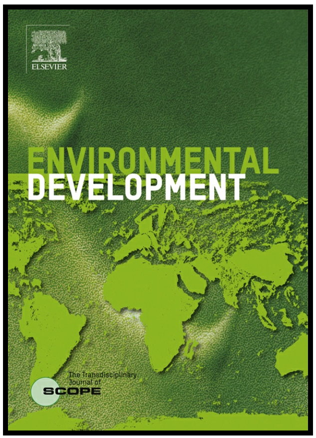

www.elsevier.com/locate/envdev

Identifying the factors that determine ecosystem services provision in Pampean agroecosystems (Argentina) using a data-mining approach

Florencia Rositano, Federico E. Bert, Gervasio Piñeiro, Diego O. Ferraro

PII: S2211-4645(17)30130-6
DOI: https://doi.org/10.1016/j.envdev.2017.11.003
Reference: ENVDEV375

To appear in: *Environmental Development*

Received date: 15 May 2017
Revised date: 28 November 2017
Accepted date: 29 November 2017

Cite this article as: Florencia Rositano, Federico E. Bert, Gervasio Piñeiro and Diego O. Ferraro, Identifying the factors that determine ecosystem services provision in Pampean agroecosystems (Argentina) using a data-mining approach, *Environmental Development,* https://doi.org/10.1016/j.envdev.2017.11.003

Identifying the factors that determine ecosystem services provision in Pampean agroecosystems (Argentina) using a data-mining approach

Florencia Rositano[1,2], Federico E. Bert[2], Gervasio Piñeiro[1,3] and Diego O. Ferraro[1,2]

[1]IFEVA, Universidad de Buenos Aires, CONICET, Facultad de Agronomía, Av. San Martín 4453 (C1417DSE), Buenos Aires, Argentina.
[2]Universidad de Buenos Aires. Facultad de Agronomía. Departamento de Producción Vegetal. Cátedra de Cerealicultura. Av. San Martín 4453 (C1417DSE), Buenos Aires, Argentina.
[3]Universidad de Buenos Aires. Facultad de Agronomía. Departamento de Recursos Naturales y Ambiente. Cátedra de Ecología.Av. San Martín 4453 (C1417DSE), Buenos Aires, Argentina.

Corresponding author: **F. Rositano**
Postal address: Cátedra de Cerealicultura, Facultad de Agronomía, Universidad de Buenos Aires. Av. San Martín 4453 (C1417DSE), Buenos Aires, Argentina.
Telephone/Fax number: +54-11-4524-8039
E-mail: rositano@agro.uba.ar

Abstract

Ecosystem services (ES) have become a key concept in the assessment of natural resources, as a way to connect human well-being and ecosystems degradation. However, ES quantification is considered a basic problem because provision varies considerably as a result of land use change and site-specific characteristics (i.e. climate, soil, topography, and time). Thus, more detailed studies are needed to assess whether these changes affect ecological variables. We explored the use of environmental and crop management variables in predicting the provision of four ES (soil C balance, soil N balance, N_2O emission control and groundwater contamination control) in three agroecosystems located in the Pampa region (Argentina). Data-mining, represented by k-means cluster and classification trees, was used to identify the dependence of ES provision on the variation of both environmental and crop management factors. We used plot level crop management and environmental field information stored in a large database during a 10-year period. The k-means method selected five different clusters. The final configuration showed two contrasting clusters: one with the lowest ES provision, and another one with the highest ES provision. The five clusters were represented in the terminal nodes of the final classification tree. Regarding the predictive power of the variables, crop and year were the most important predictors. Then, differences observed in ES provision resulted from changes in land use (variable "crop") and crop season (variable "year"). These results are meant to enlighten stakeholders in terms of how to manage Pampean agroecosystems in order to positively influence ES provision.

Keywords: ecosystem services, cluster, classification trees, land use, crop season, Pampean agroecosystems

1. Introduction

Nowadays, there is a growing interest amongst farmers, policy makers and society in designing agroecosystems which not only provide benefits such as crop yield (Schipanski et al. 2014), but also provide information on (and reduce) the environmental impacts of agricultural production (Boody et al. 2005; Bennett and Balvanera 2007; Gordon et al. 2010). Ecosystem services (ES) have become a key concept in the assessment of natural resources, as a way to connect human well-being and ecosystems degradation (Fisher and Turner 2008; Burkhard et al. 2010). Despite the fact that there is an extensive literature on ES, quantification is considered a basic problem because their provision varies considerably as a result of land use/land cover change and site-specific characteristics (i.e. climate, soil, topography, agricultural management, and time) (Daily and Matson 2008; de Groot et al. 2010).

Agriculture and ES may be interlinked through three aspects: two positive and one negative (Dale and Polasky 2007). In terms of positive aspects, agroecosystems generate benefits to society (e.g. soil retention, food production) but also require some other benefits provided by natural ecosystems (e.g. pollination). On the negative side, ES may be affected by agricultural management considering that it can reduce the ability of ecosystems to provide ES (Palm et al. 2014). From a social perspective, farmers obtain benefits from a wide range of ES, while society is benefited or harmed by agricultural management (Power 2010). Further studies are needed not only to deepen the relationship between ES and agricultural management (Tilman et al. 2002) but also to identify options for sustainable agriculture (Dale and Polasky 2007).

Argentina is one of the countries with highest agricultural production in the world. During 1988-2002, the area used for annual crop production increased at an annual average rate of 0.27% (Orúe et al. 2007). Beyond the extension of the agricultural frontier, other processes such as the introduction of different management practices or genetically modified crops, and the increase in inputs used during crop production have caused changes in agroecosystems (Pengue 2001; Satorre 2005). In Pampean agroecosystems, particularly, annual monocultures have replaced agriculture-livestock rotations, natural vegetation, perennial crops and other crop rotations (Paruelo et al. 2006). Some studies suggest, however, that these changes seemed to be of low importance because Pampean agroecosystems are considered to have low ES provision in comparison with other fragile Argentinean ecosystems (e.g. wetlands, estuaries, tropical and subtropical jungles) (Carreño and Viglizzo 2007). However, there is a significant lack of specific information on the effect of land use change on ES provision in this region. Thus, more specific studies are needed in order to assess whether the aforementioned land use changes affect ecological variables.

Changes in Argentinean agroecosystems have led to the development of several tools and methodologies in order to assess ES provision under different ecological and spatial conditions (e.g. Barral and Maceira 2012; Caride et al. 2012; Carreño et al. 2012; Laterra et al. 2015). Some patterns and mechanisms used to explain ES provision can be extracted from the analysis of data collected from farm-level production-related records. One of the main advantages of production databases is the documentation of what really happens in agroecosystems capturing, at the same time, a wide range of interactions amongst different variables (Lawes and Lawn 2005). These interactions are also captured by agricultural experiments but on a smaller scale. However, the structure of this kind of data is generally inadequate using standard statistical analysis techniques due to problems related to data transformation, unbalanced designs and non-linearity (Ferraro et al. 2009). In light of this, we propose the use of non-parametric statistical methods to analyze ES provision in Pampean agroecosystems. Particularly, we propose the use of a data mining technique called 'Classification and Regression Trees (CART)' (Breiman et al. 1984) in order to identify the dependence of ES provision on the variation of both environmental and crop management factors.

Recently, Rositano and Ferraro (2014) used direct field information to assess the provision of four ES (soil C balance, soil N balance, N_2O emission control and groundwater contamination control) under two land use scenarios (soybean vs. maize) along ten growing seasons (2000/2001 – 2009/2010) in a certain agroecosystem from the Pampa region (Argentina). The study was an attempt to represent Pampean agroecosystems in terms of their ES provision. Here, we specifically explore the effects of environmental and crop management variables on the prediction of the provision of the four ES previously assessed by Rositano and Ferraro (2014) in three study sites located in the Pampa region. We used farm and plot level crop management and environmental field information stored in a large database during a 10-year period.

2. Materials and methods

For this study, we used previously developed Bayesian Networks (BNs) originally used to assess ES provision in Pampean agroecosystems (Argentina) (Rositano and Ferraro 2014). A BN is a statistical approach used to represent a set of associated uncertainties given the conditional independence relationships established between them (López Puga et al. 2007). This methodology uses quantitative data, expert knowledge or both to fulfill (or populate) variables. For more information about this probabilistic methodology, please see Chen and Pollino (2012).

Four Bayesian models representing four ES (i.e. soil C balance, soil N balance, N_2O emission control and groundwater contamination control) were selected to be parameterized and quantified in a specific area located in Pampean agroecosystems (Rositano and Ferraro 2014). These models were assessed through two sensitivity analysis techniques (Rositano et al. 2017). Each model had an output variable with three states (High/Medium/Low). In order to achieve sustainable ecosystems, we were interested in one state of each output variable (i.e. the one that conferred desirable values for agroecosystems sustainability); that is, High C content in soil, High Available N in soil, Low Denitrification and Low NO_3 concentration in groundwater (Rositano and Ferraro 2014) (see Appendix 1).

2.1. Study site

The Pampa region is located on a more than 52 million ha plain in the center-east of Argentina (Hall et al. 1992) (Figure 1). Mean annual temperature ranges from 10ºC to 20ºC and annual rainfall from 400 mm to 1600 mm, decreasing from the northeast to the southwest (Soriano et al. 1991). Soil types are mainly Mollisols. The major crops in the region are soybean (*Glycine max* (L.) Merr.), maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annus* L.). Various sub-regions are recognized in the Pampas, based on their geomorphology, geology, physiography, soils and vegetation (Soriano et al. 1991). These sub-regions are: Rolling Pampa, Inland Pampa, Flooding Pampa, Southern Pampa, Semiarid Pampa, and Mesopotamic Pampa (Figure 1).

The analysis performed here was designed for three agroecosystems located in contrasting Pampean sub-regions (see striped area in Figure 1). North of Cordoba (NC) is located in the transitional region between Semiarid Pampa and the Chaco Region;

Center of Buenos Aires (CBA) is located in Flooding Pampa and a minor territory in Rolling Pampa; while South of Entre Ríos (SER) is located in Mesopotamic Pampa. Biophysical properties which characterize and differentiate these agroecosystems are shown in Table 1.

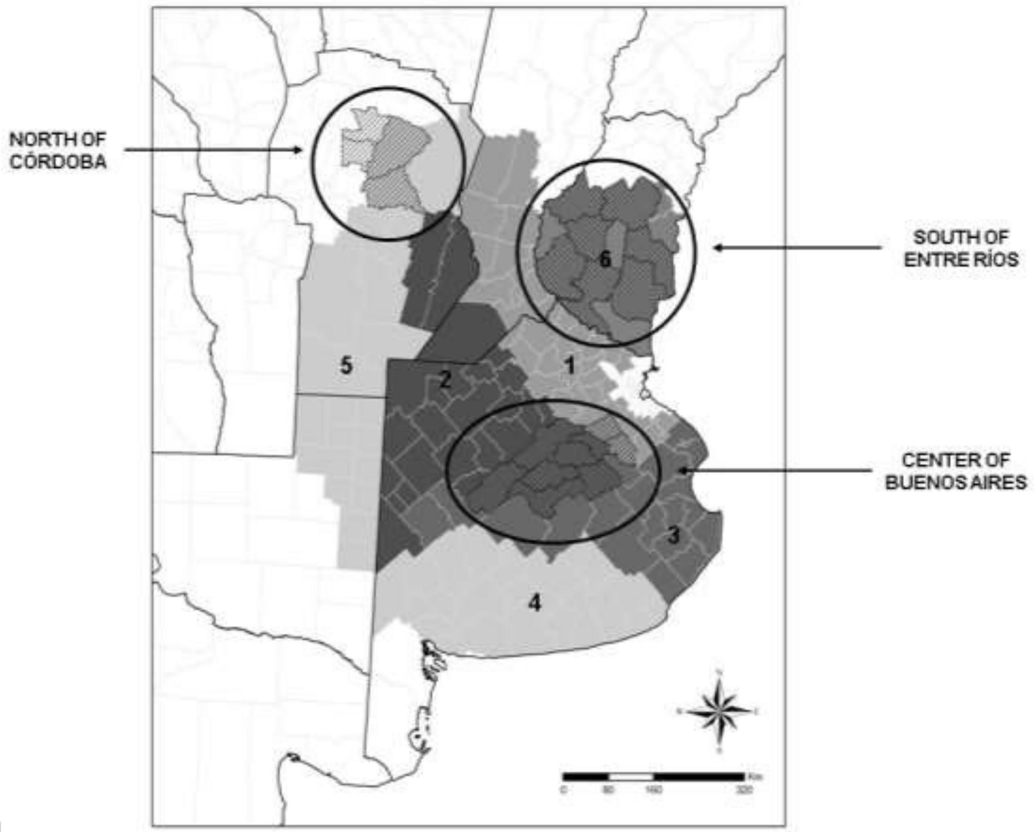

Figure 1: Location of the Pampa region (Argentina) and its sub-regions (grey shaded): 1) Rolling Pampa, 2) Inland Pampa, 3) Flooding Pampa, 4) Southern Pampa, 5) Semiarid Pampa, and 6) Mesopotamic Pampa. The estimation of ecosystem services provision was carried out for three Pampean agroecosystems: North of Córdoba, South of Entre Ríos and Center of Buenos Aires (see striped areas).

Table 1: Biophysical properties of the three Pampean agroecosystems selected. References: NC = North of Córdoba; CBA = Center of Buenos Aires; SER = South of Entre Ríos (Source: Cruzate et al. 2008a, 2008b; Panigatti et al. 2008).

Agroecosystem under study	**Soil order**	**Area under agriculture (%)**	**Annual rainfall (mm)**	**Annual temperature (ºC)**
NC	Mollisol	71	850	17,5
CBA	Mollisol	23,9	950	14,5
SER	Vertisol	35,5	1050	17,5

2.2. Data collection

Farm (i.e. each farm consists of a number of plots) and plot-level management and environmental information was obtained from the three agroecosystems under study (Figure 1). Common agricultural practices were provided by the Asociación Argentina de Consorcios Regionales de Experimentación Agrícola (AACREA) (a non-profit farmers association that gathers more than 2000 farmers all over the country). Data were collected from farms located in each study site. The data set contained information on crop rotations from the year 2000 to 2010 for each Pampean agroecosystem (NC, CBA and SER). Historical weather records were provided by Servicio Meteorológico Nacional (SMN) and soils descriptions/data by Instituto Nacional de Tecnología Agropecuaria (INTA).

2.3. Field attributes

We used categorical and continuous plot-level crop management variables in order to explore those agricultural factors which explain ES provision in Pampean agroecosystems. The categorical variables used were: crop, preceding crop and region (Table 2). Four preceding crops were selected; 1) wheat, 2) maize, 3) soybean, and 4) grassland. The continuous variable used was crop season with year as its unit (from year 2000 to year 2010).

Table 2: Description of categorical variables used for the study. The number of registered plots correspond to the ten crop seasons. References: NC = North of Córdoba; CBA = Center of Buenos Aires; SER = South of Entre Ríos.

Region	**Crop**	**Preceding crop**	**Number of plots**
NC	Wheat	Maize	521
		Wheat	0
		Soybean	1840
		Grassland	50
	Maize	Maize	89
		Wheat	359
		Soybean	2636
		Grassland	110
	Soybean	Maize	3345
		Wheat	1956
		Soybean	2490
		Grassland	77
CBA	Wheat	Maize	633
		Wheat	0
		Soybean	3048
		Grassland	0
	Maize	Maize	160
		Wheat	0
		Soybean	461
		Grassland	50
	Soybean	Maize	1368
		Wheat	2300
		Soybean	2004
		Grassland	1088
SER	Wheat	Maize	83
		Wheat	0
		Soybean	515
		Grassland	60
	Maize	Maize	25
		Wheat	80
		Soybean	1349

	Grassland	130
Soybean	Maize	1550
	Wheat	1600
	Soybean	2249
	Grassland	689

2.4. Cluster analysis

In order to identify contrasting groups of ES provision in Pampean agroecosystems, we assessed the database using a cluster analysis called K-means (Jain and Dubes 1988). The algorithm used is based on the estimation of the sum of squares (Ferraro et al. 2009). This methodology groups objects in k groups by maximizing the variation between clusters and minimizing it within each cluster (Catena et al. 2003). That is, objects in the same group share the largest allowable number of features, while objects in different groups tend to be different. As a result of a K-means clustering analysis, the means for each cluster would be examined to assess how distinct those clusters are.

Misclassification rate (r) (i.e. the proportion of errors made during the procedure of classifying objects in clusters) is used to define the final number of clusters. This rate is calculated as the average distance of objects in the database used for testing the centroid of each cluster to which they were assigned. In order to select the optimal number of clusters, we inspected the set of solutions for detecting a cut-off value of 5% in the percentage decrease of the misclassification error when adding one more cluster, and the lowest number of clusters that meets the above condition (Ferraro et al. 2012). Cluster analysis was performed using Statistica (StatSoft 2008).

2.5. Classification and Regression Trees

CART methodology was used to divide clusters into new sub-groups with the highest homogeneity and to assign variables which can define these sub-groups along divisions (i.e. branches) of the tree (Catena et al. 2003; De'ath and Fabricius 2000). A classification tree partitions all possible objects (or nodes) in order to be assigned to one cluster (Breiman et al. 1984). The two sub-groups (nodes) formed are divided again if: 1) there is sufficient diversity to produce a partition of observations, and/or 2) the node size is higher than the minimum established to continue the algorithm (Catena et al. 2003). Ideally, the node separation process continues until each node is pure (i.e. contains a single cluster of total objects) or purity of end nodes (i.e. terminal nodes) reaches a certain limit. The result is a binary tree which is usually pruned in order to obtain its final structure. We used a pruning technique called 1-SE (Breiman et al. 1984) in which the best tree is the smallest one (i.e. fewer nodes). Its estimated error rate is within one standard error of the minimum (De'ath and Fabricius 2000).

In order to assess the tree obtained, Breiman et al. (1984) proposed a method called Cross-Validation (CV). This methodology is based on a v value, which divides the database to obtain sub-samples for testing the obtained tree. For example, considering v = 10, the database is divided into 10 sub-samples from which 9 sub-samples are used to calculate the tree and the remaining sub-sample is the one against which the tree is tested. This process is repeated v-1 times. In our case, a v = 7 was used for cross-validation; therefore, the database (230 cases in total) was divided into seven sub-samples (32 cases per sub-sample) to build and assess the tree. The 1-CV error is equivalent to R^2 in a linear regression (Breiman et al. 1984), and estimates the "portion of the variance explained by the model" (Roel et al. 2007).

An output of the CART procedure considers the importance of the independent variables, which are ranked in descending order of their contribution to tree construction. CART calculates the improvement measure attributable to each variable in its role as a surrogate to the primary split. The values of these improvements are summed over each node of the tree and scaled relative to the best performing variable. The variable with the highest sum of improvements is scored 100, and all other variables have lower scores ranging downwards towards zero (Steinberg and Colla 1995). CART was performed using Statistica (StatSoft 2008).

3. Results

Misclassification rate decreased until the database was divided into n = 11 individual clusters (Figure 2). However, the 5% cut-off value of rate reduction was reached at n = 5 and, therefore, this n was selected for further analyses.

The final configuration showed two contrasting clusters (CLs) in terms of ES provision in Pampean agroecosystems: CL1 and CL5 (Figure 3). CL1 could be considered the cluster with the lowest ES provision because it had the lowest values for High Available N in soil, Low NO_3 concentration in groundwater and Low Denitrification, and intermediate values for High C content in soil. CL5 could be considered the cluster with the highest ES provision because it had the highest values for High C content in soil and High Available N in soil, and intermediate values for Low NO_3 concentration in groundwater and Low Denitrification (Figure 3). The highest values for these two latter response variables were observed in CL3, while the lowest values for High C content in soil and High Available N in soil were observed in CL2 (Figure 3).

The classification tree had eight terminal nodes in which appeared the five CLs previously obtained (Figure 4). Region was the first splitting variable. On the right branch, NC and CBA agroecosystems were located (ID = 3); on the left branch, SER agroecosystem was located (ID = 2). Preceding crop was selected in the right branch of the tree for separating soybean (ID = 30) from maize, wheat and grassland (ID = 31). Crop and year appeared frequently at the next splitting levels. Crop was selected in the final model for splitting soybean (ID = 18) from maize and wheat (ID = 19). Year was selected for splitting early crop seasons (ID = 8; ID = 32) from later ones (ID = 9; ID = 33). The CART model was able to explain 65% (i.e. 1-Cross Validation cost for the learning set) of the agricultural factors that affect ES provision in Pampean agroecosystems.

When each variable was analyzed through their contribution to the CART, year showed the highest ranking value, followed by crop (Figure 5).

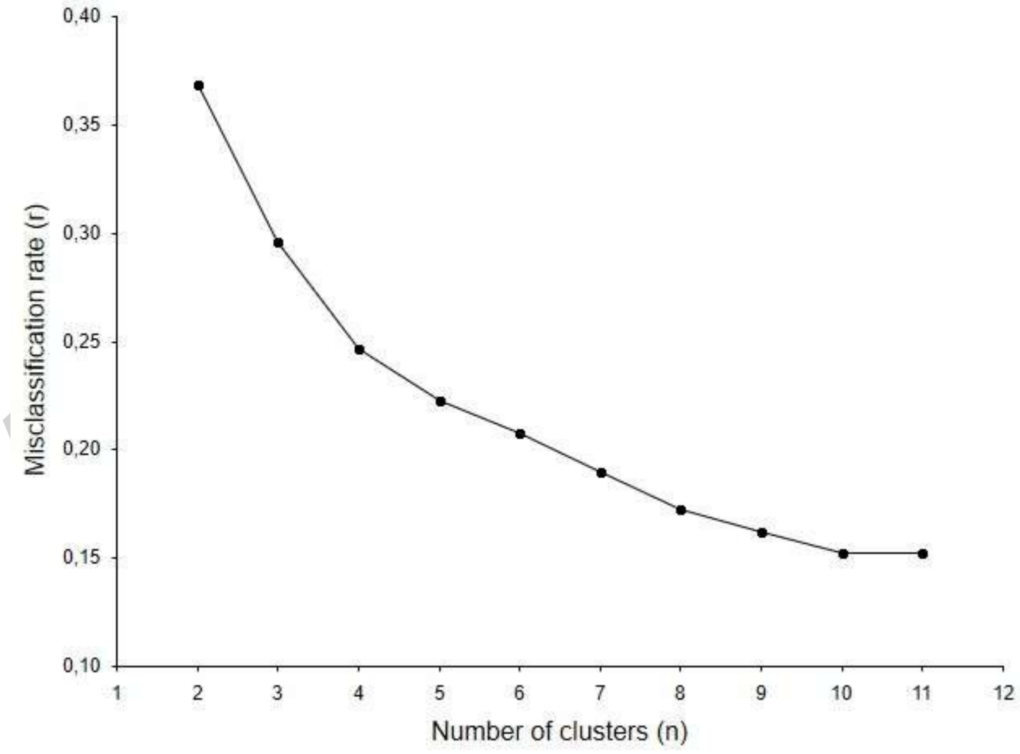

Figure 2: Misclassification rate (r) of agricultural fields used as a test set during the cross-validation procedure for optimizing the final number of clusters.

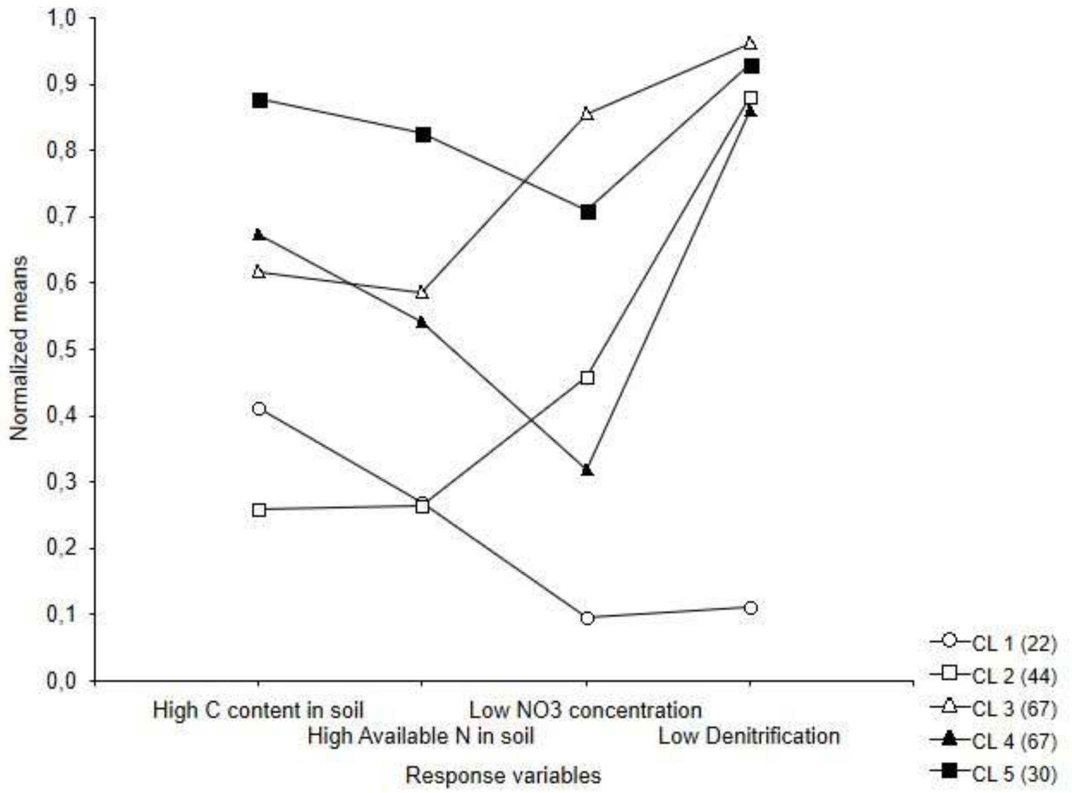

Figure 3: Normalized mean values of probability for each response variable in each of the five clusters obtained. The response variable of each model is: A) High C content in soil, B) High Available N in soil, C) Low NO_3 concentration in groundwater, and D) Low Denitrification. Numbers in parentheses refer to the number of cases present in each cluster. References: CL = cluster.

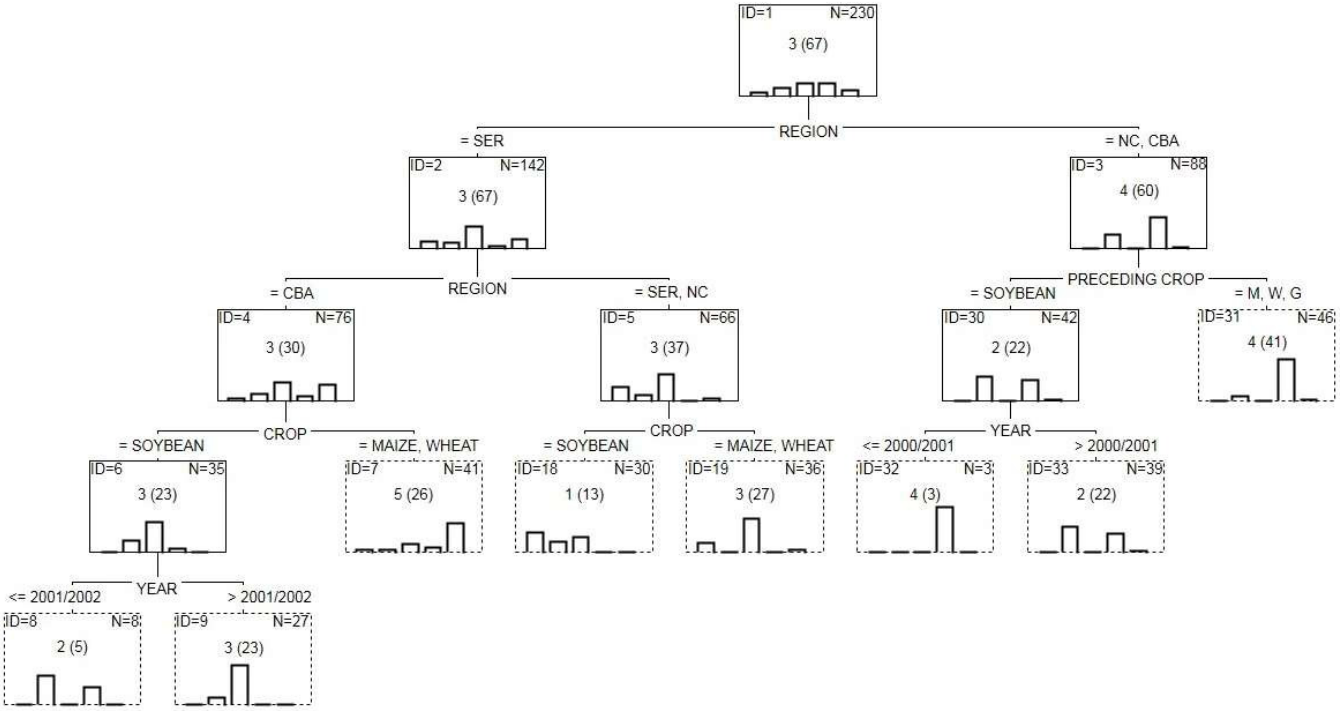
ID=1 N=230
3 (67)
REGION
= SER
= NC, CBA
ID=2 N=142
3 (67)
REGION
= CBA
= SER, NC
ID=3 N=88
4 (60)
PRECEDING CROP
= SOYBEAN
= M, W, G
ID=4 N=76
3 (30)
CROP
= SOYBEAN
= MAIZE, WHEAT
ID=5 N=66
3 (37)
CROP
= SOYBEAN
= MAIZE, WHEAT
ID=30 N=42
2 (22)
YEAR
<= 2000/2001
> 2000/2001
ID=31 N=46
4 (41)
ID=6 N=35
3 (23)
YEAR
<= 2001/2002
> 2001/2002
ID=7 N=41
5 (26)
ID=18 N=30
1 (13)
ID=19 N=36
3 (27)
ID=32 N=3
4 (3)
ID=33 N=39
2 (22)
ID=8 N=8
2 (5)
ID=9 N=27
3 (23)

Figure 4: Classification tree of the agricultural factors determining ecosystem services provision in Pampean agroecosystems, using the clusters identified by the K-means method showed in Figure 3. N indicates the number of cases in a node of the classification tree. Nodes with dotted line correspond to terminal nodes. Columns within each node correspond to the histogram representing the distribution of clusters; and the number in the center, the cluster most frequent in that node (with the number of cases within parentheses). The 1-CV error is equal to 0.65. References: SER = South of Entre Ríos; NC = North of Córdoba; CBA = Center of Buenos Aires; M = Maize; W = Wheat; G = Grassland.

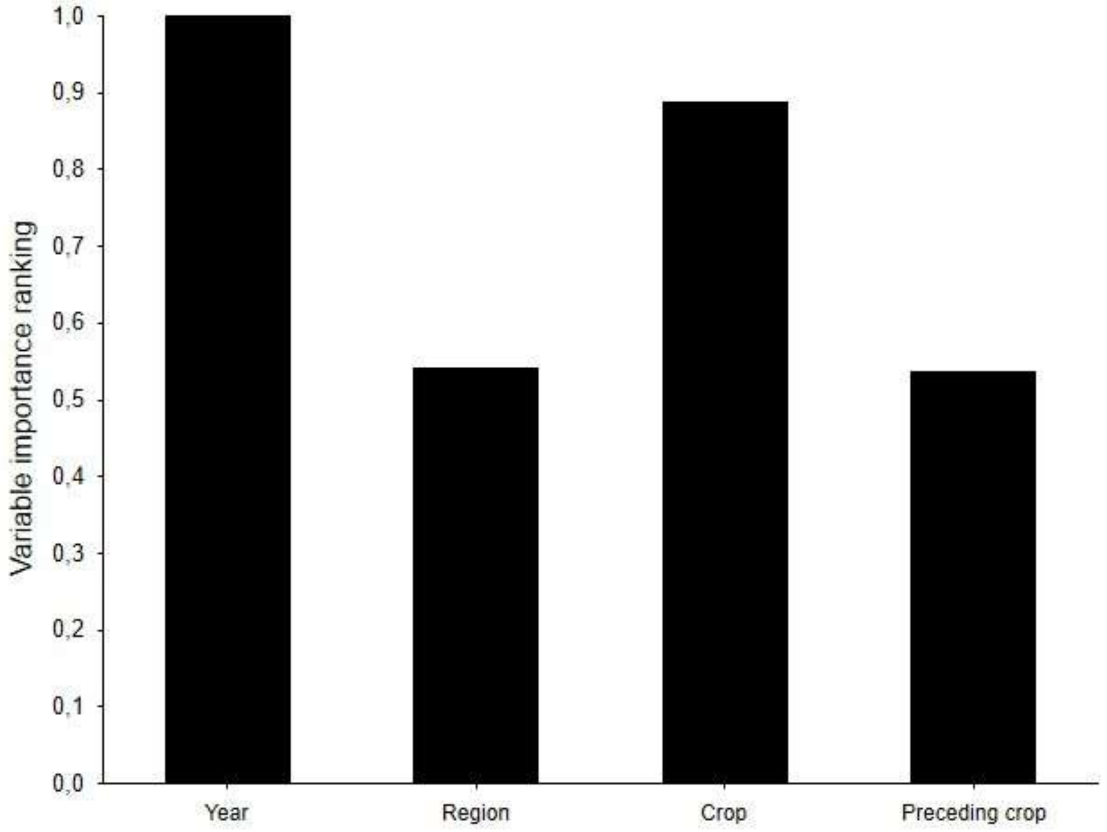

Figure 5: Variable importance ranking computed by the CART model of Figure 4.

4. Discussion

The main goal of our work was to identify those agricultural variables that determine ES provision in Pampean agroecosystems. Previously, Rositano and Ferraro (2014) qualitatively identified that environmental and management variables can influence ES provision in a given Pampean cropping system. However, this is the first time that these variables have been quantitatively considered together as possible modulators of their supply in this region. Here, differences observed in ES provision resulted from changes in land use (variable "crop") and crop season (variable "year") (Figure 5). Furthermore, Viglizzo and Frank (2006) have analysed the trade-offs between a set of economic and ecological services due to changes in land use in the Pampa region. However, they studied changes from natural vegetation to croplands, rather than amongst different crops. Despite the fact that agroecosystems are managed to obtain provisioning services (e.g. food, fiber, raw), they should also be managed to deliver multiple ES (e.g. soil conservation, climate regulation, greenhouse gases emission control) (Bennett and Balvanera 2007; Harrison et al. 2010). In light of this, the purpose of our results was to provide guidance to stakeholders on how to manage Pampean agroecosystems in a way which positively influences ES provision.

Several authors have stated the idea that ES provision changes under different land use types (e.g. Foley et al. 2005; MEA 2005; Muñoz-Rojas et al. 2011; Felipe-Lucia et al. 2014; Lawler et al. 2014; Queiroz et al. 2015; Jiang et al. 2016). However, Koschke et al. (2013) argued that there are often ambiguous data on the contribution of land use to ES provision. In our case, each crop could be associated with a good, a medium or a bad scenario of ES provision. In general terms, scenarios (CLs) are the relationships amongst the four ES selected in this study (Figure 3). For example, maize and wheat were observed in the best scenario in CBA (CL5) (ID=7), and in a medium scenario in SER and NC (CL3) (ID=19) (Figure 4). Soybean was observed in a medium scenario in CBA (CL 3) (ID=6), and in the worst scenario in SER and NC (CL1) (ID=18) (Figure 4). Conversely, soybean as a preceding crop prevailed in a bad scenario (CL2) (ID=30), while the other preceding crops prevailed in a medium scenario (CL4) (ID=31) (Figure 4). These results supported the idea that different crops can change the relationship amongst ES, creating opportunities to increase or diminish ES provision (Bennet et al. 2009; Mouchet et al. 2014).

Cropping systems are capable of maximizing yields but also of maximizing natural resources (ES) through different management strategies such as crop diversification (e.g. crop rotation, cover crops). As our results have shown, maize and wheat were the crops observed in the best scenarios; however, this did not mean that agriculture should only be focused on these two crops and not on soybean. The association of different species with each other can help to deliver ES. That is, cereal-legume associations are a well-known example of multiple cropping systems based on complementary functions that optimizes several ES (e.g. soil nitrogen) (Gaba et al. 2015; Lazzaro et al. 2017). Therefore, balanced crop rotations should be determined in order to increase both provisioning (e.g. crop yield) and also regulating, supporting and cultural services (Tittonell 2014). In the last decade, more than 70% of Pampean soils have been given over to soybean monoculture, a crop that produces little residue and roots that rapidly decompose. This has led to a process of soil degradation, groundwater ascent and an endemic development of weeds and pests. Nowadays, stakeholders are being encouraged to add different crops to current cropping systems and to analyze strategies that improve soil structure. Consequently, our results suggest that crop rotation is determinant of ES provision.

Having a mixture of different crops (in space and time), critical to providing a sustainable ES set (Felipe-Lucia et al. 2014), is not only possible with crop rotations but also with cover crops (Schipanski et al. 2014). In the Pampa region, including grasses (e.g. wheat, maize) as cover crops is essential to obtain sustainable cropping systems because their roots favour soil aeration and, after decomposition, leave conduits in order to facilitate the entry of water into deeper layers. Therefore, the main objective of cover crops is to provide multiple ES such as soil protection by ensuring that the soil is not left bare between two crops (Gaba et al. 2015). This has led to cover crops being called "service crops" because of their capability to improve and maintain different soil ES (Piñeiro et al. 2014; Pinto et al. 2017). It is important to highlight that service crops are a complementary and non-substitutive management strategy, because they do not replace an adequate crop rotation. For this reason, stakeholders should include them when fallows within a crop rotation are too long.

A large fraction of ES has not only diminished by land use but also by climatic conditions (Elmhagen et al. 2015; Fan et al. 2016). The need to mitigate negative effects of land use and climate on ES provision has been previously stated (Bu et al. 2014). Knowledge about this interaction is necessary to make sound decisions about how to manage cropping systems (Chan et al. 2006). Accordingly, our results provide some insights into the interaction between land use and weather conditions. For example, soybean was the only one which was directly linked to crop seasons (variable "year") in CBA and NC (Figure 4). Soybean prevailed in bad (CL2) and medium (CL3) scenarios (ID=8 and ID=9, respectively); and soybean as preceding crop was also observed in bad (CL2) and medium (CL4) scenarios (ID=33 and ID=32, respectively) (Figure 4). During bad scenarios (2000/2001 and 2001/2002), there was a predominance of rainfall values between 800-1000 mm in CBA. Meanwhile, medium scenarios (2002/2003-2009/2010) were characterized by annual rainfall values of less than 800 mm. The temperature pattern was constant throughout crop seasons with values around 20°C in both scenarios. For example, bad scenarios (under soybean) are characterized by low values of High C content in soil and High Available N in soil. This is mainly determined by uncovered soils due to the small amount of rapidly decomposing stubble exacerbated by high amounts of humidity and temperature. Thus, ES provision is not only determined by crop management but also by climate, with synergistic effects (Elmhagen et al. 2015).

Agricultural management is fairly homogeneous in different parts of the Pampa region (Bert et al. 2011), including the three study sites selected here. This lack of diversity (at least, in our databases) in agricultural management probably forces the climate variability as the main factor influencing differences found in ES provision. It is widely known that agriculture is highly sensitive to climatic variations (Lorencová et al. 2013). This may lead not only to differences amongst regions but also cause inter annual variability of production and disruption of ES provision within a certain region (Howden et al. 2007). Considering that climate has limited predictability, stakeholders have to deal with a lot of uncertainty during decision making (Hammer et al. 2001). Both characteristics (i.e. limited predictability and uncertainty) are then, transferred to ES making it difficult to predict their provision in the future.

Conclusions

This paper made a contribution to the identification of those factors that determine ES provision in Pampean agroecosystems. Specifically, we found differences in ES provision as a result of land use (variable “crop”) and crop season (variable “year”) changes. Thus, the importance of each land use type and crop season in supplying ES and the interaction between both factors on ES change are explained. Based on these results, stakeholders should be advised of the interactions between climate and crop management in order to positively influence ES provision. Finally, it is critical to pay careful attention to the possible limitations of the results here obtained. On the one hand, the CART data-mining procedure only shows exploratory patterns (Ferraro et al. 2012). On the other hand, this study was focused on a certain time period and area; thus, we could not affirm that these differences would usually occur amongst crops. Therefore, the information obtained here may be used to develop an experimental framework to study those crops driving changes in ES provision in the Pampa region.

Acknowledgements

This work was supported by the National Council for Scientific Research (CONICET – PIP 555) and University of Buenos Aires (UBACYT 20020110100196). F. Rositano was supported by a doctoral fellowship from CONICET. We thank Eleanor Milne (Editor) and an anonymous reviewer for their thoughtful comments on the manuscript.

Appendix 1

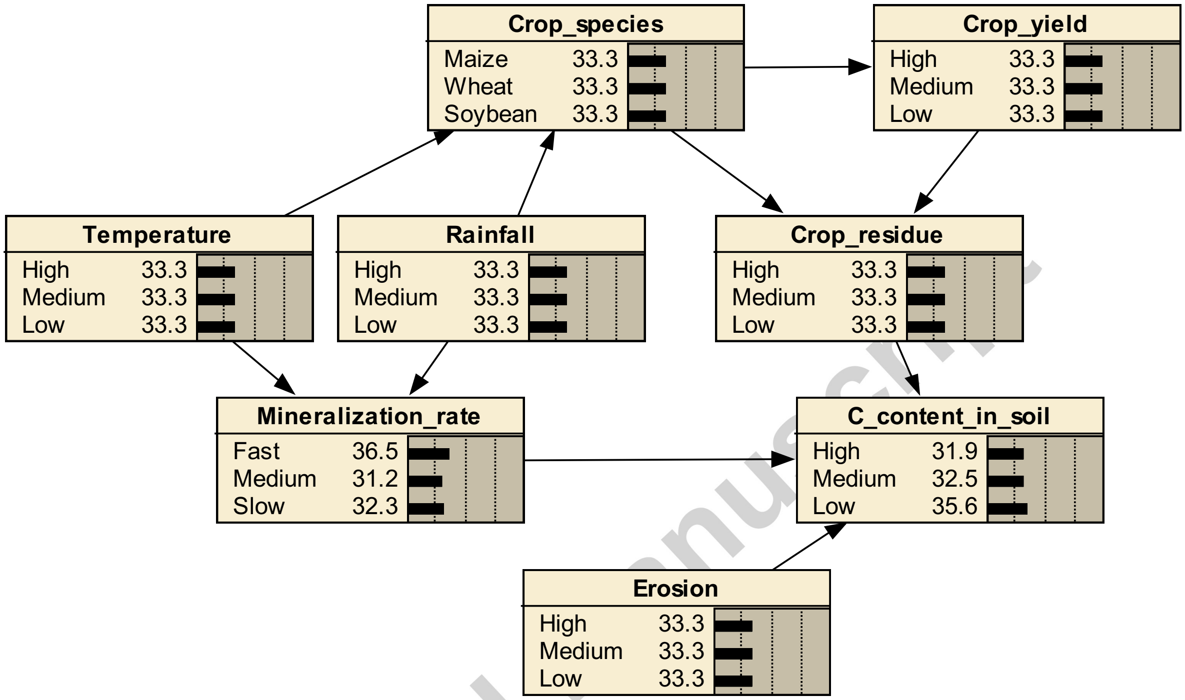

Figure 1: Bayesian network of ecosystem service soil C balance. The output variable is C content in soil. References: C = Carbono.

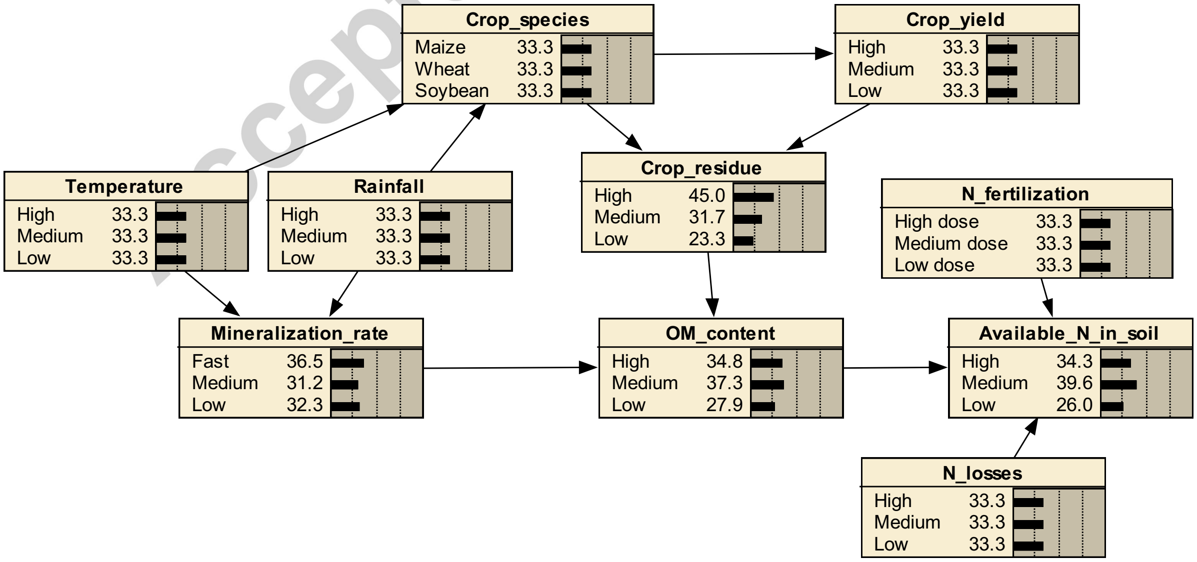

Figure 2: Bayesian network of ecosystem service soil N balance. The output variable is Available N in soil. References: N = Nitrogen; OM = Organic Matter.

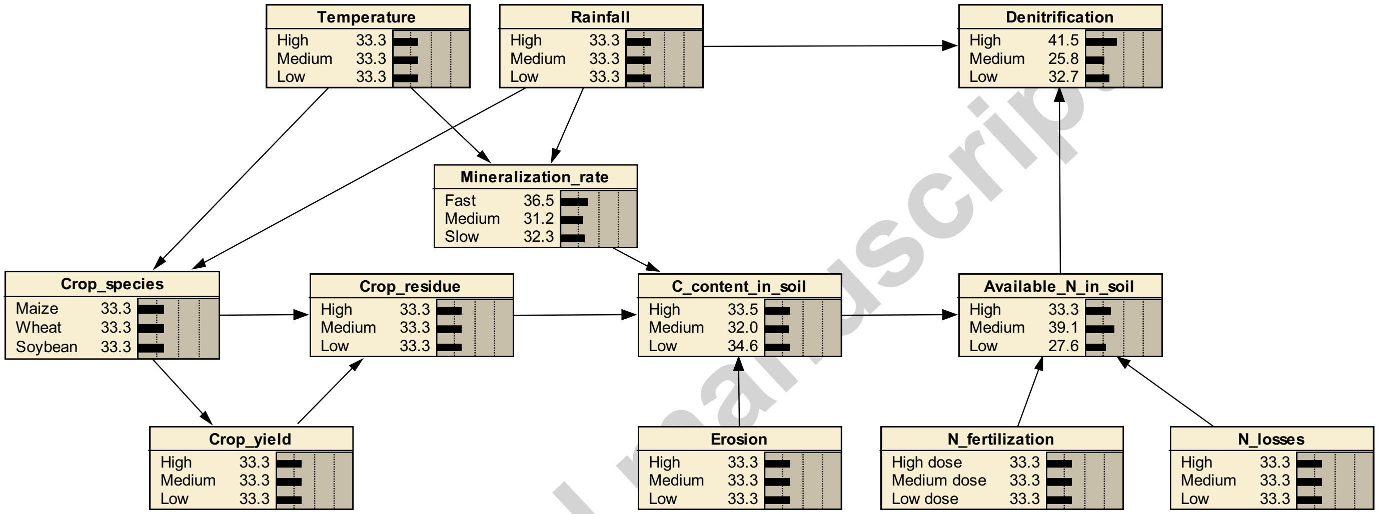

Figure 3: Bayesian network of ecosystem service N_2O emission control. The output variable is Denitrification. References: C = Carbono; N = Nitrogen.

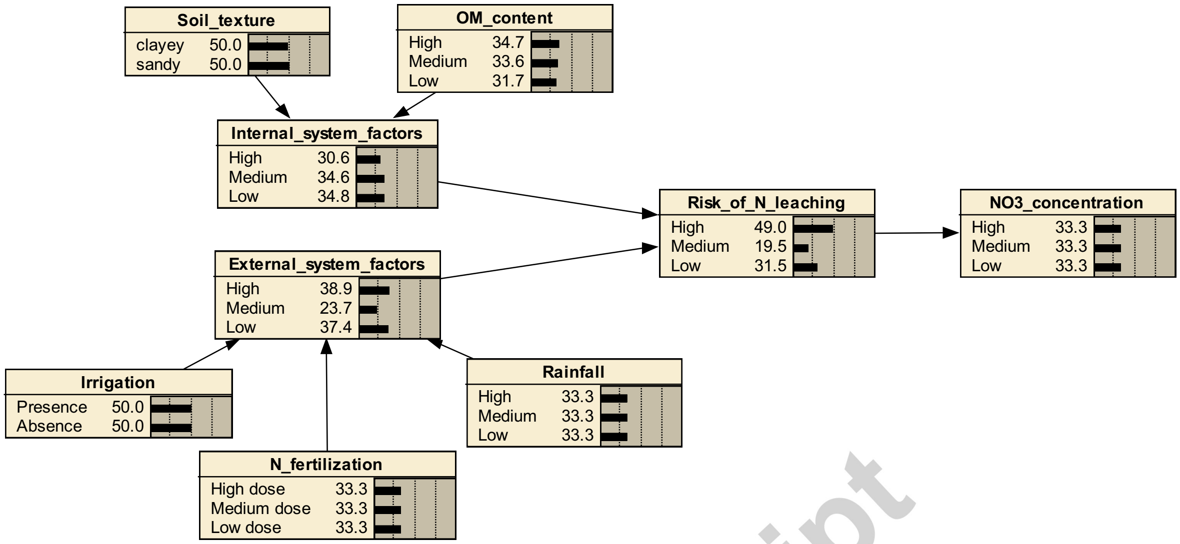

Figure 4: Bayesian network of ecosystem service Groundwater contamination control. The output variable is NO_3 concentration. References: OM = Organic Matter; N = Nitrogen; NO_3 = nitrate.

References

Barral MP, Maceira NO (2012) Land-use planning based on ecosystem service assessment: A case study in the Southeast Pampas of Argentina. Agriculture, Ecosystems & Environment 154:34-43.

Bennett E, Balvanera P (2007) The future of production systems in a globalized world. Frontiers in Ecology and the Environment 5:191-198.

Bennett EM, Peterson GD, Gordon LJ (2009) Understanding relationships among multiple ecosystem services. Ecology Letters 12:1-11.

Bert FE, Podestá GP, Rovere SL, Menéndez A, North M, Tatara E, Laciana CE, Weber E, Ruiz Toranzo F (2011) An Agent Based Model to simulate structural and land use changes in agricultural systems of the Argentine Pampas. Ecological Modelling 222:3486-3499.

Boody G, Vondracek B, Andow DA, Krinke M, Westra J, Zimmerman J, Welle P (2005) Multifunctional agriculture in the United States. BioScience 55:27-38.

Breiman L, Friedman R, Olshen R, Stone C (1984) Classification and regression trees. CRC Press. Boca Ratón, Florida, USA. Pp. 368.

Bu HM, Meng W, Zhang Y, Wan J (2014) Relationships between land use patterns and water quality in the Taizi River basin, China. Ecological Indicators 41:187-197.

Burkhard B, Petrosillo I, Costanza R (2010) Ecosystem services – bridging ecology, economy and social sciences. Ecological Complexity 7:257-259.

Caride C, Piñeiro G, Paruelo JM (2012) How does agricultural management modify ecosystem services in the argentine Pampas? The effects on soil C dynamics. Agriculture, Ecosystems & Environment 154:23-33.

Carreño LV, Frank FC, Viglizzo EF (2012) Trade-offs between economic and ecosystem services in Argentina during 50 years of land-use change. Agriculture, Ecosystems & Environment 154:68-77.

Carreño LV, Viglizzo EF (2007) Provisión de servicios ecológicos y gestión de los ambientes rurales en Argentina. Ediciones INTA. La Pampa, Argentina. Pp. 74.

Catena A, Ramos MM, Trujillo HM (2003) Análisis multivariado. Un manual para investigadores. Editorial Biblioteca Nueva. Madrid, España. Pp. 413.

Chan KMA, Shaw MR, Cameron DR, Underwood EC, Daily GC (2006) Conservation planning for ecosystem services. PLoS ONE 4(11) e379:2138-2152.

Chen SH, Pollino CA (2012) Good practice in Bayesian network modelling. Environmental Modelling & Software 37:134-145.

Cruzate G, Gorgas J, Bustos V, Panigatti JL (2008a) Suelos y ambientes de Córdoba. Ediciones INTA. Córdoba, Argentina.

Cruzate G, Panigatti JL, Moscatelli G (2008b) Suelos y ambientes de Buenos Aires. Ediciones INTA. Buenos Aires, Argentina.

Daily GC, Matson PA (2008) Ecosystem services: from theory to implementation. Proceedings of the National Academy of Sciences 105(28):9455-9456.

Dale VH, Polasky S (2007) Measures of the effects of agricultural practices on ecosystem services. Ecological Economics 64:286-296.

de Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7(3):260-272.

De`ath G, Fabricius KE (2000) Classification and regression trees: A powerful yet simple technique for ecological data analysis. Ecology 81(11):3178-3192.

Elmhagen B, Eriksson O, Lindborg R (2015) Implications of climate and land-use change for landscape processes, biodiversity, ecosystem services, and governance. AMBIO 44: S1-S5.

Fan M, Shibata H, Wang Q (2016) Optimal conservation planning of multiple hydrological ecosystem services under land use and climate changes in Teshio river watershed, northernmost of Japan. Ecological Indicators 62:1-13.

Felipe-Lucia MR, Comín FA, Bennett EM (2014) Interactions among ecosystem services across land uses in a floodplain agroecosystem. Ecology and Society 19(1):20.

Ferraro DO, Rivero DE, Ghersa CM (2009) An analysis of the factors that influence sugarcane yield in Northern Argentina using classification and regression trees. Field Crops Research 112:149-157.

Ferraro DO, Ghersa CM, Rivero DE (2012) Weed vegetation of sugarcane cropping systems of Northern Argentina: Data-mining methods for assessing the environmental and management effects on species composition. Weed Science 60:27-33.

Fisher B, Turner RK (2008) Ecosystem services: classification for valuation. Biological Conservation 141:1167-1169.

Foley JA, Defries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309(5734):570-574.

Gaba S, Lescourret F, Boudsocq S, Enjalbert J, Hinsinger P, Journet E-P, Navas M-L, Wery J, Louarn G, Malézieux E, Pelzer E, Prudent M, Ozier-Lafontaine H (2015) Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. Agronomy for Sustainable Development 35:607-623.

Gordon LJ, Finlayson CM, Falkenmark M (2010) Managing water in agriculture for food production and other ecosystem services. Agricultural Water Management 97:512-519.

Hall AJ, Rebella CM, Ghersa CM, Culot JR (1992) Field-crop systems of the Pampas. In: Pearsons CJ (Ed.) Ecosystems of the World series. Elsevier Editorial. Amsterdam, The Netherlands. Pp. 413-450.

Hammer GL, Hansen JW, Phillips JG, Mjelde JW, Hill H, Love A, Potgieter A (2001) Advances in application of climate prediction in agriculture. Agricultural Systems 70:515-553.

Harrison PA, Vandewalle M, Sykes MT, Berry PM, Bugter R, de Bello F, Feld CK, Grandin U, Harrington R, Haslett JR, Jongman RHG, Luck GW, da Silva PM, Moora M, Settele J, Sousa JP, Zobel M (2010) Identifying and prioritizing services in

European terrestrial and freshwater ecosystems. Biodiversity and Conservation 19:2791-2821.

Howden SM, Soussana JF, Tubiello FN, Chhetri N, Dunlop M, Meinke H (2007) Adapting agriculture to climate change. Proceedings of the National Academy of Sciences 104(50):19691-19696.

Jain AK, Dubes RC (1988) Algorithms for clustering data. Prentice-Hall Editorial. New Jersey, USA. Pp. 320.

Jiang C, Li D, Wang D, Zhang L (2016) Quantification and assessment of changes in ecosystem service in the Three-River Headwaters Region, China as a result of climate variability and land cover change. Ecological Indicators 66:199-211.

Koschke L, Fürst C, Lorenz M, Witt A, Frank S, Makeschin F (2013) The integration of crop rotation and tillage practices in the assessment of ecosystem services provision at the regional scale. Ecological Indicators 32:157-171.

Laterra P, Barral P, Carmona A, Nahuelhual L (2015) ECOSER. Protocolo colaborativo de evaluación y mapeo de servicios ecosistémicos y vulnerabilidad socio-ecológica para el ordenamiento territorial. Documento Introductorio. Versión 2.0. Colección Investigación, Desarrollo e Innovación No. 99. Ediciones INTA. Santa Rosa, La Pampa, Argentina. Pp. 56.

Lawes RA, Lawn RJ (2005) Application of industry information in sugarcane production systems. Field Crops Research 92:353-363.

Lawler JJ, Lewis DJ, Nelson E, Plantinga AJ, Polasky S, Withey JC, Helmers DP, Martinuzzi S, Pennington D, Radeloff VC (2014) Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences 111(20): 7492-7497.

Lazzaro M, Costanzo A, Bàrberi p (2017) Single vs multiple agroecosystem services provided by common wheat cultivar mixtures: Weed suppression, grain yield and quality. Field Crops Research, https://doi.org/10.1016/j.fcr.2017.10.006.

López Puga J, García García J, de la Fuente Sánchez L, Inmaculada de la Fuente Solana E (2007) Las redes bayesianas como herramientas de modelado en psicología. Anales de Psicología 23:307-316.

Lorencová E, Frelichová J, Nelson E, Vackár D (2013) Past and future impacts of land use and climate change on agricultural ecosystem services in the Czech Republic. Land Use Policy 33:183-194.

MEA (2005) Millenium Ecosystem Assessment. Ecosystems and human well-being: Synthesis. Island Press. Washington DC, USA. Pp. 155.

Mouchet MA, Lamarque P, Martín-López B, Crouzat E, Gos P, Byczek C, Lavorel S (2014) An interdisciplinary methodological guide for quantifying associations between ecosystem services. Global Environmental Change 28:298-308.

Muñoz-Rojas M, De la Rosa D, Zavala LM, Jordán A, Anaya-Romero M (2011) Changes in land cover and vegetation carbon stocks in Andalusia, Southern Spain (1956-2007). Science of the Total Environment 409:2796-2806.

Orúe ME, Laterra P, Cabria F (2007) Expansión de la frontera agrícola en Argentina y erosión hídrica: mapas de riesgo utilizando el modelo USLE con apoyo de SIG. XII Congreso de Asociación Española de Teledetección. Hacia un mejor entendimiento de la dinámica global y regional, 185-192. ISBN: 978-987-543-126-3. Mar del Plata, 19-21 de septiembre.

Palm C, Blanco-Canqui H, DeClerck F, Gatere L, Grace P (2014) Conservation agriculture and ecosystem services: An overview. Agriculture, Ecosystems & Environment 187:87-105.

Panigatti JL, Cruzate G, Tasi H, Bedendo D (2008) Suelos y ambientes de Entre Ríos. Ediciones INTA. Entre Ríos, Argentina.

Paruelo JM, Guerschman JP, Verón SR (2006) Expansión agrícola y cambios en el uso del suelo. Ciencia Hoy 15(87):14-23.

Pengue W (2001) Impacto de la expansión de la soja en la Argentina. Globalización, desarrollo agropecuario e ingeniería genética: Un modelo para armar. Biodiversidad – Sustento y Culturas Nº 29.

Pinto P, Fernández Long ME, Piñeiro G (2017) Including cover crops during fallow periods for increasing ecosystem services: Is it possible in croplands of Southern South America? Agriculture, Ecosystems and Environment 248:48-57.

Piñeiro G, Pinto P, Arana S, Sawchik J, Díaz JI, Gutiérrez F, Zarza R (2014) Cultivos de servicio: integrando la ecología con la producción agrícola. In: XXVI Reunión Argentina De Ecología. Comodoro Rivadavia, Chubut, Argentina.

Power AG (2010) Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society 365:2959-2971.

Queiroz C, Meacham M, Richter K, Norstrom AV, Andersson E, Norberg J, Peterson G (2015) Mapping bundles of ecosystem services reveals distinct types of multifunctionality within a Swedish landscape. AMBIO 44:89-101.

Roel A, Firpo H, Plant RE (2007) Why do some farmers get higher yields? Multivariate analysis of a group of Uruguayan rice farmers. Computations & Electronics in Agriculture 58:78-92.

Rositano F, Ferraro DO (2014) Ecosystem services provided by agroecosystems: A qualitative and quantitative assessment of this relationship in the Pampa region, Argentina. Environmental Management 53(3):606-619.

Rositano F, Piñeiro G, Bert F, Ferraro DO (2017) A comparison of two sensitivity analysis techniques based on four bayesian models representing ecosystem services provision in the Argentine Pampas. Ecological Informatics 41:33-39.

Satorre EH (2005) Cambios tecnológicos en la agricultura argentina actual. Ciencia Hoy 15:24-31.

Schipanski ME, Barbercheck M, Douglas M, Finney DM, Haider K, Kaye JP, Kemanian AR, Mortensen DA, Ryan MR, Tooker J, White C (2014) A framework for evaluating ecosystem services provided by cover crops in agroecosystems. Agricultural Systems 125:12-22.

Tittonell P (2014) Ecological intensification of agriculture—sustainable by nature. Current Opinion in Environmental Sustainability 8:53–61.

Soriano A, León RJC, Sala OE, Lavado RS, Deregibus VA, Cahuepé MA, Scaglia OA, Velázquez CA, Lemcoff JH (1991) Temperate subhumid grasslands of South America in Natural grasslands. In: Coupland RT (Ed.) Ecosystems of the World, Vol. 8. Elsevier Editorial. Amsterdam, The Netherlands. Pp. 367-407.

StatSoft, Inc. (2008) STATISTICA (data analysis software system). Version 8.0. www.statsoft.com

Steinberg D, Colla P (1995) CART: Tree-structured non-parametric data analysis. Salford Systems. San Diego, CA, USA.

Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S (2002) Agricultural sustainability and intensive production practices. Nature 418:671-677.

Viglizzo EF, Frank FC (2006) Land use options for Del Plata basin in South America: Tradeoffs analysis based on ecosystem service provision. Ecological Economics 57:140-151.

Research Highlights

1. Ecosystem services provision varies with different ecological variables.
2. Environmental and management variables may influence ecosystem services provision.
3. Data-mining techniques were used to identify these variables in the Pampa region.
4. We assessed four ecosystem services in three study sites during a 10-year-period.
5. Provision of these ecosystem services varied by changing land use and crop season.