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Industrial agriculture and agroecological transition systems: A comparative analysis of productivity results, organic matter and glyphosate in soil

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ABSTRACT

The system of industrial agriculture (IA), often implemented on a large scale and with high dependence on the supplies use, is reducing the soil organic matter (SOM) and increasing the glyphosate presence in the environment. An alternative approach to IA is agroecologywhich takes greater advantage of natural processes and beneficial on-farm interactions in order to reduce off-farm input use and to improve the efficiency of farming systems. In this study, a transition agroecological system (AT) is the alternative of the IA. Our objectives were: (i) to compare the agronomic productivity between AT and IA systems, (ii) to determine the effect of management practices on soil quality indicators such as soil organic matter content (SOM), soil bulk density, change in the weighted mean diameter (CMWD) and glyphosate and aminomethyl phosphonic acid (AMPA) concentration and (iii) to compare the economic results through a multi-temporal economic analysis between AT and IA systems. The soil sampling was carried out per soil-specific zones, delimited from apparent soil electrical conductivity (ECa) and elevation. Samples were taken at 0 to 2, 2 to 5, 5 to 10, 10 to 20, 20 to 30 and 30 to 40 cm of depth to determine the SOM content, the glyphosate concentration and main glyphosate metabolite, AMPA. Besides, the bulk density (δ_a) and CWMD were determined. The δ_a was lower in AT with respect to IA, both under no tillage (NT). No significant differences were found for CWMD between AT and IA systems, although a tendency to a lower value in AT system was observed. If we consider the percentage of organic matter as carbon matter per hectare, this means that in 6.5 years increase 540 kg ha^{-1} at 0 to 40 cm depth. The SOM content increased from 4,9 to 5,6% in AT with respect to IA. The content of glyphosate + AMPA at the first 40 cm was 0.06 kg ha^{-1} in the AT and 0.84 kg ha^{-1} in the IA system. In the AT system, the gross margin accumulated during 6.5 years, increased 244% with respect to IA. These results suggest that the AT system proposed could be applicable in extensive productions with temperate climates without interfering with the livelihood of the agricultural producers and it allows an improvement in soil conditions. It is important to carry out further studies in order to confirm the benefits of the AT system in other edaphic-climatic conditions, integrating productive, economic and environmental aspects.

1. Introduction

Society needs to assure stability in the availability, accessibility and healthy food at a regional and global scale (Bommarco et al., 2018). However, conventional agro productive systems are not solving that, because they are generating a considerable environmental pollution (Dumont and Baret, 2017; Francis et al., 2003; Gliessman, 2005, 2014). This, added to climate extreme events, population growth, policies disputes, social inequity, poor governance, the functioning of the global trade system, biofuels production, financial speculation and poverty, are threatened the global food security for next decades (Bommarco et al., 2018; Stephens et al., 2018).

The Argentine Pampas and South America in general are one of the most important agricultural zones of the world (Choumert and Phélinas, 2015; FAOSTAT, 2015; Ferraro and Benzi, 2015). In these zones, conventional system of industrial agriculture (IA) have been predominant since 90´s, contributing to generate an environmental degradation focuses on: i.- Increasing soil degradation rate which manifests itself mainly in structure loss and compaction (Costa et al., 2015; Aparicio and Costa, 2007; Fabrizzi et al., 2003; Ferreras et al.,

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2000) and a reduction in the content of organic carbon (Domínguez et al., 2010). Soils play an important role in global climate processes through the regulation of emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). According to a technical report from the "World Soil Resource State "(FAO, 2015), on a global scale, soils are the largest terrestrial reservoir of carbon and therefore have a greater influence on the concentration of carbon dioxide (CO_2) in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) estimated the accumulated soil organic carbon (SOC) in the first meter of the soil at 1.502 billion tons. Current global estimates derived from the Harmonized Soil Database of the World () suggest that approximately 1.417 billion tons of SOC are stored in the first meter of soil and about 716 billion tons of SOC in the 30 cm superiors. Globally the primary driver of SOC loss is the change in territory use. A meta-analysis conducted in 2014 and based on 119 publications showed that storage of SOC was reduced by 98% of places with an average of 52% in temperate regions (Argentina is a country with temperate regions). The global loss of SOC stored since 1850 is estimated at around 66 ± 12 billion tons. This decrease in soil organic carbon (SOC) contributes to the increase of CO_2 in the atmosphere. Carbon (C) accumulates in the atmosphere at a rate of 3,5 µg C year-1 (Pg = 1015 g), while phytocenosis stores C at approximately 550 Pg (Houghton et al., 2007); ii.- Excessive use of agrochemical, mainly glyphosate (Aparicio et al., 2013; Peruzzo et al., 2008; Primost et al., 2017; Rampoldi et al., 2011; Soracco et al., 2018; Castro Berman et al., 2018). The main metabolic pathway of glyphosate is its microbial degradation to aminomethylphosphonic acid (AMPA), which is more persistent in soils than glyphosate (Bento et al., 2016). The World Health Organization concluded that there is evidence to classify glyphosate as 'probably carcinogenic to humans' (Group 2A; WHO, 2015), and the experts on pesticide residues in food and the environment at a meeting of the FAO concluded that glyphosate together with AMPA should be considered as residues toxicological interest. For the purpose of estimating the dietary intake and to allow comparison of the calculated intakes with Acceptable Daily Intake it is preferable to express the residues in terms of glyphosate (glyphosate = 1.5 × AMPA; FAO report, 2005); iii.- Increasing pesticides and nutrients concentration on water (Etchegoyen et al., 2017; Ronco et al., 2016; Lupi et al., 2015; De Gerónimo et al., 2014; Peruzzo et al., 2008) and iv.- Displacement of rural community to urban/periurban areas (Fernández and de los Ríos Carmenado, 2010; Phélinas and Choumert, 2017).

In the next decades, if this IA system is consolidated, ecosystem services would be irreversible damaged (Phélinas and Choumert, 2017). Also, a key factor which has determined the expansion of the IA system is the lack of alternative systems which reduce the environmental impact being socially just and economically viable (Gliessman, 2014). In this context, it would be necessary to design and validate alternative agro productive systems which mitigate harmful effects of IA systems (Altieri, 2018; Bonaudo et al., 2014; Francis et al., 2003; Gliessman, 2014).

In this study, a transition agroecological system (AT) as alternative of the IA conventional system predominant. This AT system is based on: (i) to generate and validate agroecological management practices and (ii) to generate and/or validate productive, environmental and economics metrics which monitor the impact of these practices, at field scale.

Agroecology takes greater advantage of natural processes and beneficial on-farm interactions in order to reduce off-farm input use and to improve the efficiency of farming systems (Altieri, 2018; Reijntjes et al., 1992). Technologies emphasized tend to enhance the functional biodiversity of agroecosystems as well as the conservation of existing on-farm resources. Promoted technologies such as cover crops, green manures, intercropping, agroforestry and crop–livestock mixtures, and pest integrate management and nutrient balance (Altieri, 2002; Altieri, 2018; Bonaudo et al., 2014; Steenwerth and Belina, 2008). It has been widely reported that these agroecological practices not only mitigate environmental degradation caused by AI system, but also contribute to economic and social viability of agro productive systems (Gliessman, 2014).

The aim of this study was to evaluate quantitatively an alternative agroecological system using productive, environmental and economic variables. The objectives were: (i) to compare the agronomic productivity between AT and IA systems, (ii) to determine the effect of management practices on soil quality indicators such as soil organic matter content (SOM), soil bulk density, change in the weighted mean diameter (CMWD) and glyphosate and AMPA concentration and (iii) to compare the economic results through a multi-temporal economic analysis between AT and IA systems. These results would imply a clear understanding of an alternative agroecological system, which benefits can be quantified to be implemented by farmers, scientists and technicians.

2. Materials and methods

2.1. Experimental site

The experimental site was a 16 ha agricultural field located in the southeastern Pampas of Argentina (38°19′S, 60°15′W, Datum WGS84) (Fig. 1). This experimental site was selected because it represents the landscape position and spatial variability of soil depth usually found in the southeastern Pampas of Argentina. The soils are classified as Subgroups Typic Argiudoll and Petrocalcic Argiudoll; Family fine, illitic, thermic (Domenech et al., 2017; Soil Survey Staff, 2014). In the experimental field, the mean annual temperature is 14.8 °C and has a frost-free period that extends from October to March. It has a humid and subhumid hydric regime (Thornthwaite, 1948). The mean annual precipitation is about 756 mm. The lowest rains are recorded between June and August; while the heaviest rains occur between October and March (Costa et al., 2015).

2.2. Cropping management systems

In January 2011, the experimental field was divided into two plots of eight (8) hectares each. In one of them, the IA system was followed while in the other one, an extensive agroecological crop system (AT) was started, integrating agriculture and cattle breeding, focusing on biodiversity, the equilibrium and nutrients cycling and the progressive reduction in the use of pesticides.

Crops rotation and sequence, in the case of IA, corresponds to a typical sequence for Tres Arroyos area, while in the AT agroecology principles were used, in agreement with an interdisciplinary team of professionals, increasing the number of species per year (Table 1). The management of each plot allows us to see the contribution of external supplies in each system: IA and AT (Table 2).

2.3. Delimitation of soil-specific zones

Apparent soil electrical conductivity (ECa) and elevation were used as auxiliary information to delimitate soil-specific zones within the experimental site (Fig. 1).

ECa measurements were collected on September 9th, 2016 using a Veris® 3100 soil electrical conductivity sensor (Veris Technologies Inc., Salina, KS, USA). With this sensor, the system records ECa in mS m^{-1} by electrical resistivity at a shallow depth (0 to 30 cm, ECa 0-30 cm) and deep depth (0 to 90, ECa 0-90 cm) (Castro Franco et al., 2015). ECa measurements were made along parallel transects approximately 20 m apart on the surface of the experimental site. Latitude, longitude, ECa 0-30 cm and ECa 0-90 cm data were recorded in an ASCII text file and transferred to GIS software.

Elevation was measured simultaneously with ECa, using an advance differential GPS Surveying instrument GPS Trimble®R3 (Trimble Navigation Limited, CA, USA). Elevation data were post-processed with

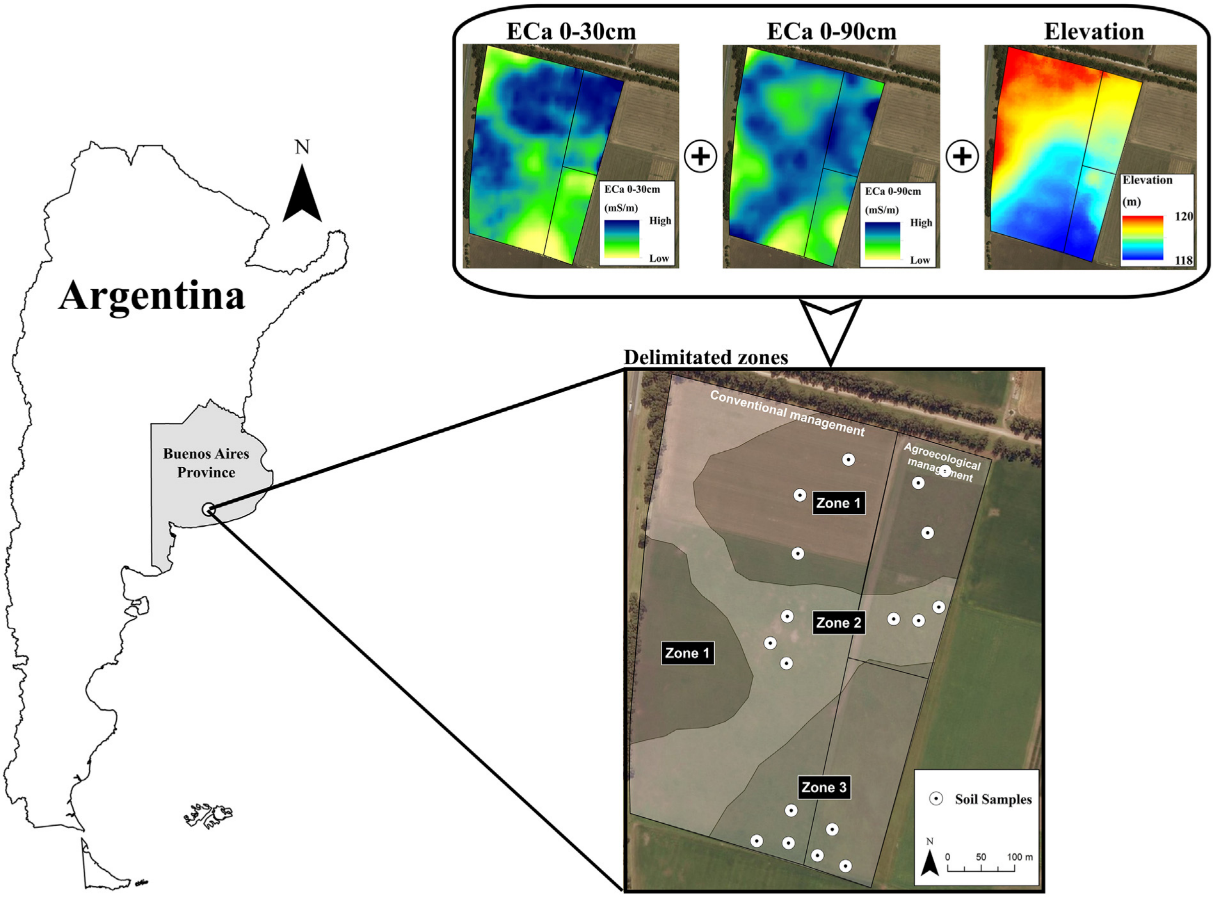

Fig. 1. Location of experimental site and spatial distribution of soil-specific zones delimited within experimental site based on apparent soil electrical conductivity (ECa) at two depths (0 to 30, ECa 0-30 cm; and 0 to 90, ECa 0–90 cm) and elevation measurements.

Trimble Business Centre Software V3.5. Processed elevation data were recorded in an ASCII text file and transferred to GIS Software.

Experimental variograms to describe the spatial variability of ECa and Elevation were computed following the procedure proposed by Diggle and Ribeiro (2007). The adjusted experimental variogram was used to interpolate ECa and elevation by ordinary kriging. The Geostatistical Analyst Module of ArcGIS Desktop V10.3 (ESRI, Redlands, CA, USA) (ESRI, 2015) was used to conduct the geostatistical interpolation.

The couple of fuzzy K-means clustering and spatial principal component analysis (KM-sPCA) was implemented as a technique to delimitate soil-specific zones within the experimental site. This couple consists of a spatial multivariate clustering algorithm which has been demonstrated to be efficient to delineate soil homogenous zones at field scale using auxiliary information derived from precision agriculture technologies (Castro-Franco et al., 2018). The fully description of the couple KM-sPCA algorithms used in this study, can be consulted in Córdoba et al. (2013). The sources of auxiliary information were ECa and elevation. To determine the number of soil-specific zones within the experimental site, two indexes were used: (i) fuzziness performance index (FPI) and (ii) normalized classification entropy (NCE) (Odeh et al., 1992). The selected number of soil-specific zones was determined when both FPI and NCE reached a minimum, which represents a lower level of overlap (FPI) or a higher level organization among clusters (NCE) (Castro-Franco et al., 2018). The KM-sPCA algorithm was run using the Spatial Statistical module of InfoStat v2016 (Di Rienzo et al., 2017).

A total of three soil-specific zones within the experimental site were identified from the KM-sPCA (Fig. 1). The soil-specific zones 1 and 3 belong to a cartography unit with two main series: Tres Arroyos (Petrocalcic Paleudoll, thin, illitic, moderately shallow thermal) and Laprida (Typic argiudoll, mixed, thermal) and a secondary series: Pillahuinco (Petrocalcic Paleudoll, thin, illitic, shallow, thermal). On the other hand, the soil-specific zone 2 corresponds to a cartography unit with two main series: Tres Arroyos and El Vigilante, and two secondary series: Lobería (Acuic argiudoll, thin, illitic, thermal and Gonzales Chaves (Natracuoll lithic, thin, illitic, thermal) (INTA, 2010).

2.4. Soil sampling scheme

A stratified sampling scheme was used to establish the locations of the soil sample sites (Corwin et al., 2006). Three geo-referenced soil sample sites were selected according to each soil-specific zone and each management zone, in a total of 18 soil sample sites across the experimental site. The selection of sample sites was made in distinctive areas within each soil-specific zone, with the aim to provide a representative coverage of the experimental site. The soil samples were collected on September 13, 2016.

In each sampling area it was determined:

1) The samples of apparent density were extracted with an Eijkelkamp sampler, whose cylinders have a height of 5 cm. To explore the first 20 cm of soil, it is necessary to make two extractions (3 to 8 and 13 to 18 cm). This samplerhas been widely used in other scientific works (Aparicio and Costa, 2007; Costa et al., 2015), accepting it as an appropriate equipment to perform this determination.;
2) Change in mean weight diameter (CMWD) was measured by the De Leenheer and De Boodt (1959) method. The De Leenheer and De Boodt instability index was determined as the measured area between the two curves corresponding to the aggregate size distributions found before and after wet sieving water-moistened aggregates

Table 1
Description of crops, machinery, labors, products and doses by month for both systems AT and IA from 2011 to 2016.

Year	Month	Agroecological Transition				Industrial Agriculture			
		Crop	Labour	Product	Amount (L or kg ha^{-1})	Crop	Labour	Product	Amount (L or kg ha^{-1})
2011	March	Oat + Vicia	Sowing	Oat seed	72	Oat	Pulverization	Glyphosate	2
				Vicia seed	48		Sowing	Oat seed	72
			Inoculation	Inoculant	0.5			Vicia seed	20
			Fertilization	Diamonic phosphate	100		Inoculation	Inoculant	0.5
							Fertilization	Diamonic phosphate	60
	April						Fertilization	Urea	100
	October		Tillage	RoloFaca	1		Pulverization	Glyphosate	2
	November	Sorghum + Soybean	Sowing	Soybean seed	40	Soybean	Sowing	Soybean seed	80
				Sorghum seed	5		Inoculation	Inoculant	0.5
			Fertilization	Diamonic phosphate	100		Fertilization	Diamonic phosphate	60
2012	January						Pulverization	Glyphosate	2.5
	April		Desmalezado	Desmalezadora			Harvest		
	June		Pulverization	Glyphosate	1		Pulverization	Glyphosate	2.5
	July	Wheat + Clover	Sowing	Wheat seed	130	Wheat	Sowing	Wheat seed + CuraSeed	130
				Clover seed	2		Fertilization	Diamonic phosphate	90
			Inoculation	Inoculant	0.5				
			Fertilization	Diamonic phosphate	100				
	September		Pulverization	MCPA	0.8		Pulverization	Pinoxaden + Cloquintocet	0.5
				Dicamba	0.08			Metsulfuron	0.005
	December		Harvest		1		Harvest		1
2013	March	Oat + Vicia	Sowing	Oat seed	50	Oat + Vicia	Pulverization	Glyphosate	2
				Vicia seed	50		Sowing	Oat seed	60
			Fertilization	Diamonic phosphate	100			Vicia seed	30
							Fertilization	Diamonic phosphate	60
	April						Fertilization	Urea	18.4
							Pulverization	Metsulfuron	0.006
	October		Suplemento animal	Afrechillo	1000		Corte e hilerado		1
							Picadora		1
							Embolsado		1
	November	Sorghum	Sowing	Sorghum seed	4	Soybean	Pulverization	Glyphosate	2.5
							Sowing	Soybean seed	80
2014	May		Rastra de discos		2		Pulverization	Glyphosate	2.5
								Picloram	0.2
	July	Wheat + Clover	Sowing	Wheat seed	140	Wheat	Pulverization	Glyphosate	2.5
				Clover seed	2		Sowing	Wheat seed + curaSeed	160
							Fertilization	Diamonic phosphate	70
	August		Pulverization	Bromoxinil	0.7		Pulverization	Pinoxaden + Cloquintocet	0.5
	September						Pulverization	2.4-D	0.6
								Dicamba	0.1
								Metsulfuron	0.0004
							Fertilization	Urea	150
	December		Harvest		1		Harvest		1
2015	March	Oat + Vicia	Sowing	Oat seed	50	Oat	Pulverization	Glyphosate	2
				Vicia seed	50		Sowing	Oat seed	70
							Fertilization	Diamonic phosphate	70
	April						Pulverization	Metsulfuron	0.006
							Fertilization	Urea	40
	October		Suplemento animal	Afrechillo	300		Pulverization	Glyphosate	2.5
	November	Sorghum/Corn + Vicia	Sowing	Sorghum seed/Corn seed	10	Soybean	Sowing	Soybean seed	80
				Vicia seed	10		Fertilization	Diamonic phosphate	40
	December						Pulverization		1
							Herbicide	Glyphosate	2

(*continued on next page*)

Table 1 (*continued*)

Year	Month	Agroecological Transition				Industrial Agriculture			
		Crop	Labour	Product	Amount (L or kg ha^{-1})	Crop	Labour	Product	Amount (L or kg ha^{-1})
2016	January						Pulverization	Clorpirifos	1
	April		Suplemento animal	Afrechillo	300		Harvest		1
							Pulverization	Glyphosate	2.5
								Picloram	0.2
	May		Tillage	Rastra de discos					
	July	Wheat + Clover	Tillage	Rastra de discos		Wheat	Pulverization	Glyphosate	2.5
			Sowing	Wheat seed	120		Sowing	Wheat seed + curaSeed	150
				Clover seed	3		Fertilization	Diamonic phosphate	90
			Inoculation	Inoculant	1				
	August						Pulverization	Pinoxaden + Cloquintocet	0.5
	September						Pulverization	2.4-D	0.6
								Dicamba	0.1
								Metsulfuron	0.0004
							Fertilization	Urea	200
	December		Harvest				Harvest		

Table 2
Yield comparison, according to product obtained, between AT and IA systems from 2011 to 2016.

Growing season	Cropping system	Type of product	Yield (kg ha^{-1} (S.E.))
	Agroecology transition		
2011	Oat-Vicia	Beef	147
2011/12	Sorghum + Soybean	Beef	163
2012	Wheat + Clover	Grain	2900 (± 193)
2013	Oat-Vicia	Beef	305
2013/14	Sorghum	Beef	94
2014	Wheat + Clover	Grain	3800 (± 221.2)
2015	Oat-Vicia	Beef	305
2015/16	Sorghum/Corn + Vicia	Beef	171
2016	Wheat + Clover	Grain	2400 (± 344)
	Industrial agriculture		
2011	Oat	Beef	100
2011/12	Soybean	Grain	1200 (± 131.8)
2012	Wheat	Grain	3600 (± 66.1)
2013	Oat	Beef	467
2013/14	Soybean	Grain	0[a]
2014	Wheat	Grain	3800 (± 123.0)
2015	Oat	Beef	227
2015/16	Soybean	Grain	2200 (± 72.8)
2016	Wheat	Grain	2000 (± 132.5)

Beef calculation: by weigth different of cow after grazing (Final weight − Initial weigth).
E.E.: Estandar error.
[a] Soybean did not germination due to water limitation.

with diameters between 2 and 8 mm. The authors determined the index graphically, but it is numerically equivalent to CMWD between the dry aggregate distribution and the water stable aggregate size distribution. The larger the value of CMWD, the more unstable the aggregates (Díaz-Zorita et al., 2002).

A total of three disturbed subsamples from each plot were dry and wet sieved, obtaining the CMWD. The samples for CMWD were collected at a depth of 0 to 20 cm with shovel. Similar procedure of sample extraction was reported in Aparicio and Costa (2007) and Costa et al. (2015);

iii.- The total SOC concentrations were determined with Leco CNS analyser® (Leco, St.Joseph, MI, USA) (Nelson and Sommers, 1996), glyphosate and AMPA by means of ultra high performance chromatography coupled with a tandem mass spectrometer (UHPLCMS/MS) (Waters Inc., Milford, MA, USA). Soil samples to determine SOC, glyphosate and AMPA were obtained at a depth of 0–40 cm in each sampling point and were fragmented in the following way: 0 to 2; 2 to 5; 5 to 10; 10 to 20 and 20 to 40 cm. The fragmented samples were dried at 30 °C with air forced circulation and grounded in a ball mill during 5 min. The SOC was expressed as soil organic matter (SOM):

$$SOM = SOC * 1.72$$

All soil analyses were conducted in the laboratory of the National Institute of Agricultural Technology, Balcarce Experimental Station, Argentina.

2.5. *Analytical determination of glyphosate and aminomethyl phosphonic acid (AMPA)*

The extraction and quantification of glyphosate and AMPA was determinate by means of ultra-high performance chromatography coupled with a tandem mass spectrometer (UHPLCMS/MS) (Waters Inc., Milford, MA, USA). This procedure was carried out as follows: 5 g of soil sample were enriched with isotopically labeled glyphosate (1.2-13C,15 N, Sigma- Aldrich) and were left 30 min to stabilize. Then, 25 ml of extraction solution were added to the samples (100 mM Na2B4O7 · 10H$_2$O/ 100 mM K3PO4, pH = 9) and they were placed in an ultrasound bath during 30 min. The samples were centrifugated for 10 min to separate phases. A 2 ml aliquot was derivatized in the liquid phase with 2 ml of FMOC-CL (1 mg ml^{-1} in ACN), letting it incubate under dark conditions at night. Then, 4.5 ml of CH3Cl2, were added to the samples, shaking them vigorously to eliminate FMOC excess, organic pollutants and minimize the effects of the matrix. The aqueous fraction separated from the organic solvent after centrifugation for 0 min. The supernatant was collected and filtered through a 0.22 µm nylon filter. In parallel, a standard curve with glyphosate and AMPA was performed (PESTANAL®, 99.9%) (PESTANAL®, 99%). Each dot on this curve was fortified with an amount of labeled glyphosate equivalent to the ones added to the soil samples to evaluate the total analytic efficiency of the method. The limits of quantification (LQ) and the limits of detection (LD) were calculated from the fortified samples chromatograms to the lowest tested level, being LQ of 0.8 µg kg^{-1} for the glyphosate and of 1.4 µg kg^{-1} for AMPA, while LD was of 0.3 µg kg^{-1} and 0.4 µg kg^{-1} for glyphosate and AMPA, respectively.

The analysis of the extracts obtained was carried out by an ultra-performance liquid chromatograph (Waters, ACQUITY UPLC®) with an ACQUITY UPLC®BEH C18 1.7 µm 2.1 × 50 mm column, coupled with Triple Quadrupole mass spectrometer (Quattro Premier® XE–MS/MS) with electrospray ionization source (ESI) of *Z*-spray design. For the chromatographic separation a methanol and water gradient was used, both with 5 mM of ammonium acetate added, at a flow rate of

0.400 ml min^{-1}. For the tandem mass spectroscopy, a positive mode ionization was performed (ESI + :3.0 kV). High purity nitrogen was used as the nebulizing and drying gas and Argon was used as the collision gas. For each molecule three mass transmissions were selected, using the most intense one for quantification and the two remaining ones, for confirmation. Masslyn x 4.1 software and its Targetlynx package were used for data analysis. Glyphosate and AMPA data are presented by adding their concentrations. This addition is done taking into account that, AMPA has a molecular weight of 111.04 g. and glyphosate has a molecular weight of 169.07 g, AMPA residues were calculated multiplied by a factor of 1.52 to generate a glyphosate equivalent:

$$\text{Glyphosate} + \text{AMPA} = \text{Glyphosate acid} + (\text{AMPA} * 1.52)$$

The differences in SOM and soil glyphosate concentration + AMPA were compared among the soil-specific zones, using a lineal mix model of PROC MIXED (SAS Institute, Inc.2002). The soil-specific zones, were considered as fixed effects, plots as random effects and sampling points within each soil-specific zone as random subsamples. The comparisons of the mean of the soil property were evaluated according to a level of significance of 0.05 using LSMEANS. Each soil-specific zone was considered as a classifying factor in a design of complete blocks at random within each plot.

3. Results and discussion

3.1. Temporal rainfall distribution

Fig. 2 shows a comparison between inter and intra-month rainfall means distribution from 2011 to 2016 agricultural cycles. During 2000–2011, rainfall pattern had high variability in October, November, December, February and March. That period plays a key role for yield definition of winter and summer crops. In the study area, this is important because soils are classified as Petrocalcic argiudolls defined by low holding water capacity due to the presence of a petrocalcic horizon (Sadras and Calviño, 2001).

During 2011 to 2016, when agroecology transition was established, several drought events occurred, for example in the second-semester 2011, 2013 and 2015 and in the first-semester 2016. These events were characterized by having at least two consecutive months with lower rainfall than mean historical records for 2000–2011. It could be highlighted that the drought in 2013 was so severe than soybean did not emergence. On the contrary, in 2014 rainfalls were extremely high. The rest of the periods had rainfall among normal mean range.

3.2. Soil properties and glyphosate concentration

The production system had a statistically significant effect on δ_a (Fig. 3). The δ_a was lower in AT with respect to IA, both under NT, although in AT a disk harrow was performed (Table 1). Even though in the South East of Buenos Aires increases of δ_a under NT have been confirmed (Alvarez and Steinbach, 2009; Aparicio and Costa, 2007; Costa et al., 2015; Taher et al., 2013), in this work we have observed a decrease of δ_a in AT probably due to the development of a diverse root mass (grasses and legumes), vegetal residue inputs, animal feces, and of course, the superficial tillage, that allowed to increase soil porosity.

Statistically, there were no significant differences for CWMD between AT and IA systems, although a tendency to a lower value in AT was observed (Fig. 3). The CWMD diminishes with the NT incorporation, related to no removal of soil which prevents the soil from remaining exposed to the impact of the raindrop. Besides, the grasses crops (wheat and corn) leave a big amount of stubble on the soil surface after the harvest. The absence of tillage and the accumulation of plant residues in the soils under NT management have contributed to decrease the CWMD. In Mollisols with loamy-clayed and muddy texture a recovery of CWMD was observed after implementing the NT system for 11 years (Micucci and Taboada, 2006). In the Southeast of Buenos Aires, in comparative tests of farming systems it was observed that, although CWMD was lower under NT than with vertical and conventional farming, an increase of this parameter in all systems of soil management tested is produced over the years (Costa et al., 2015). The CWMD represents 36% of the variability in the number of years under continuous agriculture, thus becoming the only physical parameter related to the years of continuous agriculture (Aparicio and Costa, 2007). In this work, the tendency shows an improvement in the soil structure, possibly due to the presence of more roots of different species, vegetal material inputs, application of animal feces, when carrying out both managements under NT system (only one disk was used in AT). Possibly, some more years would be necessary to confirm statistically significant difference for this tendency.

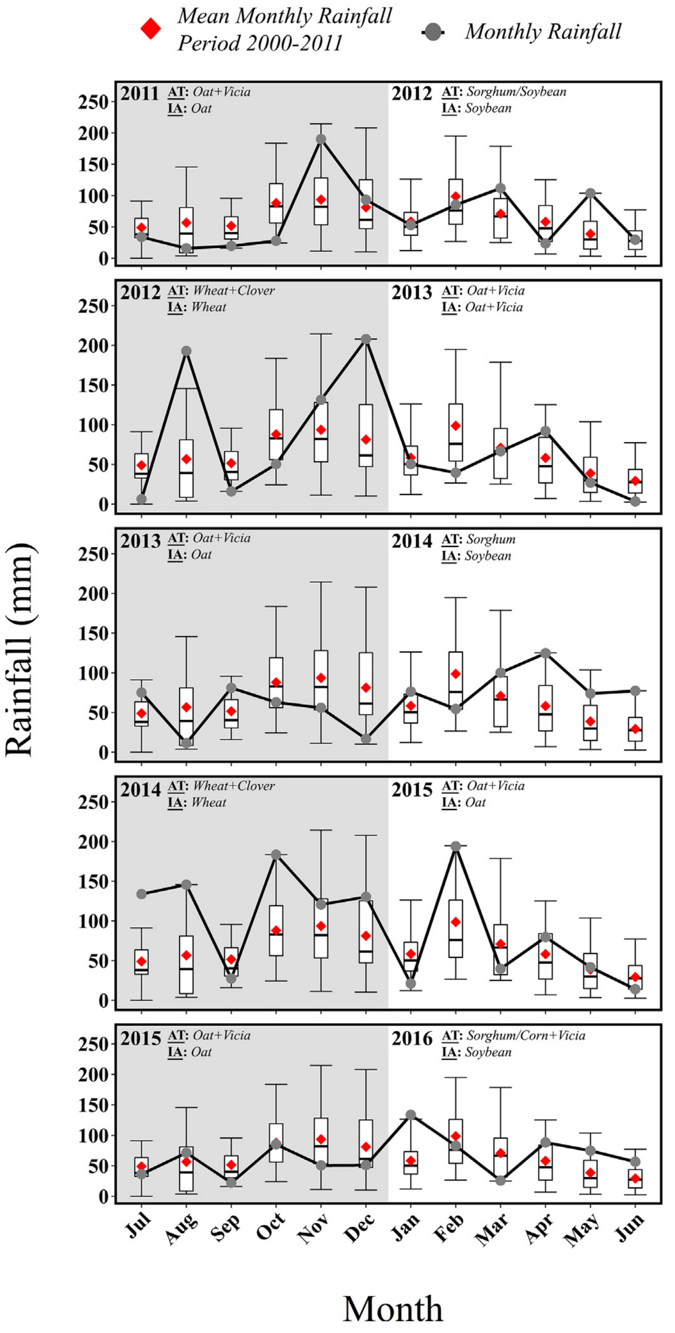

Fig. 2. Comparison between inter and intra mean monthly rainfall distribution in the experimental site from 2011 to 2016.

There were statistically significant differences in SOM content in

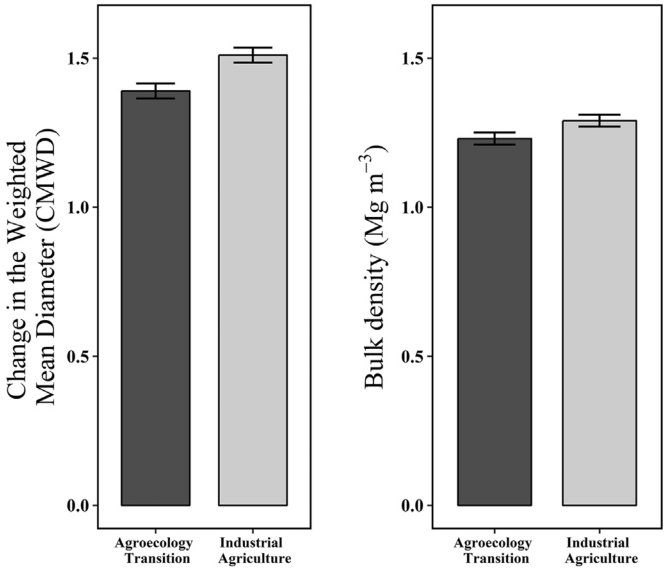

Fig. 3. Comparison of means of change in the weighted mean diameter (CMWD) and bulk density between agro ecological transition (AT) and agriculture industrialized (IA) systems.

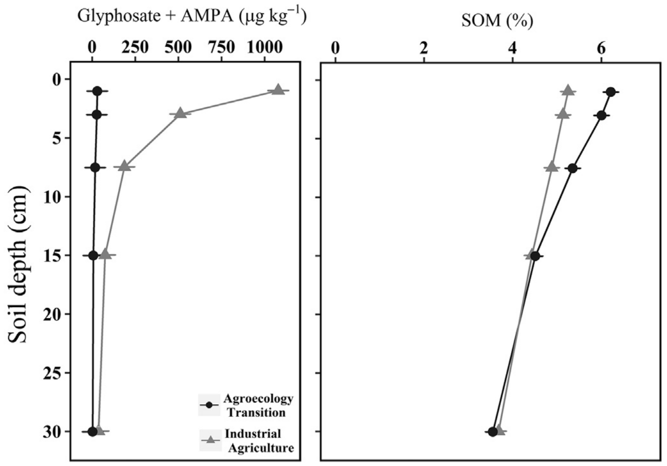

Fig. 4. Comparison of glyphosate + AMPA and soil organic matter (SOM) contents at different depths, between agro ecological transition (AT) and agriculture industrialized (IA) systems.

favor of AT compared to IA. The SOM content increased in depths from 0 to 2, 2 to 5 and from 5 to 10 cm (Fig. 4). If we consider the percentage of organic matter as carbon matter per ha, this means that in 6.5 years an increase in SOC in the depth from 0 to 40 cm of 540 kg ha^{-1} was produced. The inclusion of species like red clover, vicia, sorghum, animal feces and livestock supplementation with wheat bran in AT system increased the carbon stock, during the period analyzed. The AT system provided 44.8 kg ha^{-1} of biomass while IA system provided 20.431 kg ha^{-1}, this difference of 24.455 kg ha^{-1} in the biomass incorporated into the AT system influenced the increase of SOC content. The C stored in the first meter of soil, in most terrestrial ecosystems is, approximately between 2 and 4 times the amount found in the vegetation (Houghton et al., 2007; Jobbágy and Jackson, 2000). The time of residence of this SOC is also longer than in the biomass.

Although there has been several studies about SOM content and its evolution in time, most of the information generated was analyzed in IA production systems (Aparicio and Costa, 2007; Costa et al., 2015; Domínguez et al., 2009; Fabrizzi et al., 2003; Studdert and Echeverría, 2000), while this work has studied the role of soil as carbon sink in an AT system.

There were statistically significant differences in the glyphosate content + AMPA between the production systems at the 0 to 2, 2 to 5 and 5 to 10 cm depths (Fig. 4). The content of glyphosate + AMPA at the first 40 cm was 0.06 kg ha^{-1} in the AT system and 0.84 kg ha^{-1} in the IA system. In the IA system the glyphosate + AMPA mass appears stratified with larger values in the first 10 cm of depth (Fig. 4).

These soils received, during the last 5 years up to the sampling moment, 1 and 17.5 kg of.

active ingredient (i.a) ha^{-1}, in AT and IA system, respectively (Table 1). The masses of both molecules present in the soil at the sampling moment are strongly influenced by the most recent applications, although an accumulative process is produced with successive applications. After glyphosate application, it was observed that between 20 and 50% of the product applied remains in the soil after 60 days, depending on the soil type (Okada et al., 2016). In production systems where the glyphosate is frequently used, it is likely that the herbicide does not degrade completely when the soil gets a new application. One mg kg^{-1} soil is accumulated every 5 crop-spraying events (Primost et al., 2017). This information clearly allows us to understand that, reducing the doses and the number of application is favoring the herbicides degradation. When we decrease these molecules mass in the soil we lessen the risk that they follow other environmental destinations (surface water, groundwater, etc.). On the other hand, the absorption of glyphosate by plants protects them from the degradation caused by soil microorganisms, which increases its persistence in the environment and, therefore, the risk of environmental contamination by this herbicide increases in comparison with the risk related to a direct glyphosate application in bared soils (Mamy et al., 2016). The amount of pesticides returned to the soil with the plant may be significant (Doublet et al., 2009; Von Wirén-Lehr et al., 1997), in particular with soil conservation practices, since they keep a continuous coverage of their surface due to plant residues (Beare et al., 1993; Guérif et al., 2001). On the other hand, glyphosate residues were detected in sub-surfaces horizons in field conditions (Laitinen et al., 2007) that cannot be explained with the preferential flow since it occurred during a very dry period and without precipitations between the glyphosate applications and the soil sampling. The glyphosate translocation by means of a plant by root exudates is rather fast and might be carried out in circumstances in which no vertical transport in the soil profile is produced. The environmental impact of the translocation depends on the depth of the root area, which is determined by the dominant species and the soil hydraulic conditions. The fast liberation, through the roots, in the rhizosphere or root channels may end up in significant contributions of glyphosate available to be transported through flows by macropores towards the groundwater (Laitinen et al., 2007).

Another impact of the glyphosate presence, in crop production, is that it has as ecophysiological destiny the grain or fibers, by which the quality of the agricultural products would be affected. The grain produced in Argentina has concentrations above 40 mg of i.a of glyphosate kg^{-1} while the concentration in grains produced in the United States is less than 20 mg of i.a of glyphosate kg^{-1} (Cuhra, 2015).

It is important to highlight that in the AT system, given the reduction of the amount applied and the reduction in the application frequency, it was found a glyphosate + AMPA mass lower than in the IA system. This lower quantity, plus the larger biodiversity and the increase in the content of organic matter would offer more favorable conditions for the herbicide complete degradation. This is the first study that quantitatively report on the benefits of carrying out an extensive agroecological transition production system in temperate regions on the soil resource.

3.3. Productive and economic results

In some years there was a coincidence among the products obtained in both systems, making a comparison between both productive systems

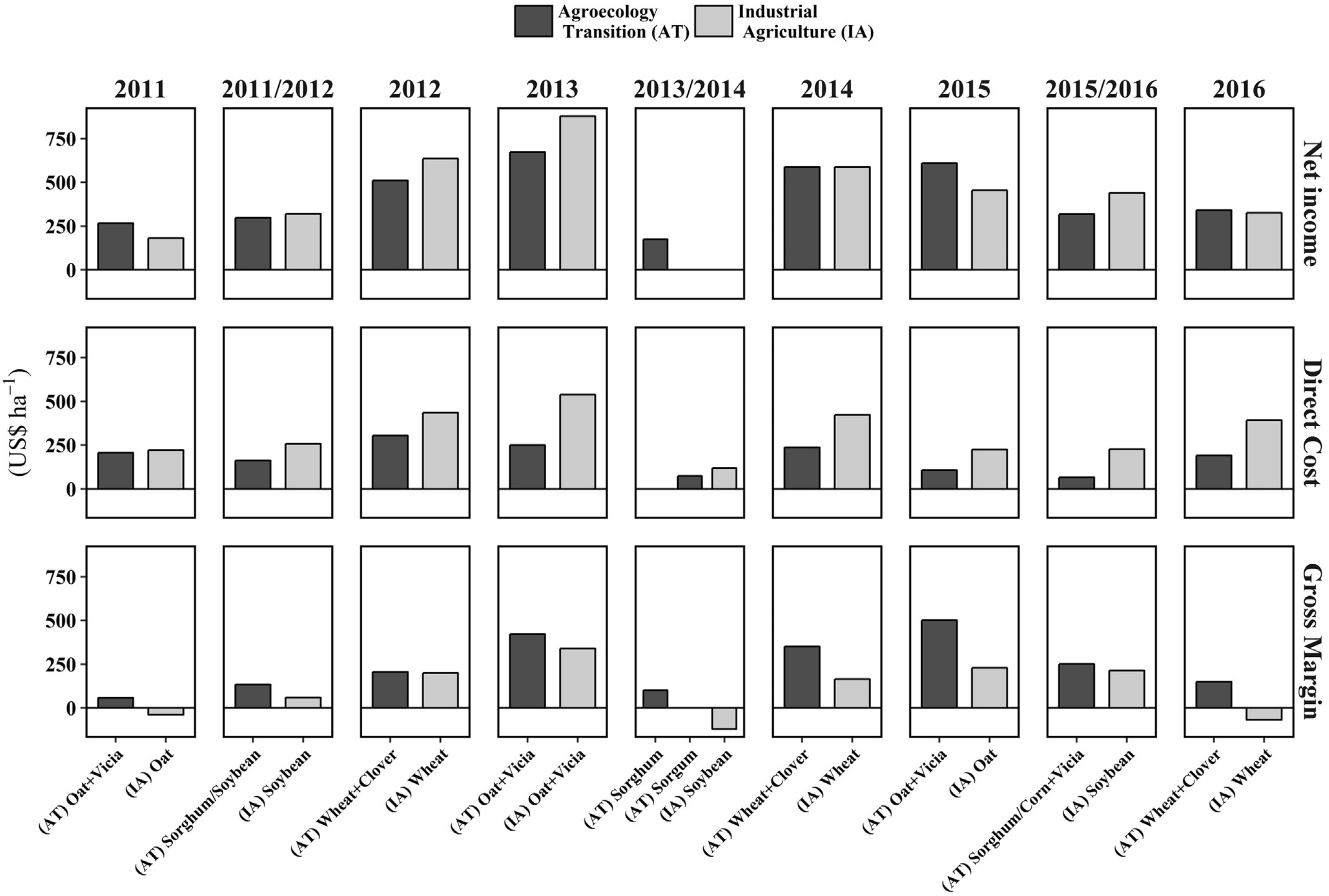

Fig. 5. Comparison of net income, direct cost and gross margin from 2011 to 2016 crop growing season, between agro ecological transition (AT) and agriculture industrialized (IA) systems.

possible (Table 2).

In the first years of the experiment, IA had higher grain yields than AT system. Since the crop period of 2013/2014 yields were equaled to. The AT system was more stable in yields, while IA system had higher yields in those years when environmental conditions were favorable (e.g., year 2012). When rains were more restrictive, the yields of the AT system were higher than the IA output (e.g., year 2016). During a draught period, in the spring and summer of 2013, in AT system it was possible to introduce a sorghum crop to produce meat, while in the IA system the soybean did not emerge which involving an economic loss. Therefore, the AT system achieved greater stability according to yields obtained and lower production costs during the studied period. The stability and the lowest cost were fundamental to diminish production risks. Economic results were also more stable in the AT, since no crops with negative gross margin were registered, while with the IA system, 3 out of 9 crops represented economic loss for the producer.

In general, with the IA system, a slightly higher net income was obtained, however the gross margin (net incomes–direct costs) was doubled in the AT system with respect to IA system in most years (Fig. 5). The cost components that showed higher differences between systems were: use of machinery (119% higher in IA system), herbicides (572% higher in IA system) and chemical fertilizers (78% higher in IA system). The low costs observed in AT were due to the use of agroecological principles, such as biodiversity increase, use of associated crops of grasses and legumes (mixed cropping), complementation with cattle breeding and use of strategic supplements (wheat-bran), among others. This system contributes to improving the physical, chemical and biological soil quality, strengthening the natural processes of fertility, reduction of the grasses seed bank when achieving greater cover, competence for light, water and nutrients for their development (niche occupation and increase in the introduced species competence). The nutrients replacement in the AT was based on the use of legumes for the nitrogen fixation and the use of supplement from the local flour-milling (wheat husks or bran) to balance the extracted phosphorous (only in the first 4 crops phosphorous of chemical synthesis was used to raise the phosphorous content available in soils), while in the IA system phosphate and nitrogen fertilizers of chemical synthesis were used in all the crops.

Finally, the accumulated gross margin in the AT system was 120% higher than in the IA model. This meant almost 1200 dollars ha^{-1} more for the AT system (130 dollars ha^{-1} for each crop, on average). This shows that the productive systems based on agroecological principles can be as profitable as the current industrial agriculture or more profitable than this one.

4. Conclusions

An AT system as alternative to the IA conventional system predominant was proposed in this study. The technical base for the AT system was focused on: (i) to generate and validate agro ecological management practices and (ii) to generate and/or validate productive, environmental and economic metrics which monitor the impact of these practices, at field scale. Management practices of AT system were based on agro ecological principles which requires an holistic vision, increasing biodiversity through crop rotation, using cover crops, mixtures of legumes and grass, biological corridors, mixed crop and livestock systems, increasing soil organic matter content and biological activity.

Based on these metrics, in the AT system we found that:

- The gross margin accumulated during 6.5 years, increased 244% with respect to IA system;
- δ_a was significantly lower and there was a tendency to decrease the CWMD;
- Increased the surface SOM content;
- There was a lower amount of glyphosate + AMPA ($kg\,ha^{-1}$) in the soil.

These results suggest that the AT system proposed could be applicable in extensive productions with temperate climates without interfering with the livelihood of the agricultural producers and it allows an improvement in soil conditions. It is important to carry out more studies of this type in order to confirm the benefices of the AT system in other edaphic-climatic conditions, integrating the productive, economic and environmental aspects.

Conflict of interest

The authors confirm and sign that there is no conflict of interests with networks, organizations and data centers referred in the paper.

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