POTASSIUM IN AGRICULTURAL SOILS OF URUGUAY
Report 2010

Traditionally, the agriculture in Uruguay has been done on soils with medium to high natural levels of potassium (K) (Hernández 1997b, Hernández et al, 1988). The decisions of K fertilization in field crops has been based on critical levels exchangeable K, referenced for other regions: 0.20-0.25 meq/100 g for medium textured soils, and 0.30 to 0.35 meq/100 g for fine soil textures (Ammonium acetate extraction). No response to K fertilization is expected above those exchangeable K levels, similarly to those operated until 2003 under tillage systems of U.S. Corn Belt (90-130 mg kg-1: 0.23 to 0.33 meq/100 g). The small number of experiments and years of study had indicated little or no response to the addition of K in soils of different textures and levels of exchangeable K. This explains why in most crops, K fertilization is not recommended. Those studies were mostly in soybean, under conventional tillage, and in soils located in the eastern region of the country, with exchangeable K levels ranging from 0.11 to 0.77 meq/100 g (Docampo et al., 1981; Marella et al., 1981; Colombo and Collares, 1982; Pereira et al., 1983).

However, the recent intensification of agriculture, crop rotations of high yields, may have decreased K levels in soils. On the other hand, the increasing expansion of the agriculture has included soils with many restrictions, some of which had already shown some response to K fertilization (Moir and Reynaert, 1962; Castro, 1965). Nutritional surveys in corn in dairy farms (Morón and Baethgen, 1996) and Lotus corniculatus L. (Barbazán et al., 2007), including many types of soil, indicated that there would be evidence for K deficiencies attributed to low levels of exchangeable K. More recent studies in the Western, Northern and Center areas of the country (Almada, 2006; Cano et al., 2007; Cano et al., 2008; Bautes et al., 2009) reported in some cases response to K even with exchangeable K levels considered medium to high under no-tillage situations, where the nutrient dynamics differs from those in conventional tillage (Bordoli, 2001).

While the country has made great effort to understand the dynamics of nutrients such as P and N in different production situations, by far much less research has focused on understanding the dynamics of K. Therefore, the country needs to set a system of fertilizer K recommendation, given the extensive area occupied by agriculture, the different soil types and the current price of fertilizers. In addition, the area with evidence of more probable response to K, in the short or medium term, is estimated in about 20% of the productive area of the country.

What are we doing now?

In this context, we are conducting several studies to understand the dynamics of K in agricultural soils under conservation tillage and get rational guidelines for K fertilizer recommendations in Uruguay. These studies are:

1) Study of the reserves of potassium: K non-exchangeable and clay type.
2) Study of buffering capacity of K in soils of Uruguay.
3) Study of leaching of K from crop residues and temporary changes in soil exchangeable K.
4) Study of equivalent K fertilizer.

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These studies are being partially carried out using the soil samples and the information from the field experiments done in previous years.
The study 1 (K non exchangeable and clay type) is carried out by Jimena Rodríguez in the soil samples we already have: Sites from Bautes trials; sites from Cano trials and Bordoli trials.
The studies 2 to 4 are being conducting at this moment, also with Jimena Rodríguez.
For these studies, we received funds from International Plant Nutrition Institute (U$S 10,000). This amount covers the salary of Lic. Jimena Rodríguez, from January 2010 to July 2010. To complete this work through June 2011, we need at least U$S 12,000 more.

Study 1. Potassium reserves in soils of Uruguay

The soil analysis is one of the tools used in agriculture for predicting the capacity of the soil to supply K to crops and to decide fertilization. This prediction is a difficult task due to the complex dynamics that governs the balance between different forms of K in the soil. These forms are: K soluble in water (soil solution), K (retained as cation in the exchange complex), non-exchangeable K (in the interlayer of some clays) and structural K of minerals. Plants take up K from the soil solution that is easily replenished by the exchangeable K in a rapid equilibrium. When these two forms decrease, the K of non-exchangeable form tends to maintain the balance of the other forms, at a slower rate.

Most of the soil K tests measure a proportion of available K. The most widely adopted globally and nationally is the extraction with 1.0 M ammonium acetate, air-dried samples or stove. In these methods, the cation NH_4^+ is exchanged with the exchangeable K. Although this method is widely used, does not estimate the proportion of non-exchangeable K fixed in the interlayer of clays that can pass to available form in the medium- and long-term. The sodium tetraphenylborate method seems to have a potential to improve predictions of K available to plants. This method, developed by Scott et al. (1960), has been considered of interest because it considers not only the exchangeable K, but also a part of K held in the interlayer of clays. This, therefore, may improve the ability to predict the availability of K. However, the dynamics of this fraction is still poorly understood because not all non-exchangeable K becomes available in the short or medium term (i.e., a crop or two successive crops). Among the factors affecting K fixation include: texture, mineralogy, alternate drying and wetting, quantity and type of organic matter and K in subsurface horizons. Dowdy and Hutcheson (1963) found that clay mineralogy was closely related to the K released of a set of soil samples. They found that the altered mica (illite) released K, while vermiculite and montmorillonite were associated with the determination of K. Some recent work suggests that exchangeable K, non-exchangeable K and clay mineralogy are considered when fertilization recommendations are made (Wang et al., 2004).

In Uruguay, mineralogical studies and identification of the clay fractions, are very scarce, partly because this technique requires a meticulous work of sample preparation and special equipment to make the determinations. These works also date back to the 70's and 80's (Alvarez and Velozo, 1974; Puentes and Altamirano, 1975; Carnelli and Guarinoni, 1976; Cayota et al., 1981; Pazos, 1981; Elliot and Manfredini, 1988), when agricultural activity in the country was concentrated in a smaller area, with other genetic materials and with different crop rotations and soil management. On the other hand, the characterization of the various pools that govern the supply of K to plants were carried out only in 10 soils (Hernandez, 1989), which is a limited number of soils.

Unlike other agricultural regions, such as the U.S. Corn Belt, where most of the soils are very homogeneous in their clay fraction and with properties similar to those of the western zone of the country, at Uruguay it is expected that $NaBPh_4$ would provide advantages in interpreting the causes of differences in the responses to K. The detection of the predominant type of clay would help to understand the dynamics of K in soil types and adjusting fertilizer recommendations.

Activities

In this study we are working with the soil samples and crop yield of those trials testing K response. Most of the sites were identified according to the Soil Survey of Uruguay (*Carta de Reconocimiento de Suelos de Uruguay*) (MAP, 1976). In some soils, additional analysis were made: exchangeable cations, pH, organic matter, and texture (Table 1). Non-exchangeable K was measured by the methods of nitric acid and $NaBPh_4$ in selected soils samples.

Results

In July of 2010 we presented in Colonia, Uruguay, a summary of all the recent investigation in K, in the paper by Barbazan et al. (2010). Table 1 shows the soil characterization of the sites studied. With this type of information we intent to discriminate the soils, as we can see in the Fig. 1.

The advances in this study have been very limited. We were not able to analyze the clay mineralogy yet, because of the cost of the clay analysis and uncertainty about the procedure of the technique. We may send soil samples to a laboratory in Argentina, but we still need to adjust the processing of the soil samples. This process is tedious and time consuming. Moreover, many of the soil samples taken opportunely for the different groups are not conserved in order to perform the analyses needed to characterize all the sites. In some of the cases (Bordoli and Cano´s sites), we had to take new soil samples.

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Table 1. Selected soil properties of the sites.

Field experiment	Nº site	Texture	% Ar.	% L	% Ac	pH (H2O)	pH (KCl)	MO	Na	K	Ca	Mg	BT	CIC	P Bray1
								%		meq/100g					ppm
Bordoli	1	Fr	44	33	23	5.3	4.6	5.4	0.70	0.20	13.78	3.00	17.7	32.8	17
Bordoli	2	Fr Ar	66	17	17	5.8	5.0	4.3	0.33	0.23	15.39	1.61	17.6	27.3	4
Bordoli	3	Fr Ac	28	41	31	6.1	5.3	4.3	0.44	0.39	22.86	2.86	26.6	38.5	11
Cano	1	Fr Ac Ar													
Cano	2	Fr Ac Ar	50	27	23	5.1	4.5	6.1	0.42	0.38	17.03	3.92	21.8	41.9	65
Cano	3	Fr Ac	36	31	33	5.4	4.8	6.3	0.42	0.46	25.03	3.42	29.3	58.3	13
Cano	4	Fr Ac Ar													
Cano	5	Fr Ac Ar													
Cano	6	Fr Ac Ar	51	25	24	5.7	4.9	4.2	0.40	0.15	20.14	3.37	24.1	38.1	14
Cano	7	Fr Ac Ar													
Cano	8	Fr Ac Ar													
Cano	9	Fr Ac Ar													
CB_CALM	1	Fr	37	39	24	5.4	4.7	3.3	0.38	0.37	20.06	3.13	24.0	30	21.9
CB_CALM	2	Fr				4.74		1.37		0.18	2.00	0.57	2.8		
CB_CALM	3	Fr Ar	65	31	4	4.3	3.8	2.1	0.30	0.20	2.54	0.68	3.7	15.7	13.4
CB_CALM	5	L Ac				5.76		5.42		0.48	25.80	4.27	30.6		
CB_CALM	6	Fr Ar				5.37		5.17		0.31	15.73	2.93	19.0		
CB_CALM	7	L Ac				5.73		4.17		0.30	11.60	2.50	14.4		
CB_CALM	12	L Ac				5.54		3.10		0.24	9.20	2.00	11.4		
CB_CALM	13	L Ac													
CB_CALM	15	L Ac													
CB_CALM	16	L Ac													
CB_CALM	17	Fr L	26	56	18	5.2	4.3	4.0	0.40	0.55	8.89	1.70	11.5	27.8	9.5
Inia_LE	1	Fr						1.64	0.20	0.96	10.00	2.20	13.40	19.10	
Inia_LE	2	Fr						1.91	0.68	1.10	13.10	5.30	20.20	23.90	
Inia_LE	3	Fr Ac						2.3	0.18	0.32	10.30	2.30	13.10	16.20	
Inia_LE	4	Ar						1.81	0.11	0.40	14.60	2.30	17.40	22.30	
Inia_LE	5	Fr Ar						2.33	0.13	0.44	22.90	3.80	27.30	30.70	
Inia_LE	6	Fr Ac						2.28							
Inia_LE	7	Fr						1.64							
Inia_LE	8	Fr						2.01							
Inia_LE	9	Fr						1.97							

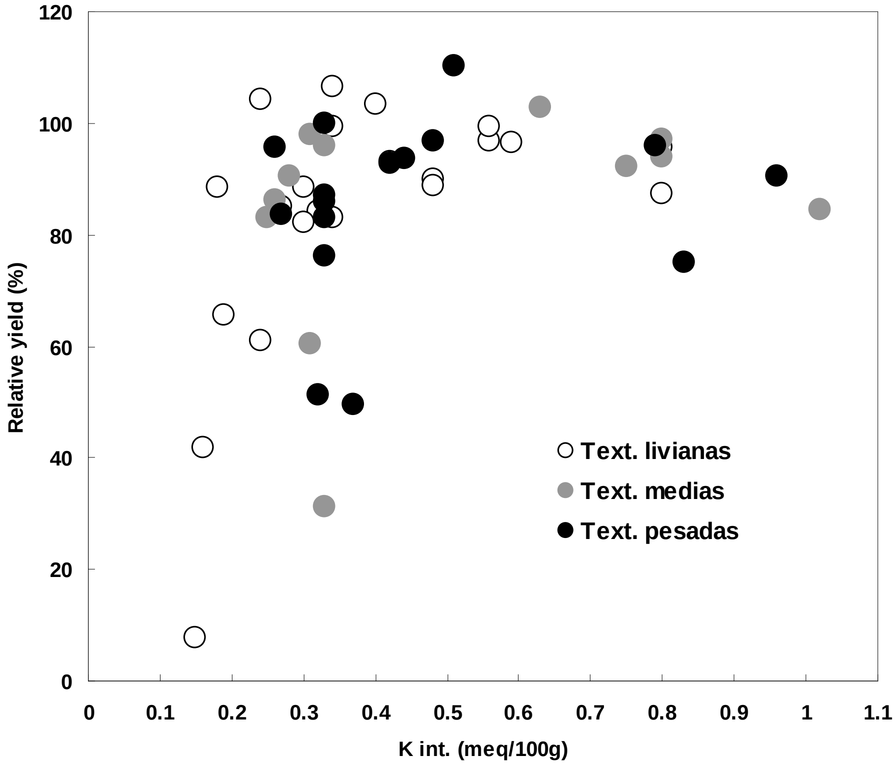

Fig. 1. Relative yield and potassium exchangeable for the potassium fertilizer studies.

Study 2. Buffer capacity of K in soils of Uruguay

A study of the buffering capacity should be another approach to understand the dynamic of K. When ions are added or removed from the soil solution exerts a resistance to change according to their effect concentration buffer or buffer capacity. Plants take up K from the soil solution that is easily replenished by the exchangeable K in a rapid equilibrium. When these two forms decrease, the K of non-exchangeable form tends to maintain the balance of the other forms, at a slower rate.

Buffer effect is given by the resistance to change of concentration in soil solution when ions are added or extracted from the soil solution. When plants absorb ions from the soil solution, it is expected that the soil replace the amount extracted. When fertilizer is added, the ions are retained by the soil, adsorbed on the surface of the particles. Moreover, these reactions occur faster when the nutrient content in the soil is low. As the particles are saturated will maintain higher levels of nutrients in solution and this causes an increase of concentration in the soil solution, which will be greater the larger the aggregate amount. Consequently, the graph that relates the concentration of the nutrient solution with respect to the total available nutrient is not a line but a curve. According to Junk et al. (1995), one can calculate the soil buffer as follows: b= change C /change CL, where = change C is the change in total concentration (adsorbed + solution) of the nutrient in the soil (mol cm^{-3} soil); change CL is the change of concentration in the soil solution (mol cm^{-3} soil solution).

The knowledge of the shape of the buffering capacity of soils, and its relationship to other properties (texture, type of clay) will help us better understand the processes that occur when K fertilizer is added to soils. This fact is especially important since K fertilization is not fully incorporated as a routine practice, and requires more elements than the simple fact of the amount of exchangeable K to improve fertilizer recommendations. Therefore, the objectives of this study are: 1) to study the buffer K properties in 4 contrasting soils, 2) correlate these patterns with soil characteristics.

Activities

This experiment was installed in the Facultad de Agronomía, in June 2010. We use 4 soils, 5 K rates, and 3 replications. The soils used in this experiment were taken from the surface layer soil (0-15 cm) of contrasting soil properties. Soils (1 kg) with filed moisture (fresh soils), were crumbled to pass a sieve of 1 cm, and then spread in a thin layer on a nylon. Solution containing K was added to the soils, in amounts corresponding to 0.0, 0.25, 0.50, 0.75 and 1.00 meq K / 100 g soil. This solution also contains N and P. Enough water was added to bring soils to field capacity. The soils were placed in bags, and left in the greenhouse for two months, weighing the pots regularly to replenish the evaporated water.

The soil solution was displaced with water, using a 250 mL cylinder with a hole in the bottom covered with moist soil up with a layer of sand 1 to 3 cm. The displacement was made slowly by dripping water on the top. Depending on the conditions (soil moisture, texture), the first drops of soil solution were displayed on the bottom after two to six hours.

Soil exchangeable K and K in the soil solution were extracted with ammonium acetate for subsequent determination by emission spectrometry.

Photo 1: Experiment in greenhouse: Bags containing soil with different amount of K.

Photo 2: Soil solution displacement.

Preliminary results

The soil types used in this study presented different relationship between the K added and K in solution, suggesting the different buffering capacity of the soils, and this was similar for both sampling dates (Fig. 2).

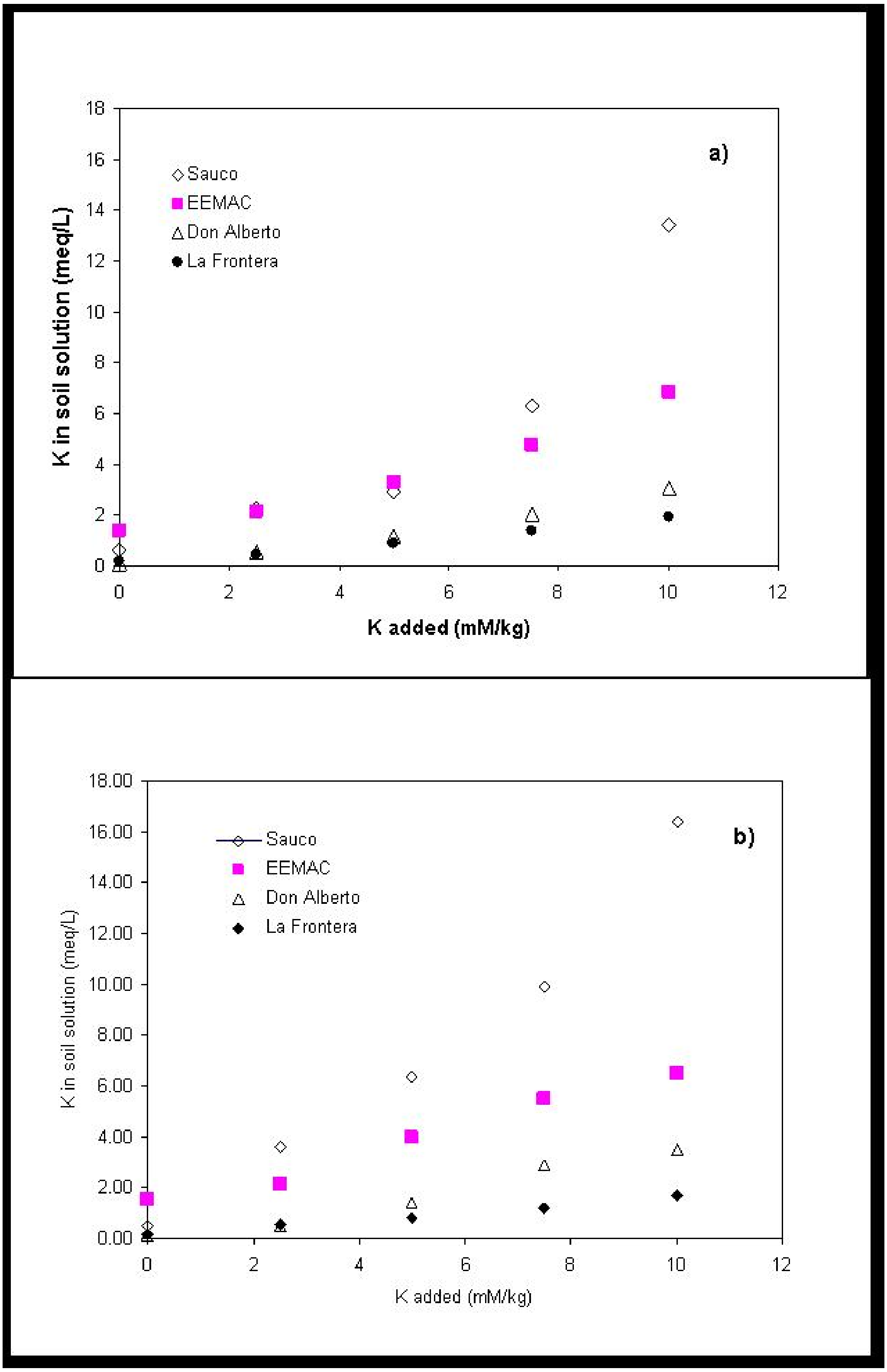

Fig. 2. K in soil solution in relation with K application for four different soils. a) 30 days and b) after 60 days of K application.

3. Study of K leaching from crop residues and temporary changes in soil exchangeable K

Under soil conservation systems, crop residues are leaved on the surface of the soil, affecting the distribution of nutrients in time and space. There is very little information on the fate of K from crops and their influence on the K exchangeable. This information is useful also to understand the dynamics of K in soils. Therefore, it is proposed to study the leaching or release of K from crop residues by experiments in situ.

Activities

Experiments *in situ* tests are being conducted in corn and soybean at the Experiment Station Mario A. Cassinoni (EEMAC) Dept. of Paysandú. Composite crop residues samples of 50 g (stems and leaves) were placed within litter bags (one per sampling date and repetition). A sample of crop residue was taken for the calculation of dry matter at the beginning of the experiment, and analysis of K. Soil temperature registers were placed on the surface and rain is registered periodically. All the litter bags were covered with a wire mesh for protection. The sampling is made periodically every 15 days until the second month, and then every month for 12 months. Each time a sample bag is removed for weighing, grinding and analysis, to determine dry matter loss and K content. Crop residue K content is determined by emission spectrometry.

At the same time, in this research we are studying the changes in soil exchangeable K, with periodic sampling for 12 months at depths of 0-3, 3-6, 6-9, 9-12, and 12-15 cm. This stratification allows more information about the dynamics of K in production situations. Exchangeable K is analyzed by the ammonium acetate method, measuring the K emission in the samples. All the analysis is made in the laboratory of Soil Fertility of the Faculty of Agronomía, Montevideo.

The study is being conducted since April 28, 2010, and it will continue until no more crop residues remain in the bags. Crop residues and soil sampling are made by the student María José Fiorelli and M. Barbazán. Samples are taken to the lab and analyzed by María José Fiorelli and supervised by Lic. Jimena Rodríguez.

Preliminary results

Preliminary results are shown in the following figures (Figs. 3 to 6). The K concentration of corn and soybean decreased with the sampling date. Precipitation amounts are related with this process. The K concentration at the harvest date in corn and soybean were 0.87% and 0.86%, respectively.

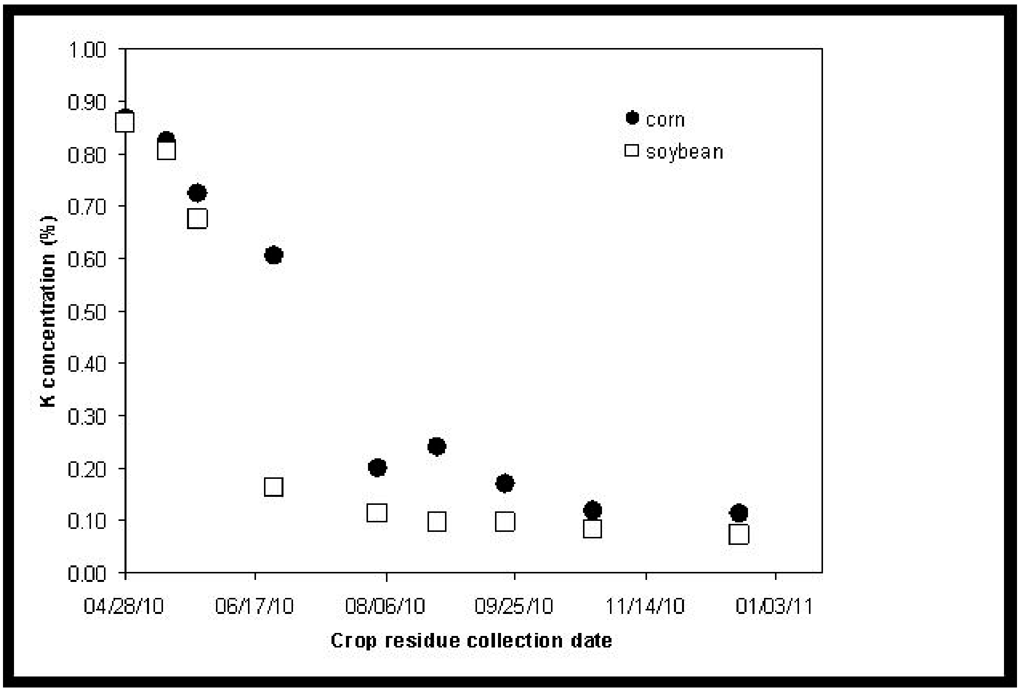

Fig. 3. Potassium concentration in crop residues for different sampling dates.

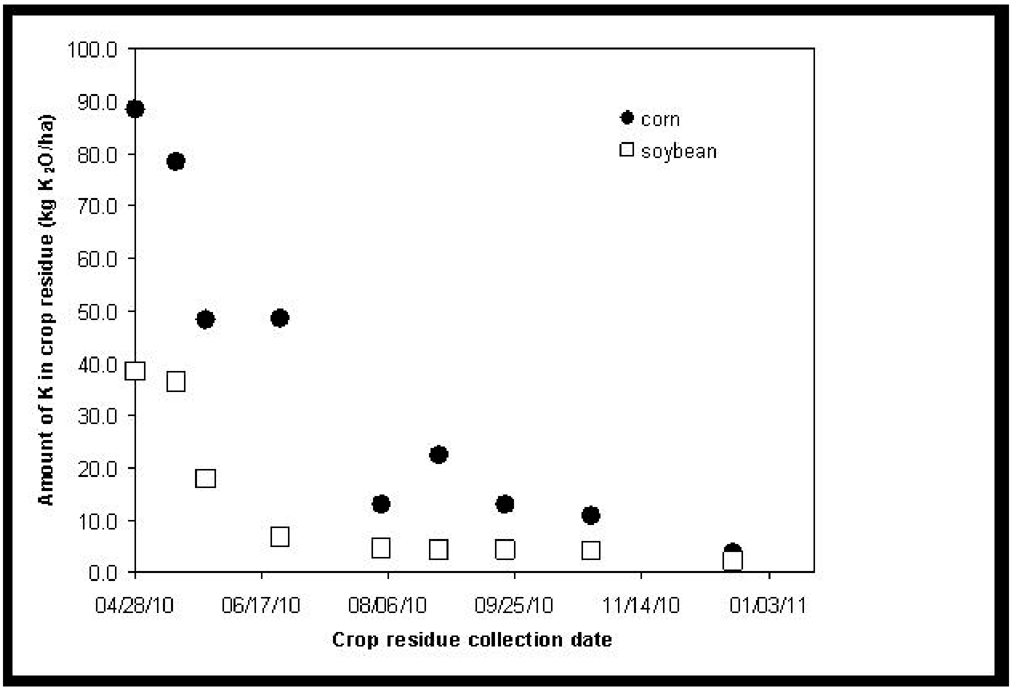

Fig. 4. Amount of potassium leaching from crop residues in different sampling dates.

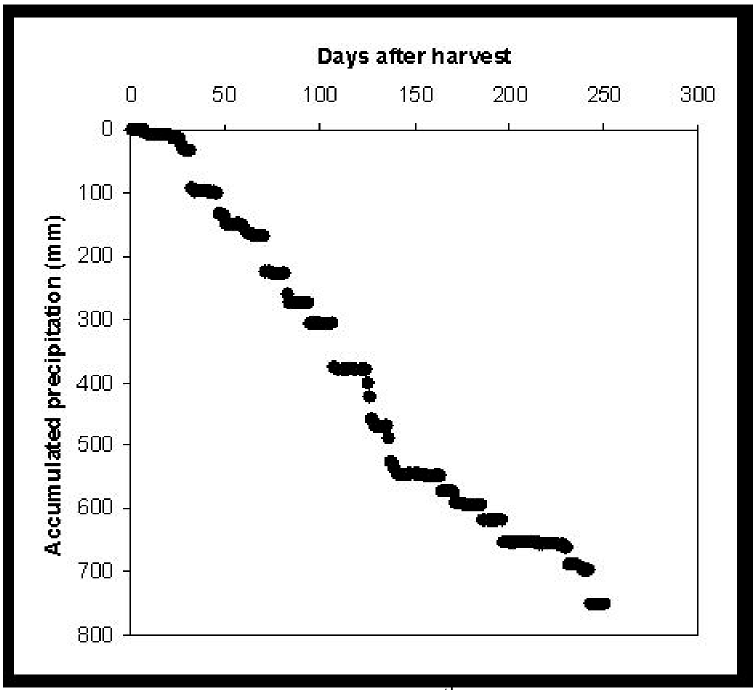

Fig.5. Accumulated precipitations since April 28th 2010 to January 2011.


Photo 3: Crop before harvest.


Photo 4: Litter bags with crop residue for the leaching study. On the left: soybean residues; on the right: corn residues.


Photo 5: Soil samples to study the temporal variation of K in the soil. On the left: soil sample at 15 cm depth; on the right: soil sample cores cut each 3 cm.

Fig. 6 shows the soil pH variation in depth for four soil sampling dates for the two crops evaluated. The rest of the analysis (K, P, Ca, Mg, and Na) is in process.

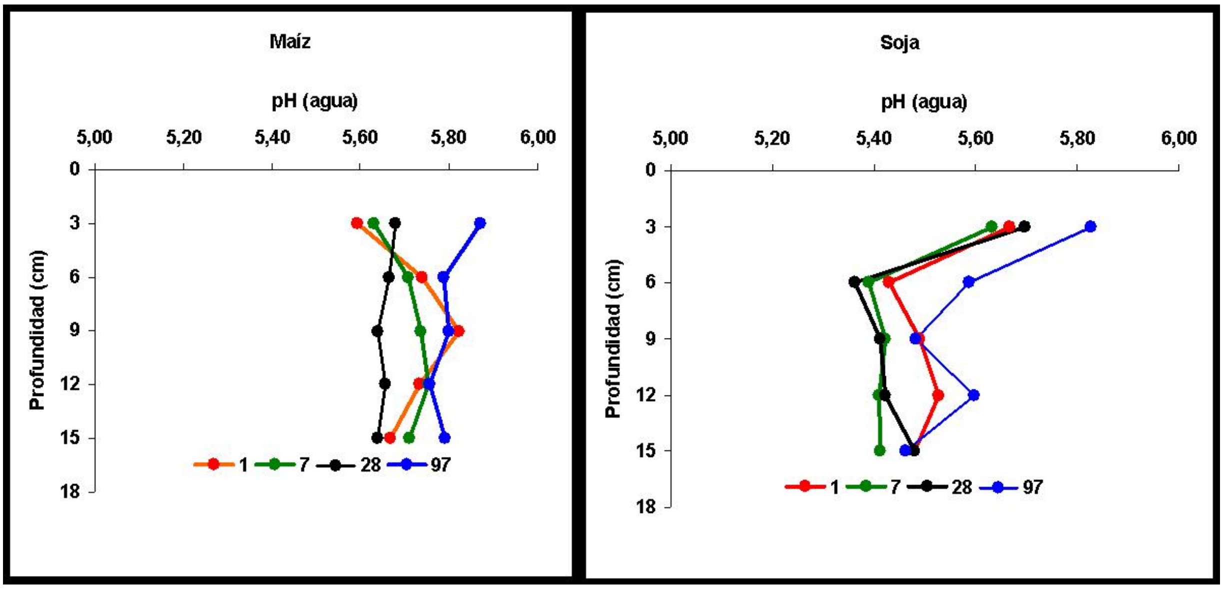

Fig. 6. Soil pH variation in depth.

Study 4. Equivalent K fertilizer

When we make recommendations for fertilization, we assume that there is an equivalent fertilizer. In the case of K, this refers to the rate of K required to raise the level of soil K by 0.1 meq / 100 g of soil, which is about 117 kg of K_2O/ha. This value is theoretical, since it means that the cation exchange is instantaneous, there is no fix or release of fixed K from the soil and that everything happens in the 20 cm deep. However, this value can vary depending on the soil. For this we need to know how much exchangeable K changes when we add K. This experiment was set with 36 soils from different parts of Uruguay, and is currently carried out by an undergraduate student as a Thesis with the help of Jimena Rodríguez.

Activities

The first activity was to get soil samples (about 8-10 kg) from the representative zones of the agricultural production (Fig. 7). Soils were sent to our lab by technicians or producers. Soil samples were crushed with a sieve opening of 1 cm, spread a thin layer of each sample on a tray, and fertilizer solution added evenly for each treatment. Approximately 800 grams of soil were placed in plastic trays, adding enough water to reach field capacity. The moisture of each experimental unit was kept constant during the experiment. Soils were characterized for texture, pH, organic matter, CEC, and P (Table 2).

Two treatments were applied: a solution containing K in doses equivalent to 0 and 117 kg/ha of K_2O. Each treatment was repeated 3 times, and exchangeable K was determined in two soil sampling dates: 30 and 60 days after the experimental setup.

The experiment set up was established by Amabelia del Pino, Jimena Rodríguez, Mónica Barbazán, and the student Gabriel Faggionato. The maintenance of water content, and soil samplings and analysis were conducted by Gabriel Faggionato. Soil analyses were supervised by Jimena Rodriguez.

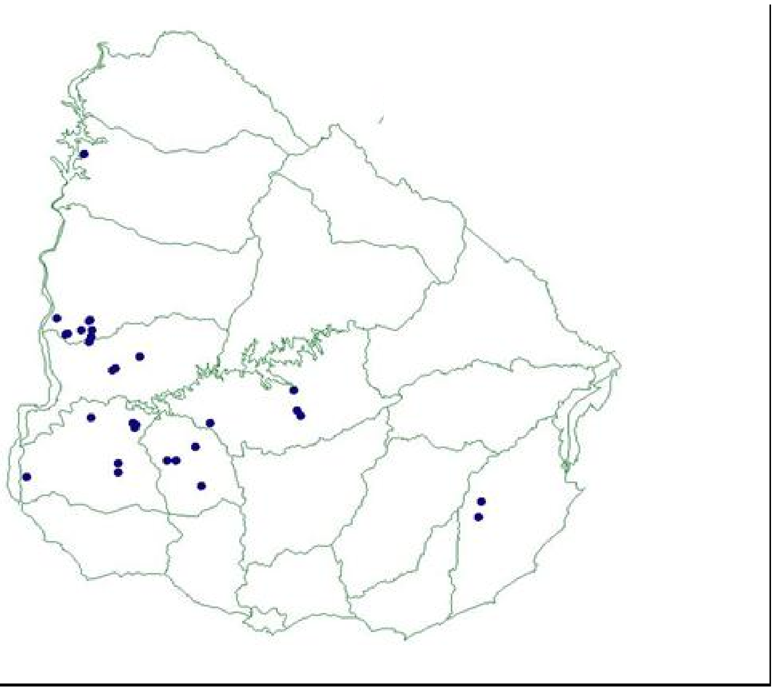

Fig. 7. Location of soil samples.

Preliminary results

Preliminary results from this study shown that equivalent fertilizer ranged from 103 to 417 kg K_2O/ha, with an average of 215 kg/ha of K_2O. This is part of the undergraduate thesis of Gabriel Faggionato.

This study is almost done. We are checking the results and running some extra analysis. The thesis is expected to finish by March 2011.

Table 2. Selected soil properties.

Soil	Coarse	Silt	Clay	pH (H_2O)	pH (KCl)	SOM	Na	K	Ca	Mg	BT	CEC	SB	P Bray1
	……… % ………					%		……… meq/100g ……					%	mg/kg
1	35	37	28	5.5	4.8	6.2	0.32	0.32	23.26	3.35	27.3	41.5	65.7	29.3
2	21	50	29	5.4	4.9	7.0	0.35	1.21	23.20	1.90	26.7	45	59.2	22.5
3	41	48	11	4.4	3.9	4.7	0.46	0.37	4.61	1.29	6.7	25.2	26.7	5.9
4	25	47	28	4.9	4.6	7.5	0.41	0.46	19.00	3.23	23.1	46.6	49.6	7.4
5	16	53	31	5.4	4.6	5.9	0.59	0.42	17.26	3.56	21.8	58.2	37.5	6.1
6	14	56	30	5.7	5.0	5.6	0.45	0.46	20.55	3.77	25.2	42.3	59.6	20.1
7	31	41	28	5.6	5.0	5.0	0.45	0.57	20.61	3.28	24.9	38.4	64.9	6.6
8	15	58	27	6.2	5.5	6.9	0.50	0.47	22.46	3.48	26.9	28.9	93.1	6.6
9	39	40	21	6.3	5.6	6.0	0.44	0.98	24.52	2.91	28.9	35.2	82.0	33.7
10	31	44	25	5.4	4.8	5.6	0.43	0.66	16.25	2.16	19.5	36.1	54.0	16.3
11	40	34	26	5.9	5.3	6.9	0.38	1.47	22.71	2.09	26.7	52.6	50.7	15.6
12	39	34	27	6.1	5.2	6.1	0.35	0.96	20.08	1.92	23.3	49.5	47.1	21.3
13	26	56	18	5.2	4.3	4.0	0.40	0.55	8.89	1.70	11.5	27.8	41.5	9.5
14	41	33	26	7.9	7.2	5.9	0.33	0.69	34.55	0.53	36.1	42.3	85.3	12.9
15	36	35	29	5.8	5.1	6.6	0.38	0.67	25.24	2.37	28.7	39	73.5	10.6
16	36	32	32	7.5	6.8	7.7	0.34	0.57	39.68	0.95	41.5	44.5	93.3	8.8
17	39	36	25	5.4	4.5	6.0	0.40	1.22	14.31	4.05	20.0	42.3	47.2	2.9
18	42	33	25	5.6	5.1	5.2	0.35	0.97	20.05	1.63	23.0	44.9	51.2	12.9
19	35	41	24	4.9	4.6	4.5	0.38	0.48	19.16	1.97	22.0	39.8	55.3	10.6
20	52	23	25	5.5	4.8	6.3	0.41	0.30	18.26	2.56	21.5	37.8	57.0	15.8
21	32	40	28	5.6	5.0	6.8	0.35	0.77	23.54	2.16	26.8	35.9	74.7	10.4
22	46	26	28	5.1	4.6	6.0	0.40	0.31	22.26	2.67	25.6	40.5	63.3	10.6
23	42	31	27	5.7	5.0	5.7	0.36	0.71	22.30	1.52	24.9	37.5	66.4	18.6
24	31	40	29	5.7	5.3	6.8	0.39	0.53	21.43	1.94	24.3	48.1	50.5	
25	33	45	22	5.1	4.6	6.4	0.39	0.53	18.10	1.86	20.9	39	53.5	13.8
26	51	31	18	5.1	4.5	5.3	0.37	0.45	12.80	2.84	16.5	30	54.9	7.7
27	65	31	4	4.3	3.8	2.1	0.30	0.20	2.54	0.68	3.7	15.7	23.7	13.4
28	37	39	24	5.4	4.7	4.7	0.38	0.43	20.06	3.13	24.0	30	80.0	21.9
29	58	21	21	5.2	4.6	4.1	0.44	0.20	11.11	2.25	14.0	30.4	46.1	8.8
30	22	57	21	5.6	5.0	5.3	0.43	1.58	14.72	2.06	18.8	35	53.7	17
31	50	27	23	5.1	4.5	6.1	0.42	0.38	17.03	3.92	21.8	41.9	51.9	65
32	36	31	33	5.4	4.8	6.3	0.42	0.46	25.03	3.42	29.3	58.3	50.3	12.9
33	51	25	24	5.7	4.9	4.2	0.40	0.15	20.14	3.37	24.1	38.1	63.1	14.4
34	44	33	23	5.3	4.6	5.4	0.70	0.20	13.78	3.00	17.7	32.8	53.9	17.4
35	28	41	31	6.1	5.3	4.3	0.44	0.39	22.86	2.86	26.6	38.5	69.0	10.6
36	66	17	17	5.8	5.0	4.3	0.33	0.23	15.39	1.61	17.6	27.3	64.3	3.8

Photo 6. Equivalent potassium fertilizer study.

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