
Variable	**Unit**	**Description**
Farm		
Operated land (land)	ha	Including land planted inside and outside the basins, is a measure of farm business scale.[1]
Rented land (rent)	%	Percentage of the land operated that is rented
Professional advise (prof)	Binary [0,1]	= 1 if someone with a college degree in agriculture is in charge of farm management decisions, = 0 otherwise
Land use		
Crop diversity index (div)	[0.0001, +inf]	The inverse of the Herfindahl-Hirschman coefficient (1/HH*100). The HH is computed for each farm as the sum of the squared percentage of land assigned to each crop
Land assigned to full season soybeans (fsoy)	%	Percentage of land assigned to full season soybeans
Land assigned to double crops (dcrops)	%	Percentage of land planted with a winter/cover crop and a summer crop in the same cropping year
Environmental indicators		
Soil organic carbon balance (CB)	tn ha^{-1} year^{-1}	OC addition to soil through crop straw, stubble, roots and rhizodeposition. (m*k1)—SOC mineralized (k*Ca) (Figure 3)
Nitrogen balance (NB)	kg ha^{-1} year^{-1}	N inputs (N fertilizers + N biological fixation + N precipitation)—N output (N harvested grain + N lixiviation). (Figure 4)
Phosphorus balance (PB)	kg ha^{-1} year^{-1}	P inputs (P fertilizers)—P output (P harvested grain). (Figure 4)
Economic indicators		
Crop revenue (CR)	u$s ha^{-1} year^{-1}	is the sum of crop production*market price
Replacement cost for N and P negative nutrient balances (NPcost)	u$s ha^{-1} year^{-1}	computed by multiplying the magnitude of the negative balances by nutrients' prices
Cost associated to soil OC loss (SOCcost)	u$s ha^{-1} year^{-1}	computed based on the relationship between soybeans productivity and SOC content
Environmental cost (ecost)	u$s ha^{-1} year^{-1}	is the sum: NPcost + SOCcost

Note: Operated land is the only case when all land is considered, all other variables are computed only based on data from the plots inside the basins.

Figure 3. Diagram for the three-component model for soil organic carbon dynamics (Andriulo et al., 1999; Milesi Delaye et al., 2013).
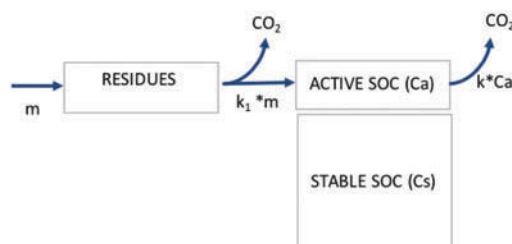
m: annual C input to soil - include C in stubble, roots and rhizodepositions (tn C ha^{-1})

k₁: humification rate of crop residues

k: mineralization parameter

SOC: soil organic carbon

Ca: Active soil organic carbon (tn C ha^{-1})

Cs: Stable soil organic carbon (tn C ha^{-1})

## 2.4. Nitrogen and Phosphorus balances

A simple mass balance for nitrogen and phosphorus was computed for each plot and growing season. Inputs from fertilization, for both nutrients, biological nitrogen fixation from leguminous crops (soybean and peas) and N atmospheric deposition were considered (Figure 4). Based on Di

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Table 2. Parameters for the three-component model for soil organic carbon dynamics				
	Average yield	**Harvest index**	**Humification coefficient (k1)**	
Crop	**(tn MS ha $^{-1}$)**		**No-tillage**	**Tillage**
Corn	6.56	0.5	0.13	0.21
Pop-Corn	2.08	0.4	0.13	0.21
Soybean	3.11	0.38	0.17	0.29
Wheat	3.9	0.34	0.13	0.21
Barley	3.22	0.34	0.13	
Pea	1.83	0.3	0.17	
Oats (cover crop)			0.25	
Ryegrass (cover crop)			0.25	
Chamomile	0.72	0.24	0.18	
Initial total COS		42.8	tn COS ha^{-1}	
Stable SOC		31.7	tn COS ha^{-1}	
Mineralization coefficient (k)		0.07	No-tillage	
		0.11	Tillage	

Note: Farm-level yields and the proportion of land assigned to each crop were used to compute annual C input to soil for each farm.

Figure 4. Diagram for soil nitrogen and phosphorus balances models in agriculture.
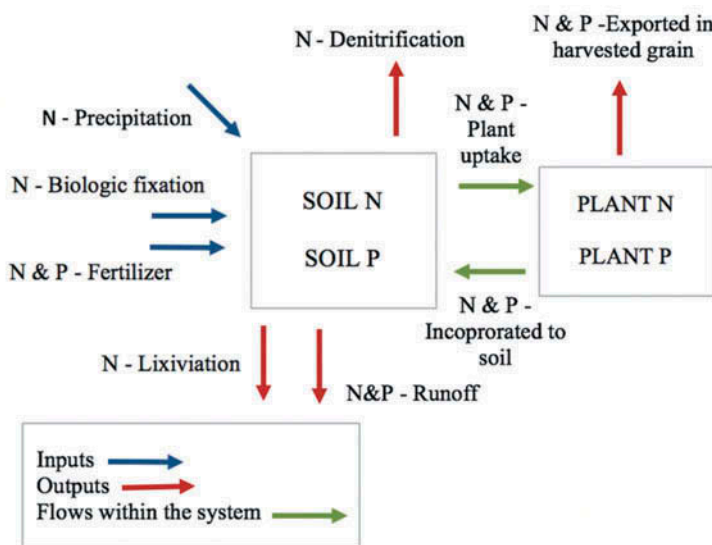
Ciocco et al. (2011), N biological fixation was estimated as 86% of harvested N. Fertilization rates were obtained from the questioners. Nitrogen inputs through wet and dry atmospheric deposition were estimated using ammonium and nitrate-N concentrations in rain samples collected monthly at Pergamino within the Rio de la Plata Atmospheric Deposition Network (Carnelos et al., 2014) and rainfall volume measured at the weather station of Pergamino Experimental Station of INTA.

Nutrient exports in grain harvest were estimated based on grain yields obtained from the questioners, and nutrients content in the grains (Table 3). Nitrogen leaching was estimated based on measures of deep drainage and nitrogen leaching for different rotations in Pergamino reported by Portela, Restovich, Gonzalez, and Torti (2016). Nitrogen losses from denitrification and nutrient losses from surface runoff are expected to be very low, and difficult to measure therefore

Table 3. Parameters for the nitrogen and phosphorus balances					
	Nutrient concentration			N Biological fixation (% of N exported with grain)	
	N	P			
	kg nutrient per tn dry matter product				
Corn	14.96	3.04			
Wheat	20.70	4.00			
Barley	17.88	3.04			
Soybean	60.00	6.16		87%	
Oats	20.00	3.00			
Pea	30.23	4.09		87%	
				N leaching	
Crop year	Precipitation	N input in precipitation	Deep drainage	Single summer crop	Double crop
	mm ha^{-1} year^{-1}	Kg N ha^{-1} year^{-1}	mm ha^{-1} year^{-1}	Kg N ha^{-1} year^{-1}	
2009/2010	1272	5.14	239.3	39.35	10.23
2010/2011	881.8	4.79	163.5	22.10	5.75
2011/2012	858.3	6.1	11.8	3.46	0.90

were not considered in balance computations. The following equations (Equation (2) and Equation (3)) show balance computations for both nutrients:

$$Nbalance = Nfertilizer + Nbiological\ fixation + Nprecipitation - (Nlixiviation + Nharvested\ grain)$$

$$(Equation 2)$$

$$Pbalance = Pfertilizer - Pharvested\ grain$$

$$(Equation 3)$$

2.5. Economic indicators
The economic indicators considered are crop revenue and the cost associated with soil organic carbon and nutrients losses. Crop revenue is computed for each farm by multiplying crop yields by market prices. Grain prices were obtained from the *Bolsa de Comercio de Rosario* (www.bcr.com.ar). Average prices at harvest time for the three crop years considered were: soybean: 292, wheat: 151, barley: 190, corn: 167, pop-corn: 493, chamomile: 750 and pea: 240 u$s tn^{-1}.

The productive and economic impacts of changes in soil properties are not easy to assess. Although the relationship between the content of SOC and several soil properties has been well documented, the quantification of the relationship between SOC content and crop yields is complex. Loveland and Webb (2003) indicate that although a critical value of SOC of 2% for the first 20 cm of soil depth (3.4% SOM) was proposed for agricultural soils of temperate zones, there is not enough quantitative evidence to justify this value. The available evidence suggests that the threshold is not uniform but depends on soil and climatic characteristics and cropping systems.

In the Rolling Pampas, Alvarez and Grigera (2005) evaluated the factors that explain the variability of corn and wheat yield through simulation models. The results showed that the SOM content was not a direct determinant of performance, considering SOM levels between 1.87% and 5.95% (0–20 cm). However, there is an indirect effect on the yield of these crops due to the high correlation between the MOS level and the initial nitrogen level caused by mineralization during the fallow periods. More recently, Bacigaluppo et al. (2011) proposed to identify the most influential edaphic and climatic factors in soybeans' yield. They collected data from production fields in four cropping seasons. The MOS values in the surveyed fields were from 2.23% to 3.55% (0–20 cm). The results showed a significant positive correlation

between yield and MOS content. They quantified, through multiple regression models, the loss of yield in soybean based on the MOS content. They found an average expected loss of 4qq ha^{-1} for every 1% reduction in MOS in the first 20 cm of the soil, for crop years without extreme drought conditions. This coefficient is used in this study to find the economic value of the expected difference in soybean yield planted in a soil with the benchmark content of SOM (2.84%) versus soybean planted in a soil with the long-run equilibrium SOM, for each farm.

The replacement cost of N and P negative balances was computed by multiplying the average nutrient loss by the nutrient price of 1.15 and 2.8 u\$s Kg^{-1} for N and P, respectively. These values were determined based on fertilizers' market prices for the three crop years (urea: 0.53 u\$s Kg^{-1} and triple surperphosphate: 0.6 u\$s Kg^{-1}) and fertilizer composition. Nutrient replacement costs were expressed as a percentage of crop revenue.

The total economic value for SOC, N and P losses is computed, this value can be interpreted as an estimation of the expected decrease in the annual economic results in for Pergamino crop farms.

2.6. The diversity of farming systems

The hierarchical cluster analysis (Euclidean distance, Ward criteria) was used to study the natural grouping of farming systems based on the similarity of farm characteristics and land-use variables. Average values for environmental indicators were computed for each group. One-way ANOVA tests for groups effect were made on each of the continuous variables considered to characterize the farming systems.

3. Results

Average farm size was 590 ha and, on average, 50% of the area corresponded to rented land. However, 9 out of 19 farms were based on rented land (100% rented land) and 8 out of 19 were land owners (0% rented land) (Table 4). Most farmers (89%) received professional advice for management decisions.

Crop diversity index ranged between 0.01 for farmers that planted only one crop (full season soybean, farms 9 and 17) and 0.036 for those with a well-balanced combination of four crops. Land assigned to full-season soybean was, on average, 53%. Two farms had 100% of the area assigned to full-season soybean (farms 9 and 17), and 7 farms planted soybean (full or second season) as the only summer crop. Soybean was the predominant crop in all cases, followed by corn and wheat. On average, 31.5% of the land was assigned to double crops. Two farms (2 and 4) planted all land with winter crops or cover crop, and summer crops (total land assigned = 200%). Nine of the farms planted three or more harvest crops, and three farms planted cover crops (two of them is a very small percentage of land). Barley and pea were planted in 3 farms and chamomile is planted in one farm. It is interesting to remark the high diversity in the rotation schemes found in the study area.

Soil organic carbon balance was negative in 16 of the 19 farms; the average C loss was 0.17 tn ha^{-1} year^{-1} (Table 4). Maximum SOC gain was 0.27 tn ha^{-1} year^{-1}, and the highest loss was 0.39 tn ha^{-1} year^{-1}. Based on the SOC model, soil organic matter contents (0–20 cm) in the long-run equilibrium (Equation 1) range between 2.5% and 3.1%, with an average of 2.6%. This average value is 12% lower than the organic matter level for 2010 (2.95%). The long-run equilibrium reached, approximately, in 35 years. The estimated cost for SOC losses is, on average, 19.29 u\$s ha^{-1}. For the farm with the highest SOC loss, the estimated cost is 45.66 u\$s ha^{-1}, and for the farm with the highest SOC gain, there is a benefit of 31.05 u\$s ha^{-1}.

Average annual nutrient balances were also negative: −29,5 and −6,36 kg ha^{-1} for N and P, respectively. All farms had negative N balances, with some very close to neutral. In the case of P, 3 farms had positive balances (id 2,12,14).

Table 4. Descriptive statistics for land use, environmental and economic indicators

farm id	land	rent	prof	div	fsoy	dcrops	CB	NB	PB	CR	ecost	crops (1)
	ha	%		(1/HH *100)	—%.—		tn ha⁻¹ year⁻¹	—kg ha⁻¹ year⁻¹—		—uSs ha⁻¹ year⁻¹—		
1	215	100	1	0.023	50	25	-0.13	-34.27	-6.47	1282	73	2S-1W/S-1C
2	60	100	1	0.027	0	100	0.00	-1.64	5.82	1224	2	1Oc/S-1Oc/C
3	2500	100	1	0.016	90	10	-0.28	-32.12	-12.53	975	103	9S-1W/S
4	30	0	1	0.020	0	100	0.27	-44.06	-7.74	1504	41	1W/S
5	350	0	1	0.036	0	67	-0.17	-0.61	-1.92	1163	22	1W/S-1P/S-1Cp
6	520	100	1	0.030	38	25	-0.31	-11.59	-4.65	1249	62	6S-6Cp-1W/S-1B/S-1P/S-1Av/S
7	96	0	1	0.016	67	33	-0.08	-44.12	-11.97	1175	93	2S-1W/S
8	169	0	1	0.012	90	0	-0.23	-36.84	-7.12	1110	89	9S-1W/S
9	4000	100	1	0.010	100	0	-0.21	-46.68	-22.03	1116	140	1S
10	1071	0	1	0.017	70	0	-0.30	-16.43	-2.92	1053	62	7S-3Cp
11	60	100	0	0.016	70	10	-0.34	-48.39	-11.68	1020	121	7S-2C-1P/S
12	56	0	0	0.027	33	50	-0.02	-29.14	5.37	986	36	2S-2W/S-1B/S-1M
13	370	100	1	0.019	33	67	-0.05	-29.48	-7.57	1116	62	2W/S-1S
14	238	100	1	0.023	43	13	-0.39	-4.66	1.45	968	51	3S-1Cp-1W/S-1B/S-1R/S
15	464	0	1	0.015	70	0	-0.19	-42.44	-4.98	1221	85	7S-3C
16	282	0	1	0.017	70	20	-0.22	-38.03	-4.75	1220	74	7S-2W/S-1C
17	450	100	1	0.010	100	0	-0.32	-39.16	-3.32	919	92	1S
18	45	27	1	0.018	50	50	-0.36	-32.59	-17.15	2610	128	1S-ChS
19	236	28	1	0.025	40	30	0.03	-28.52	-6.73	1327	49	4S-3C-3W/S
Average	590	50	0.89	0.020	53	32	-0.17	-29.5	-6.4	1223	73	
Minimum	30	0	0	0.010	0	0	-0.39	-48.4	-22.0	919	2	
Maximum	4000	100	1	0.036	100	100	0.27	-0.6	5.8	2610	140	

Note: land: Operated land. rent: Rented land. prof: Professional advice. div: Crop diversity index. soy1: Land assigned to full season soybeans. soy1: Land assigned to double crops. CB: Organic carbon balance. NB: Nitrogen balance. PB: Phosphorus balance. CR: Crop revenue. ecost: Environmental cost. Variables' definitions are presented in Table 1. Crops (1): C corn, Cp pop-corn, S soybeans, W wheat, Oc oats cover crop, P pea, B barley, R ryegrass and Ch chamomile. Numbers indicate the proportion of land assigned to each crop.

	land	div	fsoy	dcrops	CB	NB	PB	ecost
land	1	−0.39*	0.51**	−0.39*			−0.55**	0.48**
div		1	−0.84***	0.57**		0.76***	0.56**	−0.76***
fsoy			1	−0.88***	−0.58***	−0.58***	−0.50**	0.8***
dcrops				1	0.71***			−0.63***
CB					1			−0.53**
NB						1	0.55***	−0.7***
PB							1	−0.85***

Table 5. Significant correlation coefficients between variables considered to characterize the farming systems, Pergamino District, Buenos Aires, Argentina

Note: land: Operated land. rent: Rented land. prof: Professional advice. div: Crop diversity index. fsoy: Land assigned to full season soybeans. drops: Land assigned to double crops. CB: Organic carbon balance. NB: Nitrogen balance. PB: Phosphorus balance. CI: Crop revenue. ecost: Enviroenmental cost. Variables' definitions are presented in Table 1.

*** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1.

Cost associated with N replacement was on average 36.62 u\$s ha^{-1}, with a maximum of 55.65 and a minimum of 0.71 u\$s ha^{-1}. Phosphorus replacement costs were 23.19, 61.69 and 0 u\$s ha^{-1} for average, maximum and minimum values, respectively.

The total cost associated with SOC and nutrients balances is highly variable between farms, with an average value of 73 u\$s ha^{-1}. Crop revenue is on average 1223 u\$s ha^{-1}, and the average environmental cost represents a 6% of this value (last two columns in Table 4).

The correlation structures of the set of variables that characterize farming systems are presented in Table 5, only significant correlations are listed (α = 0.10). Operated land is related to land-use variables and phosphorus balance. Smaller farms have higher diversification level, more land assigned to double crops and less land assigned to full-season soybeans. Also, farm size is negatively related to phosphorus balance.

Within land-use variables, the proportion of full-season soybeans is the one that shows the strongest negative correlation with the environmental indicators. Nitrogen and phosphorus balances are positively correlated. The environmental cost from SOC and nutrient losses is positively related to farms size and the proportion of full-season soybeans and negatively related to diversification, the proportion of double crops.

4. The diversity of farming systems

The hierarchical cluster procedure rendered three groups, with 11, 5 and 3 farms each (Figure 5 and Table 6). The first group has 11 farms, the proportion of rented land is 60%, the proportion of land assigned to full-season soybeans is the lowest and the proportion of land assigned to double crops is the highest, compared to the other groups. On average, this group of farmers has the lowest cost related to SOC and nutrient losses.

In the other extreme, group 3 includes three farms. These are the largest farms, with 100% of rented land. The average diversification level and the land assigned to double crops are the lowest, and the proportion of land assigned to full season soybean is the highest. The farms in group 3 have on average more negative balances for SOC and both nutrients, and therefore the highest value for the environmental cost. For most variables, the average values in group 2 are in between the values for the other two groups. The differences between groups are statistically significant for the proportion of rented land and for the three variables related to land use.

Figure 5. Hierarchical cluster dendrogram for Pergamino farms.
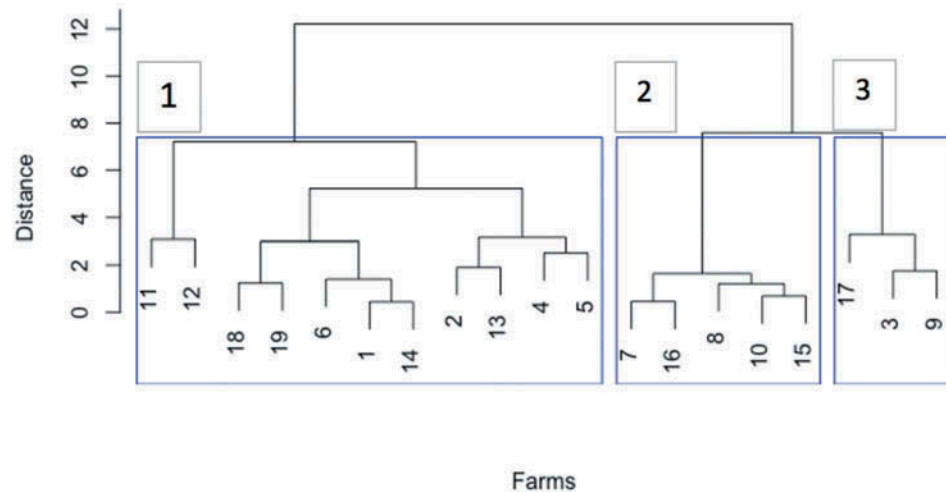
5. Discussion

The sample considered in this study includes farms of different size and land tenancy schemes, most having professional advice. Average values of farm size, land tenancy and professional advice are relatively similar to those reported by Cabrini and Calcaterra (2008) for farming systems of the department of Pergamino.

Results agree with previous studies carried out in the Argentine Pampas in that, on average, soil organic carbon and nutrients tend to decrease, under current land use and crop management practices (Alvarez et al., 2014; Cabrini et al., 2013; Flores & Sarandón, 2002; Garcia & Vázquez, 2012; Wingeyer et al., 2015; Zazo et al., 2011).

In this study, the impact measured by the environmental indicators is presented as the on-farm environmental cost. Expressing soil organic carbon and nutrients balances in monetary terms allows to assess the magnitude of these impacts for crop production systems. The estimated values for environmental cost, that range from 2 to 140 u\$s ha^{-1} year^{-1} for the different farms, indicate that these costs are relevant in the study region. These values can be interpreted as an estimation of the expected decrease in the annual economic results for Pergamino crop farms.

It is important to remark that the environmental costs computed in this study do not include all the costs associated with the environmental impacts of crop production systems in Pergamino. There are also off-farm environmental impacts associated with simplified production systems that were not included in the cost estimation. For instance, contamination risk associated to nitrogen leaching is higher when no winter crops are included in rotations (Portela et al., 2016). Also, there are negative externalities associated with CO_2 emission for production systems with SOC negative balances. And simplified land-use schemes are likely to be more dependent on pesticide use.

The farm-level dataset allowed to evaluate the diversity of land use schemes in Pergamino Department. Results indicate that while, on average, the proportion of land assigned to soybeans is high, there are also farms with different levels of diversification and intensification of rotations. Larger farms tend to have more simplified production systems, what is probably explained by the opportunity to take advantage of economies of scale. Multivariate statistics technics are useful to identify farming systems with better performance based on a set of indicators.

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	Operated land	Rented land	Professional advice	Crop diversity index	Land assigned to full-season soybeans	Land assigned to double crops
	-ha-	%			%	%
1	198.18	**59.55**	0.82	**0.024**	32	49
2	416.4	**0**	1	**0.012**	73	11
3	2316.67	**100**	1	**0.015**	97	**3**
	Soil organic carbon balance	Nitrogen balance	Phosphorus balance	Crop revenue	Environmental cost	
	tn ha^{-1} year^{-1}	—kg ha^{-1} year^{-1}—		—u\$s ha^{-1} year^{-1}—		
1	−0.13	−24.09	−4.66	1313	52	
2	−0.2	−35.57	−6.35	1156	81	
3	−0.27	−39.32	−12.63	1003	112	

Table 6. Descriptive statistics by cluster

Note: Variables definitions are presented in Table 1. Variables in bold show significant differences between groups, based on ANOVA tests ($\alpha = 5\%$).

6. Conclusion

This study employs farm-level data of land use and crop management practices to explore the relationship between farm characteristics, land use schemes and economic and environmental indicators at the farm level. Results show that under current land use and crop management practices, soil nutrients and organic carbon tends to decrease, on average, which would imply a decrease in the economic result.

However, there is high diversity in the rotation schemes found in the study area. There are farms in the sample with high level of diversification and intensification of crop sequences and low values for the environmental cost associated to soil organic carbon and nutrient losses. Farm size is the variable that shows the strongest correlation with land use indicators. However, more research is needed for a deeper understanding of the relationship between farm size, land rental agreements, land-use decisions and the performance of agricultural systems.

Results suggest the need to continue monitoring cropping systems by adding more years and observations, in order to improve sustainability assessment. More economic, environmental and social indicators should be included in order to consider both on-farm and off-farm impacts to measure the performance of agricultural production systems in Argentine Pampas.

Competing Interests
The authors declares no competing interests.

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