Analysis of different crop sequences: contributions to the production system

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ABSTRACT

The objectives of the study were: i) evaluate the production of biomass and yield of different crop sequences, four years in length (S1: wheat / 2nd soybean - maize - soybean - wheat; S2: barley /2nd soybean - maize - soybean - wheat; S3: oat / 2nd soybean - maize - sunflower - wheat; and S4: canola / 2nd soybean - maize - sorghum - wheat) under two technological management methods: average level (NTM: used by the average farmer) and high level (NTA used by the top farmer), ii) evaluate nitrogen (N), phosphorus (P), sulfur (S) and potassium (K) extraction and N and P balance, for each complete sequence. The trials were conducted at the Experimental J. Hirschhorn (Los Hornos) dependent on the Universidad Nacional de La Plata. The experimental design was in random blocks with four replicates and in divided plots. The Tukey test was used for the comparison of means (P<0.05). Total biomass tended to generate a higher volume in S2, which resulted in higher total grain yield in that sequence (32212 kg ha-1). The harvest date of the predecessor crop, such as the volume and/or quality of the stubble left, modified the successor's response. The greater contribution of nutrients in the NTA caused total biomass and yields to be higher with a difference of 4715 and 1865 kg ha-1, respectively, increasing the nutrient extraction. The highest extractions of N occurred in S2 and S1, which in addition to their high yields, included soybean with the highest frequency, and in S4 with rape crop and S3. The highest phosphorus and sulfur extractions occurred at S4 followed by S2, S1, and S3. In the case of potassium, the largest extractions were given in S2, followed by S4, S1, and S3. The N and P balances were negative for all cases analyzed. The levels of technology used in this work, which are usually carried out by the farmer in the area, are not enough to satisfy the extractive capacity of the crops. Therefore it is difficult to expect to find zero balances in it.

Keywords: *balance, nutrient extraction, rotations, yields, sustainability.*

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INTRODUCTION

In recent decades, Argentine agriculture has become increasingly specialized and homogeneous, with large areas constantly under high-pressure, no-tillage systems to produce the most profitable crop: soybean (Andriulo et al., 2004; Altieri and Pengue, 2006).

Nearly 50% of Argentina's sown area is dedicated to this crop, which contributes nearly 50% of the country's agricultural production. This poses a problem for crop sequences ("rotations") that allow considering profitability in the short term, but also system sustainability in the long run (Ventimiglia and Carta, 2005).

When properly managed, crop rotations increase yields, contribute to the soil's organic matter content, and improve its fertility. Forjan and Manso (2010) argue that the contribution of plant waste is one of the most important factors that influence the balance of soil organic matter. The high C/N ratio of winter and summer cereal stubbles determines a slow decomposition and favors the formation of stabilized organic matter.

The growth of roots helps improve soil structure, they generate cracks and channels that, by improving the surface porosity of the soil, increase the infiltration rate of water and the exchange of gases, and facilitate the development of other crops' roots. In addition to improving physical conditions, it improves chemical and biological properties (Casas, 2006; Forjan and Manso, 2010).

Also, no-tillage allows greater erosion control, reduces the formation of surface crusts (Bragachini et al., 2015), improves rainwater harvesting, and reduces losses due to evapotranspiration. This, in turn, increases the chances of obtaining better responses to fertilization (Maddonni et al., 2003).

It is key to determine an adequate fertilization schedule, effectively include it in the rotation schemes, and to adapt the doses to the resulting extraction levels. Thus, it is key to know the macronutrient balances in the main crops.

It is also necessary to consider the preceding crop since it can determine changes in the dynamics of each nutrient and modify the response to fertilization. Starting from healthy soil, the ideal situation is to have a balance close to zero. If the balance is negative, it would result in soil degradation due to a reduction in chemical fertility associated with the provision of nutrients (Abbona and Sarandón, 2014).

The Facultad de Ciencias Agrarias y Forestales de la Universidad Nacional de La Plata [Faculty of Agricultural and Forestry Sciences of the National University of La Plata] (UNLP) hs a wide scope and covers several districts in the province of Buenos Aires, mainly the district of Magdalena. Recent work indicates that about 40% of soils in this district are suitable or moderately suitable for soybean cultivation (Etchegoyen, 2011). This emphasizes the need for generating local information to avoid or minimize environmental and social problems related to monoculture.

The objectives of the work were to evaluate the biomass production and the yield of the different crop sequences under two different technological management approaches, to estimate nutrient extraction, and the balance of N and P of each complete sequence.

MATERIALS AND METHODS

Studies were conducted in the Experimental Station J. Hirschhorn, Faculty of Agricultural and Forestry Sciences (National University of La Plata) [Facultad de Ciencias Agrarias y Forestales (UNLP)]. The soil was typical Argiudol soil, similar to most of the agricultural soils in the Magdalena district. Field trials started in 2011 and compared different sequences of agricultural crops in the long term. Each sequence lasted four years. S1: wheat/soybean 2nd – maize – soybean – wheat. S2: barley/soybean 2nd – maize – soybean – wheat. S3: oats/soybean 2nd – maize – sunflower – wheat. S4: rapeseed/soybean 2nd – maize – sorghum – wheat.

Second crop soybean (2nd) is the crop that is sown immediately after the preceding winter crop without mediating fallow. The opposite case is soybean (mentioned above) is also known as first crop soybean. These sequences were managed under two forms of production: average technological level (NTM) considered as the one implemented by the average producer in the region, and high technological level (NTA), used by the producers who usually obtain higher yields on their crops. We learned about both management practices through interviews with local technicians and producers.

The experimental design consisted of randomized blocks with four repetitions and divided plots. The main plot corresponded to the crop sequence and the subplot to the technological management. The surface of each main plot was 22 m^2. The biomass production and grain yield of each crop were obtained after cutting the plants at ground level on an area of 0.6 m^2 for winter crops, 1 m^2 for first and second crop soybean, 7 m^2 for maize, 7 m^2 for sorghum, and 1.35 m^2 for sunflower. After, total biomass and grain yield for each complete sequence were calculated.

Based on literature research on the extraction of nutrients from grains we individually calculated the average amounts of nutrients (nitrogen: N, phosphorus: P, potassium: K, and sulfur: S) exported by crops and by each complete sequence based on their yields.

Nutrient inputs are those from fertilizers and the biological fixation of N in soybean. The N and P balance was calculated from the fertilizer doses used for each complete sequence (four years), to determine the level of replacement in each sequence. For soybean, an estimated biological fixation of N was considered at 40% (González, 2002).

The data obtained were processed by analysis of variance. The main factors and their interactions were analyzed for all the variables considered. Regarding the latter, they were never significant except for the phosphorus balance. The Tukey test was used for the comparison of means ($P < 0.05$). We used the statistical program InfoStat, 2010. Crop management and fertilization management details are shown in Tables 1 and 2.

Crops	Winter cereals	Rapeseed	Second crop soybean	Maize	First crop soybean	Sunflower	Sorghum	Wheat
Sowing time	July 7, 2011	May 24, 2011	*(1)	Oct. 26, 2012	Nov. 18, 2013	Nov. 4, 2014	Nov. 13, 2013	July 5, 2014
Density	300 pl/m^2	100 pl/m^2	50 pl/m^2	8 pl/m^2	40 pl/m^2	5,7 pl/m^2	14 seeds/m line	300 pl/m^2
Genetic material	- Trigo Buck Meteoro - Barley Scarlett - Oats Bonaerense INTA Calén	Hybrid Hyola 571	*(2)	DM 2741 MG RR2	NTM: DM 5.1 NTA: DM 4210	Paraíso 22	Hybrid AD64	Buck Meteoro
Phytosanitary treatments	Herbicide Misil II 0.1 l ha	Herbicide Misil II 0.1 l/ha (p.a: Dicamba, Metsulfuron M)	- Glifosato	Glyphosate 1.5 l/ha in pre-seeding	- Fallow: Glyphosate 2 l/ha + 2.4 D o, 5 l/ha	- Barbecho: Glyphosate 2 l/ha +2,4 D 0,5 l/ha	- Barbecho: Glyphosate 2l/ha +2,4 D o,5 l/ha	Not necessary
	(p.a: Dicamba, Metsulfuron M)		- Cypermethrin 100 cm^3/ha + endosulfan 0, (p.a: Dicamba, Metsulfuron M) 7l/ha		- Glyphosate 2,5l/ha	- Fluorochloridone 1 l/ha + Glyphosate 2 l/ha	- Pre-seeding: glyphosate 2 l/ha	
			- Cypermethrin 100 cm^3/ha + dimethoate 1,6l/ha		- Endosulfan 0,7l/ha + Lambda Cihalotrin 150 cm^3/ha		- Pre-emergence	
							- Atrazine 2 l/ha + propachlor 2 l/ha	

* (1) Soybean sown on Nov. 14, 2011 for the rapeseed predecessor, Dec. for barley, Dec. 13 for oats, and Dec. 16 for the wheat predecessor.
* (2) DM4970 for wheat and oats predecessor. DM4210 for the barley predecessor and, in the case of rapeseed, we used DM3810 for NTA and DM4210 for NTM.

Table 1. Crop management

RESULTS

There were no significant differences between sequences in the total biomass. Total biomass tended to be greater in S2, followed in descending order by S1, S4, and S3 (Figure 1). In all, there was an important contribution made by the maize and winter cereals crops cultivation of corn and winter cereals of the first year (Figure 1). Although there were significant differences between the two technology levels, in response to higher fertilization NTA presented the highest biomass (72750 kg ha^{-1}) when compared to NTM (68035 kg ha^{-1}).

Figure 2 shows the total yields of each sequence and the contribution per crop. The total grain yield (kg ha^{-1}) was higher in S2, which differed significantly from the remaining sequences although there were no differences between them. Maize was the greatest contributor in the four sequences.

In S1, the contribution of wheat in the first year and of first crop soybean was noteworthy. In S2, the contribution of barley and first crop soybean positioned this sequence as the one with the highest yield. The lowest yields of S3 and S4 are attributed to the low grain contribution of the sunflower and rapeseed crops, respectively. There were significant differences in grain yield in the two evaluated technological levels. NTA presented the higher values (29391 kg ha^{-1}) when compared to NTM (27526 kg ha^{-1}), with a difference of 1865 kg ha^{-1}. As indicated above, there were no interactions between sequences and technological levels.

In all four sequences nitrogen presented the highest extraction levels, followed by potassium, phosphorus, and sulfur. Significant differences between the sequences were found for nitrogen extraction. S3 presented the lowest extraction value, and there were no significant differences in this parameter among the remaining sequences (Table 3).

The highest extraction values for P and S were found in S4, followed by S2, S1, and S3. In the case of K, the highest extraction values were found in S2, followed by S4, S1, and S3 (Table 3). For the four nutrients, the highest absolute extraction values were found in NTA, but significant differences were only found in N and P (Figure 3).

In all the cases we found a significant negative effect of the crop sequences on the nitrogen balance. S3 presented the least negative value (Figure 4). According to tech-

Year	Crops	Fertilizers (kg/ha)				
		Type	Equivalent grade	Base*	NTM	NTA
1	Winter cereals	Fosfato diamónico	18-46-00	50		
		Urea	46-00-00		100	140
	Colza	Diammonium phosphate	18-46-00	50		
		Urea	46-00-00		100	120
		Sulfur-enriched monoammonium phosphate	11-34-00-9S			100
	Second crop soybean	Niebla (foliar)**	9-6-00-5,5S			6
2	Maize	Triple superphosphate	00-46-00	80		
		Urea	46-00-00		100	140
3	First crop soybean	Start fert (foliar)***	8,9-1,6-3,7-1,1S			1
	Sunflower	Diammonium Phosphate	18-46-00			60
		Urea	46-00-00			50
	Sorghum	Urea	46-00-00			50
4	Wheat	Diammonium Phosphate	18-46-00	50		
		Urea	46-00-00		100	140

*Basic fertilization: applied in all plots for both technological levels.
** Composition: 09-2,6-00, 5,5% sulphur.
*** Composition: Total N: 8,9%, Assimilable P: 1,6%, Water soluble K: 3,7%, Ca: 0,3%, Mg: 0,3%, Fe: 0,8%, Mn: 0,2%, Zn: 0,2%, Cu: 0,2%, SO4=: 1,1%, B: 0,2%, Mo: 0,06%, Total Humic Extract: 15,7%, Humic acids: 0,8%, Fulvic acids: 14,9%.

Table 2. Fertilization management.

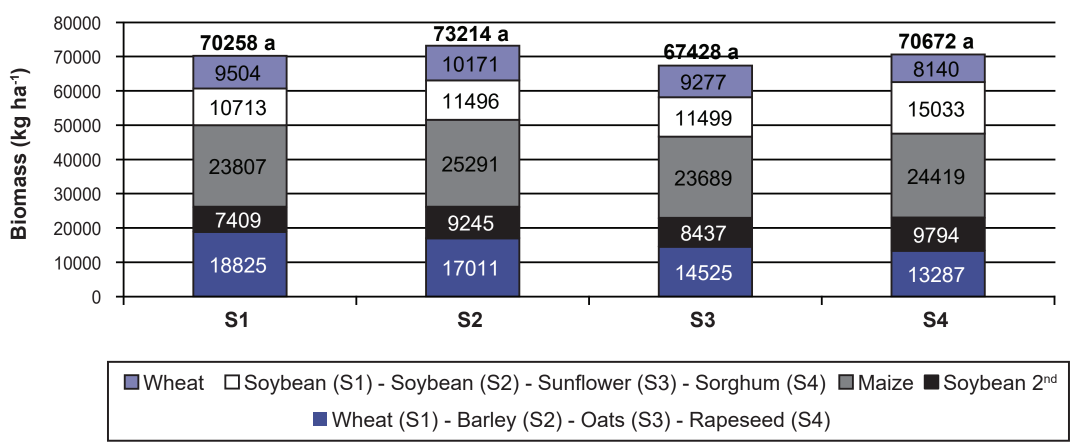

Figure 1. Total biomass (kg ha^{-1}) for four crop sequences and contribution of each crop. Means with the same letter do not differ significantly according to the Tukey test (p <0.05)

nological levels, the least negative nitrogen balance was observed in the NTA treatment (-351 kg ha^{-1}), and -393 kg ha^{-1} in NTM, associated with the greater nutrient input from fertilizers. We found a significant interaction between the sequence and the used technological level in P balance. There were no significant differences between sequences for NTM, but in the case of NTA, S3 presented the best response (Figure 5).

DISCUSSION

Biomass and yield

Although there were no significant differences in total biomass between the different crop sequences, S2 presented a tendency to generate higher values while presenting a grain yield significantly higher than the rest. Likewise, the greater contribution of nutrients in the NTA resulted in hig-

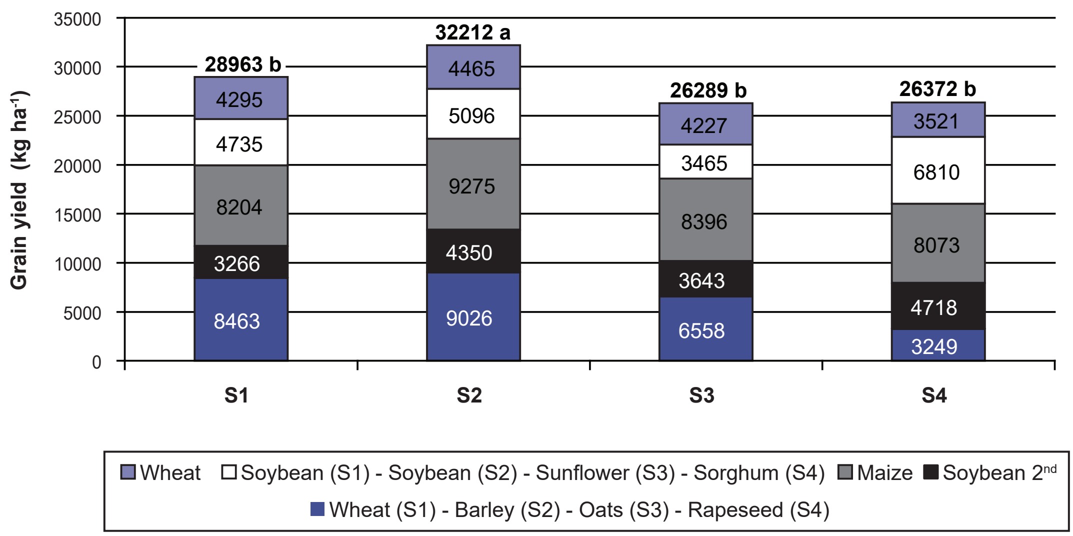

Figure 2. Total grain yield (kg ha^{-1}) for four crop sequences and contribution of each crop in yield. Means with the same letter do not differ significantly according to the Tukey test (p <0.05)

	N extraction				P extraction			
Year	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
1	153	135	131	123	30	27	20	36
	95	127	106	137	18	23	20	25
2	107	122	110	106	22	24	22	21
3	138	148	83	132	26	28	24	26
4	78	81	77	64	15	16	15	12
Total	**571 a**	**613 a**	**507 b**	**563 a**	**110 bc**	**118 ab**	**101 c**	**121 a**
	K extraction				**S extraction**			
	S1	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
1	30	45	20	91	13	18	12	23
	55	73	61	79	9	12	10	13
2	28	32	29	28	10	11	10	10
3	80	86	21	26	13	14	7	13
4	15	16	15	12	6	7	6	5
Total	**208 b**	**252 a**	**146 c**	**237 a**	**52 b**	**63 a**	**46 c**	**64 a**

S1: wheat/soybean 2nd - maize - soybean - wheat. S2: barley/soybean 2nd - maize - soybean - wheat. S3: oats/soybean 2nd - maize - sunflower - wheat. S4: rapeseed/soybean 2nd - maize - sorghum - wheat.

Table 3. Nutrient extraction (N, P, K, S) in kg ha^{-1} for each sequence and for each crop. Means with the same letter, for each sequence, do not differ significantly according to the Tukey test (p <0.05).

her biomass and yields, with a difference of 1865 kg ha-1 of grain when compared to yields obtained with NTM. In general, the yields obtained in all the crops in the sequences were higher than the national averages.

When they were not conducted simultaneously, the harvest dates of the preceding crops modified the behavior of the following crop. In fact, in the case of second crop soybean plants from earlier plantings grew taking better advantage of the environment, without excessive temperatures accelerating the stages of development. This allowed plants to capture more resources (radiation, water, nitrogen) and achieve greater production according to their genetic potential (Baigorri et al., 2009).

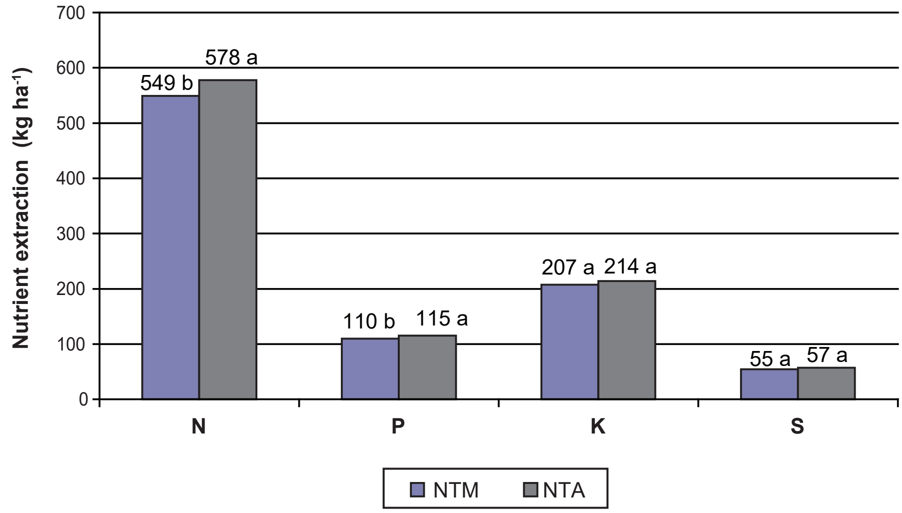

Figure 3. Nutrient extractions in kg ha^{-1} according to the used technological level: average technological level (NTM) and high technological level (NTA). Means with the same letter, for each nutrient, do not differ significantly according to the Tukey test ($p < 0.05$).

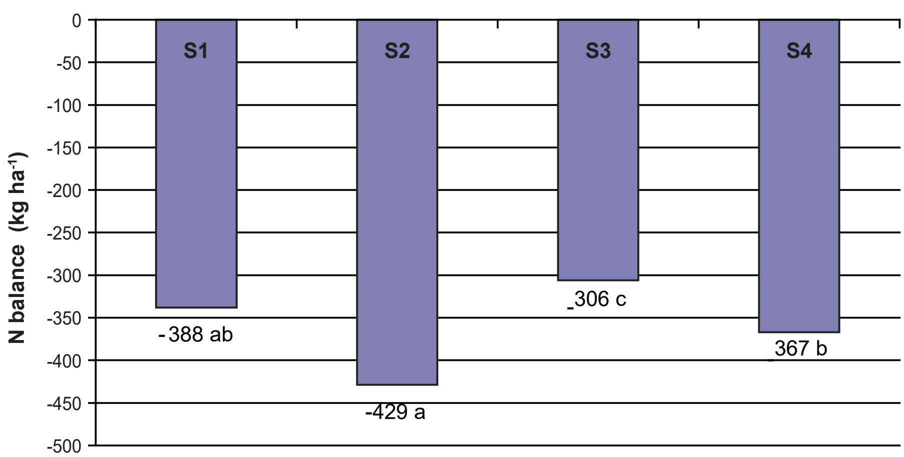

Figure 4. N balance in kg ha^{-1} for four crop sequence. Means with the same letter do not differ significantly according to the Tukey test ($p < 0.05$).

Therefore, the highest yields of the second crop soybean occurred when the predecessor was rapeseed, followed by barley, oats, and wheat. Also, in many cases, the volume and quality of the stubble left by the predecessor influenced the behavior of the following crop. Working on the same trial, Pellegrini et al. (2014) determined before the planting maize that crop sequences do not change significantly the volume of stubble.

However, they found statistical differences in particulate organic carbon (corresponding to the labile fraction of organic matter). S3 and S2 presented the highest results, 1.29 g kg^{-1}, and 1.17 g kg_{-1}, respectively, followed by S1 (1.11 g kg^{-1}) and S4 (1.0 g kg^{-1}).

This higher content of particulate organic carbon was in turn associated with higher maize yields, which would indicate that the quality of stubble could favor the development of maize crops. The same type of response was found for the first crop soybean (S1 and S2) that presented a good performance when the predecessor was maize.

On the one hand, Bacigaluppo et al. (2009) found a 10% difference in yield in favor of soy when it was cultivated in rotation with grasses, and when compared to its production as a monoculture. On the other hand, the low C/N ratio of soybean stubble caused them to decompose rapidly, increasing the availability of nitrogen for the development of the next crop, which favored the wheat that followed in the rotation.

The intermediate C/N ratio of sunflower plus its low contribution of stubble could increase the availability of nitrogen, but to a lesser extent than in S1 and S2. On the contrary,

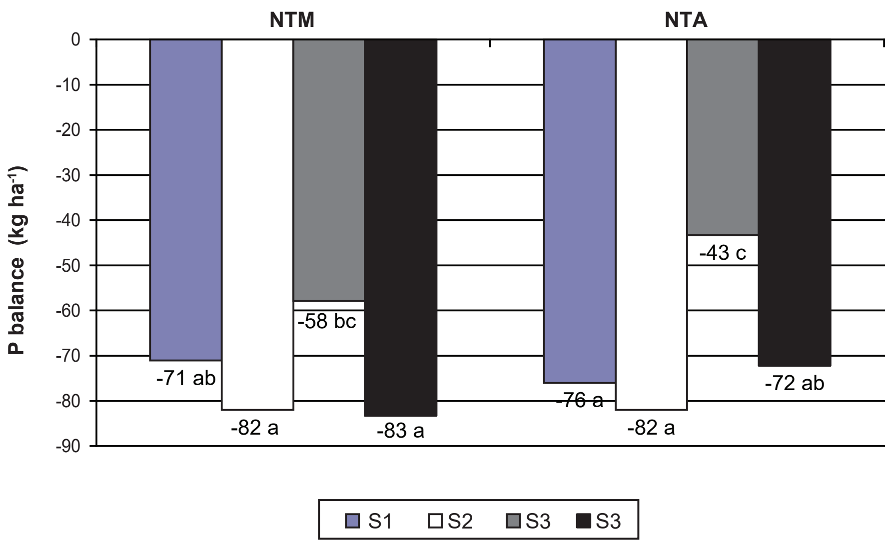

Figure 5. P balance in kg ha-1 for four crop sequences under two technological levels: average technological level (NTM) and high technological level (NTA). Means with the same letter do not differ significantly according to the Tukey test (p <0.05).

the microbial immobilization of nitrogen in S4, produced by the high contribution of stubble from the sorghum and its high C/N ratio, would have affected the availability of this nutrient for the following culture.

Nutrient extraction and balance

S2 and S1 presented the greatest nutrient extractions. These were the sequences with higher yields and higher soybean frequency, which is a crop that has high nutrient extraction per ton of grain (Ciampitti and García, 2009). Also, S4 since it is a rapeseed crop. S3 was the least extractive. The N balances were deficient for the four sequences.

The greater contribution of nutrients in NTA resulted in higher total biomass and yields, and increased nutrient extraction. Although the NTA ensured a higher level of replacement, especially of N, both in NTA and NTM the nitrogen balance was negative. As in the previous case, the balance of P was negative for the four sequences. The sequences with the most negative balances were S1 and S2, which included soybeans twice, and S4 with rapeseed cultivation, which requires twice as much phosphorus per ton of grain as soybeans, 1.5 times more phosphorus than sunflower and between 3 and 4 times more than grasses (Ciampitti and García, 2009).

In any case, we found a significant interaction in the balance of P between the sequences and the implemented technological level. There were no differences in the response of sequences under NTM, although there were differences in the response of the sequences under NTA. This indicates that under NTA S3 presented better behavior.

The obtained negative nutrient balances are consistent with those found by Flores and Sarandón (2002) during the 1990s for wheat, maize and soybean crops in the Pampas region. There, the cost-benefit analysis usually used by producers does not include the cost of degradation of the natural capital of the soil, overestimating the benefits of agricultural activity. Therefore, this cost should be included to sustain agricultural systems from an ecological point of view.

On the national level, Cruzate and Casas (2012) found that the percentage of total nutrient replacement is 35% of the extracted, with a 39% replenishment of N, 64% of P, 6% of K, 54% of Ca, and 52% of S.

CONCLUSIONS

The harvest date of the preceding crop and the volume and quality of its stubble modify the response of the following crop. The highest yields of second crop soybean were obtained when the preceding crop was harvested early. In turn, the yields of maize, first crop soybean, and wheat of the last year depended on the quality of the stubble volume of the previous crop.

The greatest N extractions occurred in S2 and S1 which, in addition to being the highest yield sequences, included soybean with greater frequency, and in S4 with rapeseed crops. The greatest P and S extractions occurred in S4, followed by S2, S1, and S3. For K, the greatest extractions occurred in S2, followed by S4, S1, and S3. The N and P balances were negative for all analyzed cases.

The levels of technology used in this work, which are usually used by producers in the area, are not enough to satisfy the extractive capacity of the crops and therefore it is difficult to expect to find zero balances.

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