Cations and phosphorus changes and budgets in a long term fertilization experiment on an Argiudol soil in Argentina

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Abstract
The rise in crop production in Argentina is explained by an increase in both cropped area and production per unit area. Fertilization was one of reasons that pushed crop production. Nitrogen (N), phosphorus (P) and sulphur (S) fertilizers are commonly used. Potassium (K), calcium (Ca) and magnesium (Mg) content in soils is above reported thresholds values of response in other regions of the world. Fertilization strategies do not include these nutrients, and there is some concern about the behaviour of these nutrients in soils and the impact on K, Ca and Mg balance. The objective of our work was to evaluate the effects of continuous application of K, P and Mg on soil K, P and Mg status after three maize-wheat/soybean cycles. Continuous applications of P, K and Mg in a crop sequence had a positive impact in soil K and Mg levels, even when no response to K and Mg addition was observed. Final soil P levels were lower than at the beginning of the experiment. Analysing nutrient budgets in the system, including nutrient harvest index and the dynamics of nutrient release from residues will be of particular importance to construct a nutrient budget at the system scale.

Key Words
Phosphorus, potassium, magnesium, calcium, long term, nutrient budget.

Introduction

Agricultural production in Argentina has increased from 40 million ton in 1990 to 95 million ton in 2007. This rise in crop production is explained by an increase in both cropped area and production per unit area (Garcia and Salvagiotti 2009a). Fertilization, among other factors, was one of reasons that pushed crop production. Before the 90's, agriculture was performed without fertilization, and thus, negative nutrient balances in fields occurred. Nitrogen (N) fertilization in wheat and maize showed large response to fertilization and response to phosphorus (P) fertilization appeared even in areas with medium soil P content. Response to sulphur (S) fertilization also was observed, mainly in soils that suffered intensive erosion processes that reduced organic matter contents and in fields that had high yield levels (Garcia and Salvagiotti 2009b). No other nutrient is used extensively in Argentinean agriculture. Cation levels in soils of the Pampean region are historically high. Potassium (K) content in soils is above reported thresholds values of response in other regions of the world. The same happens with calcium (Ca) and magnesium (Mg). Also, these cations, in equilibrium in the soil, determine cation exchange capacity (CEC), which is an indicator of soil chemical fertility. Since fertilization strategies do not include these nutrients when crops are fertilized, there is some concern about the behaviour of these nutrients in soils and the impact on K, Ca and Mg balance. Typically, crop nutrient balances take into account the amount of nutrient exported with grains and applied as fertilizers. This partial balance gives an idea of the magnitude of nutrient reposition. However, when analysing the impact of fertilization in a system (e.g. a crop sequence), the amount of nutrients returned with residues have an important role. Nutrient harvest index (i.e. proportion of nutrients exported with grains) is a crucial variable in this analysis. For instance, K, Ca and Mg have shown low harvest index in opposition to P or N. Therefore, it is expected that nutrients with low nutrient harvest index will make nutrient budgets in the system less negative than nutrients with high harvest index, even when fertilization is not supplying these nutrients. In order to explore these issues, long term fertilization experiments that show temporal changes in soil nutrient content and the impact of fertilization are needed. The objective of our work was to evaluate the effects of continuous application of potassium, phosphorus and magnesium on soil K, P and Mg status after three maize-wheat/soybean cycles. Based on reported K, P and Mg harvest indexes we estimated the effects of different fertilization strategies on nutrient budget of the system.

Methods

A long term experiment aimed at studying the cumulative effects of phosphorus, potassium and magnesium fertilization in a maize-wheat/soybean rotation was carried out under no tillage in Oliveros, Argentina (32º 3´ Lat S y 60º 51´ Long W). The experiment began in the 2000/2001 season with a maize crop and ended on 2006 season with wheat. Crop management each season is described in Table 1. Treatments included various

rates of potassium (K), chloride, sulphur and magnesium (Mg). Grain yield results have been evaluated previously (Melgar *et al.* 2006). In the present study, the following treatments were analysed: i) check (no fertilizer addition); ii) NP (Nitrogen (N) + Phosphorus (P)); iii) NPK1 (N+P+ potassium (K); iv) NPK2 (N+P+K) and v) NPK2Mg (N+P+K2+Magnesium (Mg)). Only wheat and maize were fertilized. Soybean was not fertilized. Nitrogen rates were 60 and 90 kg/ha for wheat and maize, respectively, P rate was 20 kg P/ha, K rates were a respective 25 and 50 kg K/ha for K1 and K2. Finally, Mg rate was 6 kg Mg/ha. Fertilizers used were: urea, triple super phosphate (TSP), potassium sulphate, and magnesium sulphate. All fertilizers were applied top-dressed or incorporated broadcast at sowing, except TSP, which was applied banded at planting. The experiment was arranged in a randomized complete block design with four replications. Each plot was 5 x 15 m plot (75 m^2). Weeds and pests were controlled conveniently. Soil samples were taken at 20 cm depth at the beginning of the experiment (i.e. in 2000) and after harvesting wheat in 2006. P (Bray I), K, Mg and calcium (Ca) content was extracted with ammonium acetate. Changes in nutrient concentration over time were determined. Nutrient harvest index: 0.21 or K, 0.76 for P, 0.53 for Mg and 0.07 for Ca and internal use efficiency for P, K, Mg and Ca reported in the literature (IPNI 2007) were used to estimate apparent nutrient consumption, apparent nutrient export with grains and apparent nutrient return with residues.

Table 1. Crop Management each season in a long term fertilization experiment performed in Oliveros - Argentina.

Season	Crop	Genotype	Planting date	Plant density plants m^{-2}	Row spacing m
2000/01	Maize	Dekalb 752	Oct 10th	8	0.70
2001/02	Wheat	Coop. Nahuel	June 21st	300	0.175
	Soybean	DM 4800	Dec 26th	44	0.52
2002/03	Maize	Siroco	Sept 23th	8	0.70
2003/04	Wheat	Klein Escorpion	June 25th	300	0.175
	Soybean	RA 500	Dec 18th	44	0.52
2004/05	Maize	Ax 890	Sept 15th	8	0.52
2005/006	Wheat	Buck Guatimozin	June 15th	350	0.175

Results

All years, ertilization increased grain yield. However, only maize in 2004-05 responded significantly to K application ($P<0.06$). No response to K or Mg fertilization was observed in other crop-year situations (Table 2).

Table 2. Grain yield (kg/ha) corrected by moisture (13% in wheat and soybean; 14% in maize) in different crops in the maize-wheat/soybean sequence in a long term fertilization experiment performed in Oliveros - Argentina.

Season	Crop	Check	NP	NPK1	NPK2	NPK2Mg	*SE* *
2000/01	Maize	5004	8559	8397	7914	8521	*602*
2001/02	Wheat	1772	3168	3381	3468	3339	*136*
	Soybean	2498	2241	2647	2674	2592	*99*
2002/03	Maize	5545	8871	9279	9213	9507	*348*
2003/04	Wheat	1165	3105	3131	3078	3152	*130*
	Soybean	501	474	456	505	590	*85*
2004/05	Maize	3151	6381	7223	7503	7378	*563*
2005/006	Wheat	1931	4275	3950	4226	3893	*196*

* Standard error for the comparison between two means in the same row (crop x season).

Figure 1 shows K, P, Mg and Ca content in soil at the beginning (2000) and ending (2006) of the experiment in each treatment. Initial K levels in the soil were 490 ppm and significantly increased up to 650 and 728 ppm in the K1 and K2 treatments. A significant decrease in K content was observed in the check treatment. At the end of the three cycles of rotation ca. 288 and 570 kg K/ha were applied as fertilizer (Figure 2), which increased soil K content by 33 and 49% (Figure 1). Likewise, Mg content significantly increased 11% (from 180 to 200 ppm) after a cumulative application of 36 kg Mg/ha as fertilizer. In contrast, continuous P fertilization did not show significative increases in P Bray content. In fact, soil P Bray decreased from 49 ppm at the beginning of the experiment to 40 ppm averaging all fertilization treatments in 2006. Calcium, which was not included in the fertilization showed a slight decrease during three cycles of rotation.

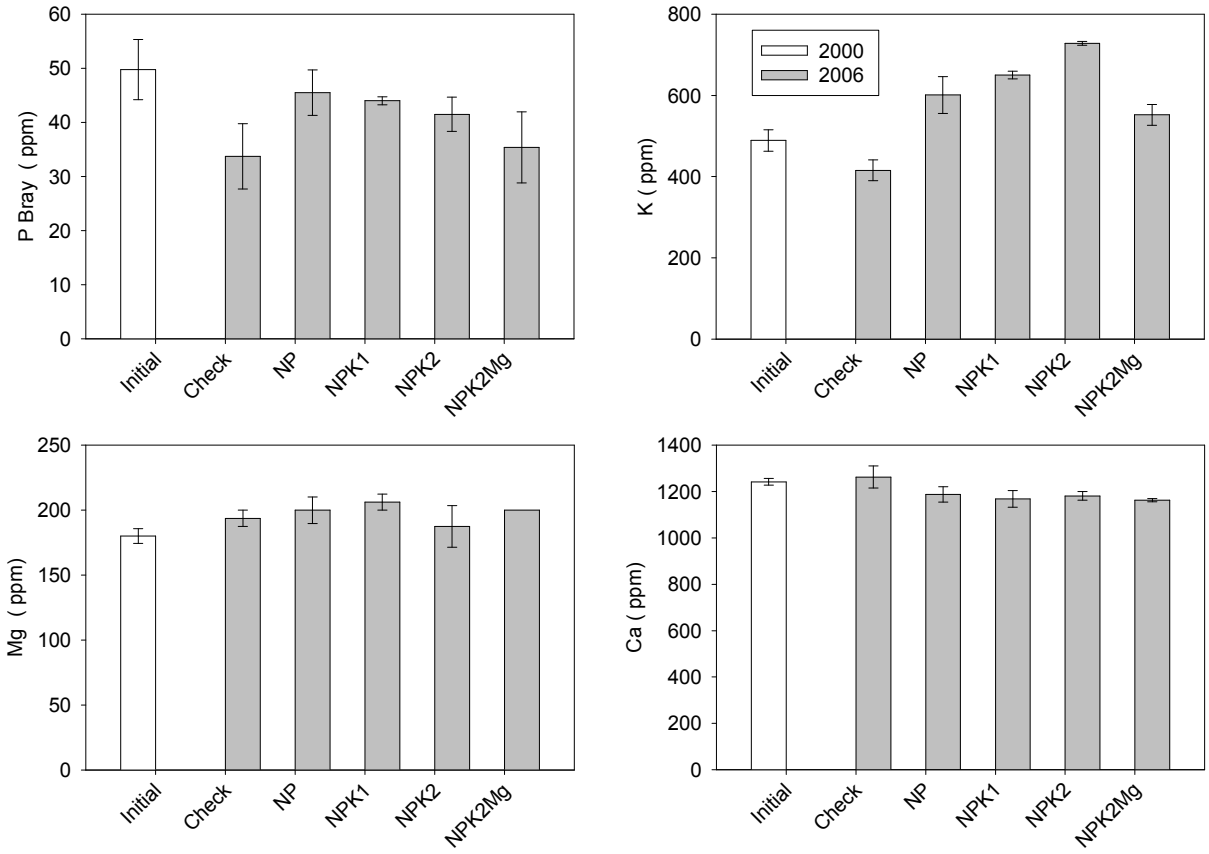

Figure 1. Phosphorus (P Bray), Potassium (K), Magnesium (Mg) and Calcium (Ca) content in soils at the beginning (2000) and end (2006) of the long term fertilization experiment in Oliveros - Argentina.

Nutrients balances at the end of the cycle showed different results depending on the nutrient. Negative partial balances (nutrient exported with grains – nutrient applied as fertilizer) were observed in all treatments with P, showing that P applied as fertilizer was not enough to repose P export with grains. The same happens with Mg. On the other hand, K fertilization was enough to make partial balances positive (Table 3). However, this type of balance, useful for analysing nutrient balances for a particular crop, does not give complete information for analysing nutrient balances in a crop rotation. Figure 2 shows balances including the apparent amount of nutrient that is returned to the soil with residues. In the case of K and Mg, which have lower harvest index than P, the nutrient budget of the system showed more positive values. On the other hand, P budge in the system was neutral or slightly positive. System balances for Ca were highly positive, mainly because the very low Ca harvest index of all crops in the sequence.

Table 3. Partial Balance and Application/ removal ratio (A:R) for Phosphorus (P), Potassium (K), Magnesium (Mg) and Calcium (Ca) in the different fertilization treatments in a long term fertilization experiment in Oliveros – Argentina.

		Check	NP	NPK1	NPK2	NPK2Mg
P	Partial Balance	-70	-8	-12	-13	-13
	A:R	-	0.93	0.90	0.89	0.89
K	Partial Balance	-115	-166	113	393	392
	A:R	-	-	1.64	3.22	3.21
Mg	Partial Balance	-39	-65	-68	-68	-32
	A:R	-	-	-	-	0.53
Ca	Partial Balance	-12	-16	-17	-17	-17
	A:R	-	-	-	-	-

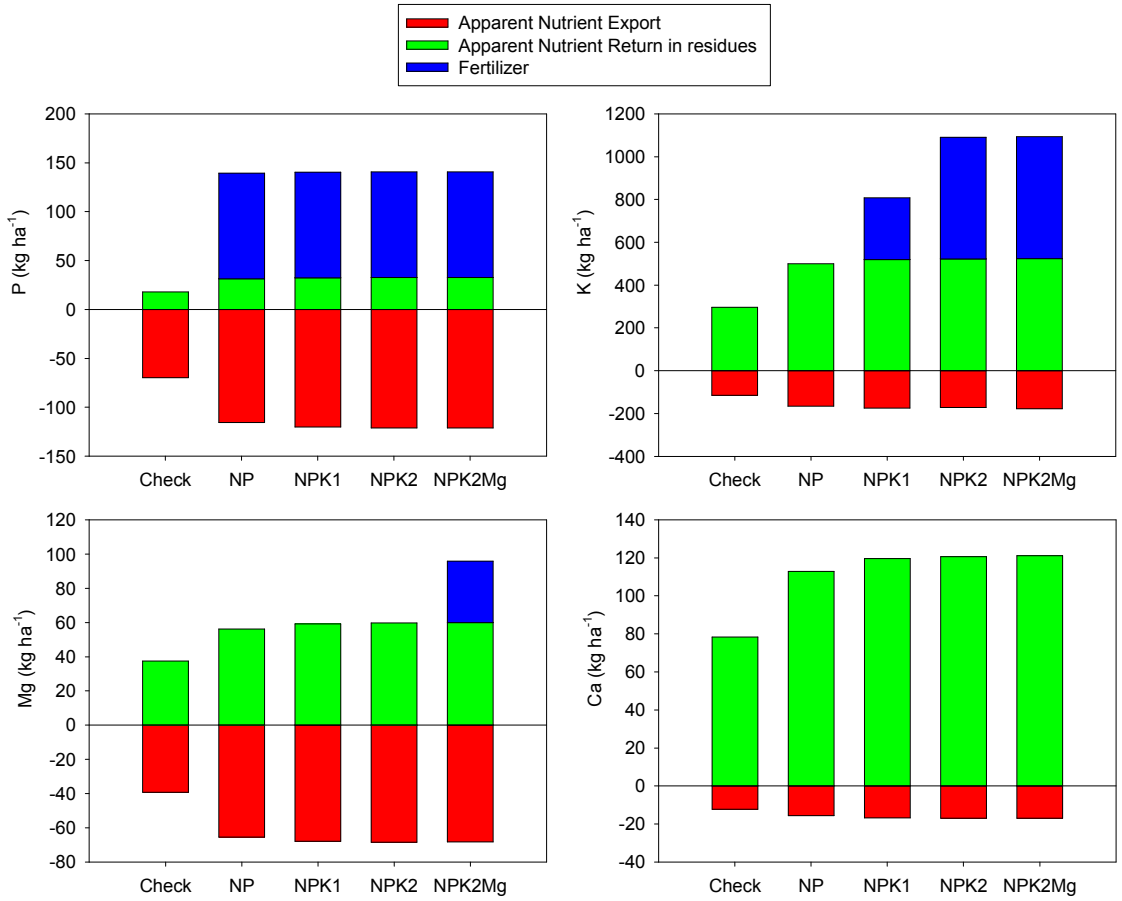

Figure 2. Apparent Phosphorus (P), Potassium (K), Magnesium (Mg) and Calcium (Ca) export with grains and return with residues after three cycles of a maize-wheat/soybean rotation in a long term fertilization experiment in Oliveros - Argentina.

Conclusion

Continuous applications of P, K and Mg in a crop sequence had a positive impact in soil K and Mg levels, even when no response to K and Mg addition was observed. Final soil P levels were lower than at the beginning of the experiment. When analysing nutrient budgets in the system, partial balances may be not suitable, since a cropping system is characterized not only by nutrient export but also by a continuous nutrient recycling of nutrients from nutrients that remained in the residues. Nutrient harvest index, which drives nutrient export from the system, and the dynamics of nutrient release from residues will be of particular importance to construct a nutrient budget at the system scale.

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