Potassium research at Uruguay

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The Oriental Republic of Uruguay is located in the southeastern region of South America. It is bordered by Argentina to the west and Brazil to the north and east, with the "*Río de la Plata*" ("Silver River") to the south and with the Atlantic Ocean to the southeast. Uruguay is home to 3.3 million people, with an area of approximately 176,000 km^2. Agriculture at Uruguay contributes to 11.8% of the gross domestic product (GDP), almost half from livestock and half from crop and vegetable production (DIEA-MGAP, 2015). Agriculture is largely oriented towards exportation with agricultural products representing 75% of the total exportations, mainly soybean, beef cattle, dairy products, forestry, and rice.

Agriculture at Uruguay has historically developed in high potassium (K) soils, under conventional tillage and crop rotations that included pastures, resulting in no K fertilizer recommendations (Hernández, 1997, Hernández et al., 1988). However, soils of Uruguay present a wide range of soil test K (STK) (**Fig. 1**). According to the Soil Survey Guide of Uruguay, soil units covering approximately 5 million ha would have low K availability. In the typical historical agricultural area of western Uruguay, native STK has been medium to high.

Efforts to understand soil K dynamics have been scarce compared with those for understanding nitrogen (N) and phosphorus (P) dynamics, which have been studied in different situations and cropping systems. Initial studies in K response to fertilization were done for crops that have high-K requirements such as sugarcane, sugar beet, potato, onion, and cotton, for which some guidelines for fertilizer recommendations based on soil type were established. In grain crops, the first K studies were made in the 60's, and K responses were observed in wheat grown in soils developed from cretaceous sandstones (Moir and Reynaert, 1962). Two decades later, a few studies in soybean showed little or no K response in soils of the northeastern region (Colombo y Collares, 1982; Docampo et al., 1981; Marella et al., 1981). The lack of K studies has likely been due to the development of agriculture in high K soils, under conventional tillage and crop rotations that included pastures, resulting in no K fertilizer recommendations. Potassium fertilization was recommended only below 0.30 cmol kg^{-1} (117 ppm) (Oudri et al., 1976), following the references of the US Corn Belt, which reported low K response probability with STK over 0.23-0.33 cmol kg^{-1} (90-130 ppm) in soybean and maize under conventional tillage.

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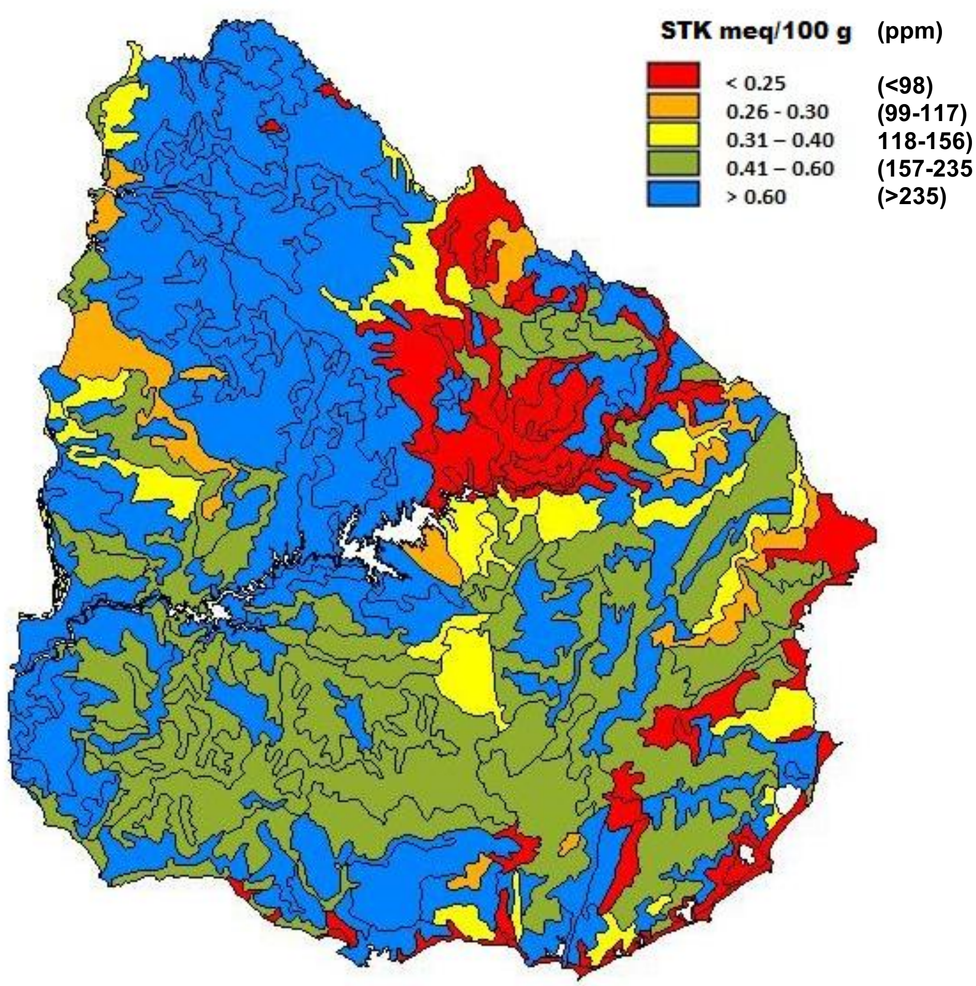

Fig. 1. Soil test K (STK; 0-20 cm) according to the soil recognition guide of Uruguay. Scale: 1:1,000,000. From Califra y Barbazán (unpublished).

Agriculture scenarios of Uruguay have changed during the last decades driven by increasing grain prices (Wingeyer et al., 2015; Ernst et al., 2016). The annual cropped area increased from 700 thousand in 2002 to above 2 million ha in 2014, with soybean and wheat sown on 67% and 20% of the area in 2014, respectively. Cropping systems have been intensified, shifting the production systems from crop-pasture rotations to continuous annual cropping under no-till systems showing a current index of 1.5 crops per year (**Fig. 2**).

The K balances in Uruguay (application minus removal), have historically been negative due to the absence of K fertilization (Mancassola and Casanova, 2015). Furthermore, as soybean has increased in area in the last two decades, due to its high K requirements, K balance has become more negative; i.e., soybean exports for 2014 were 3.6 M t, implying a K removal of approximately 63,000 t of K_2O, considering an average grain content of K. In addition, agriculture has expanded to marginal soils in the northcentral and eastern regions of the country, where low STK soils are common.

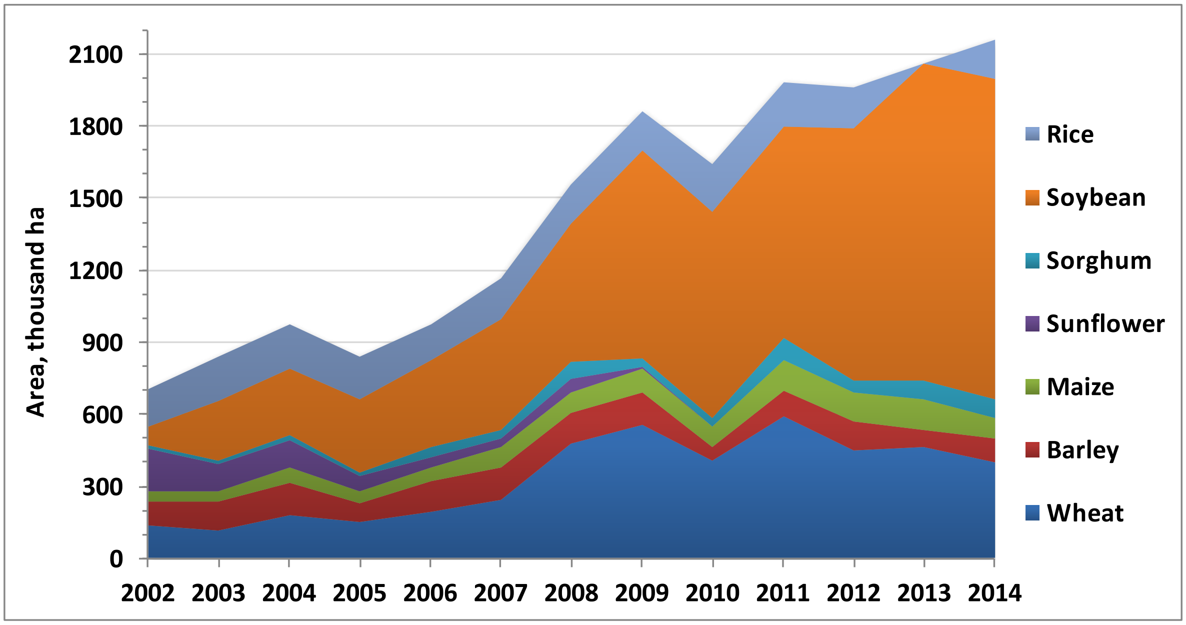

Fig. 2. Cropped area by the seven main crops in Uruguay during the 2002-2014 period. Based on DIEA-MGAP (2015).

Inception of K deficiencies and responses

In the late 90´s and early 2000´s, field research by the Faculty of Agronomy (UdelaR), INIA, and other organizations reported some cases of K deficiency symptoms in soils with low STK in maize, white clover, alfalfa, and *Lotus corniculatus* L. (Moron and Baethgen, 1996; Moron, 1998, 1999, 2000; Barbazan et al., 2007). Moreover, the increasingly frequent occurrence of visual K deficiency symptoms, confirmed by plant analysis, lead to more specific studies which showed K response in several crops.

Several experiments were carried out exploring and showing crop responses to K (Almada, 2006; Bautes et al., 2009; Cano et al., 2007; Garcia Lamothe et al., 2009). Barbazan et al. (2011) summarized data from 50 K–response experiments in barley, wheat, corn, soybeans, sorghum, and sunflower, conducted by different working groups from 2004 to 2010, in soils with different texture and STK levels. Potassium fertilizer increased crop yields in 15 of 50 sites ($p<0.10$). Across all sites and crops, the critical level of exchangeable K was 0.3-0.40 cmol kg^{-1} (120-160 ppm; 0-20 cm depth) (**Fig. 3**). This study represented a breakthrough in K research in Uruguay and its results have demonstrated the need for further studies of K dynamics in soils of Uruguay.

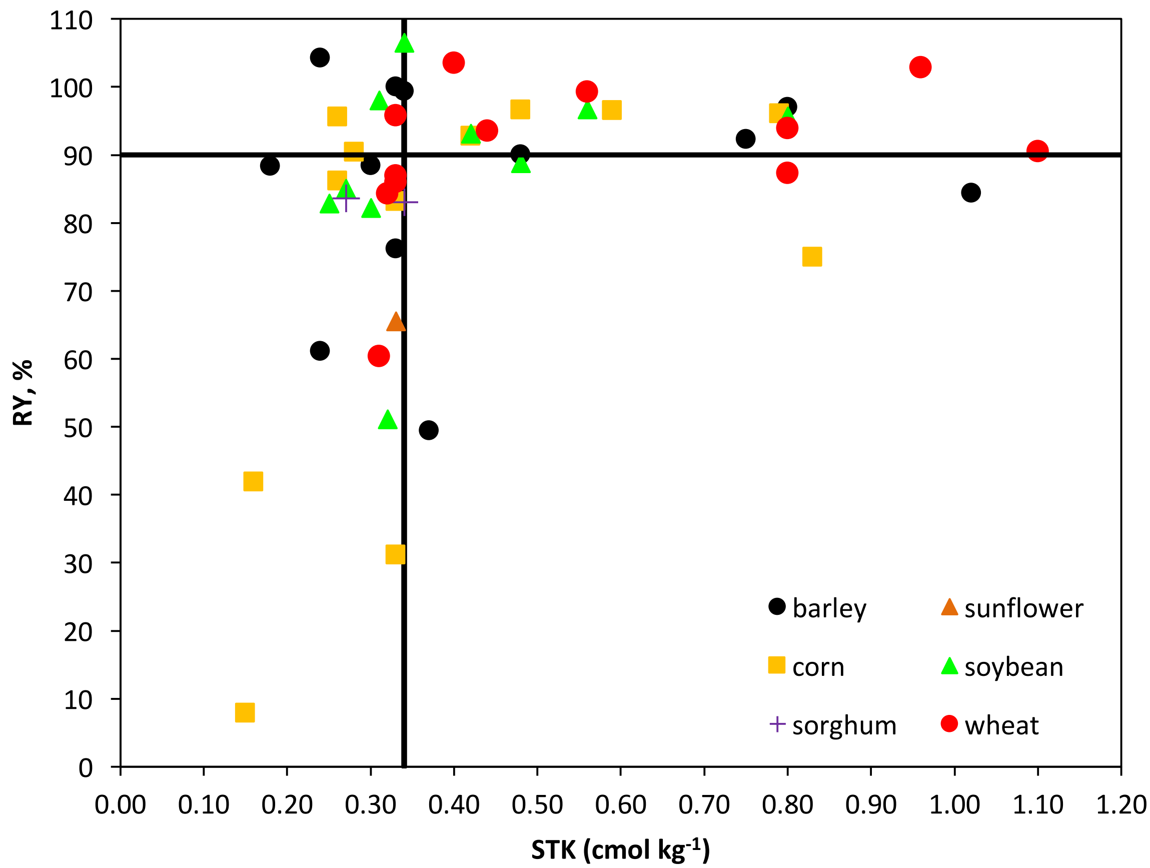

Fig. 3. Relationship between relative crop yield (RY) and soil test K (STK; 0-20 cm) in Uruguay. Based on data of 50 field experiments. RY expressed as the percent ratio between averaged yields of Check and Fertilized plots (100-200 kg/ha of KCl). Source: Barbazán et al. (2011).

Recent K research at Uruguay

Research in the last 4-6 years has been directed towards the improvement on the diagnosis of K deficiencies and crop responses. Several factors affect the relationship between STK, measured as exchangeable K, and K response by field crops: Drying of soil samples, sampling time, soil minerology, release of K from non-exchangeable fractions, etc. (Zorb et al., 2014). A summary of the recent and current issues under study at Uruguay is included below.

1. Update on soil test calibration for K (Barbazan et al., 2013)

Field studies developed after 2010 confirmed the STK critical range of 0.3-0.40 cmol kg^{-1} (120-160 ppm; 0-20 cm depth) observed in the initial studies (**Fig. 4).** However, the variability in the prediction of K response persisted and indicated the need to consider other factors which potentially would affect K response such as sampling time, STK variability across fields, drying of soil samples, soil texture, pH, and soil mineralogy, among others.

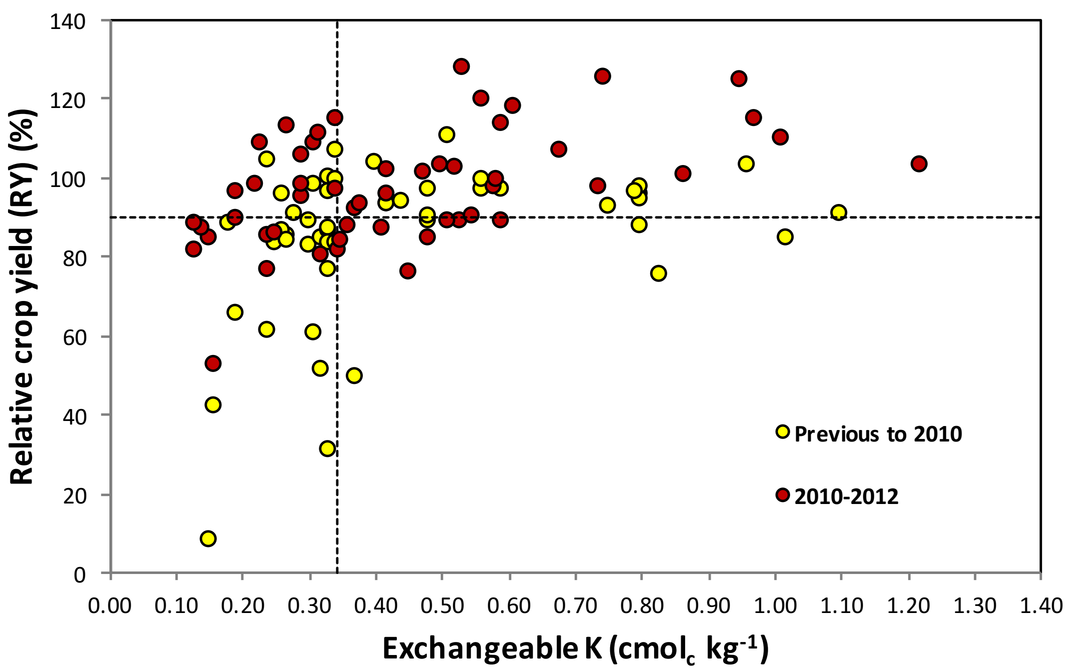

Fig. 4. Relationship between relative crop yield (RY) and exchangeable K (STK; 0-20 cm) in Uruguay. Based on data through 2010 and experiments conducted in 2010-2012 (n=57). RY expressed as the percent ratio between averaged yields of Check and Fertilized plots. Source: Barbazán et al. (2013).

2. Estimation of the K fertilizer equivalent for Uruguayan soils (Faggionato, 2011)

Faggionato (2011) studied the changes of STK under the application of different fertilizer K in 36 agricultural soils under controlled incubations (**Fig. 5**). Field work has shown that rates of K needed to increase 0.1 cmol kg^{-1} soil of exchangeable K varied from 127 to 526 kg K_2O ha^{-1}, averaging 231 kg K_2O ha^{-1} (4.9 kg K ha^{-1} per ppm K). Data for Iowa (USA) indicates that there is a need of 106-354 kg K_2O ha^{-1} to increase 0.1 cmol kg^{-1} soil of exchangeable K (2.3-7.6 kg K ha^{-1} per ppm K) (Mallarino et al., 2013).

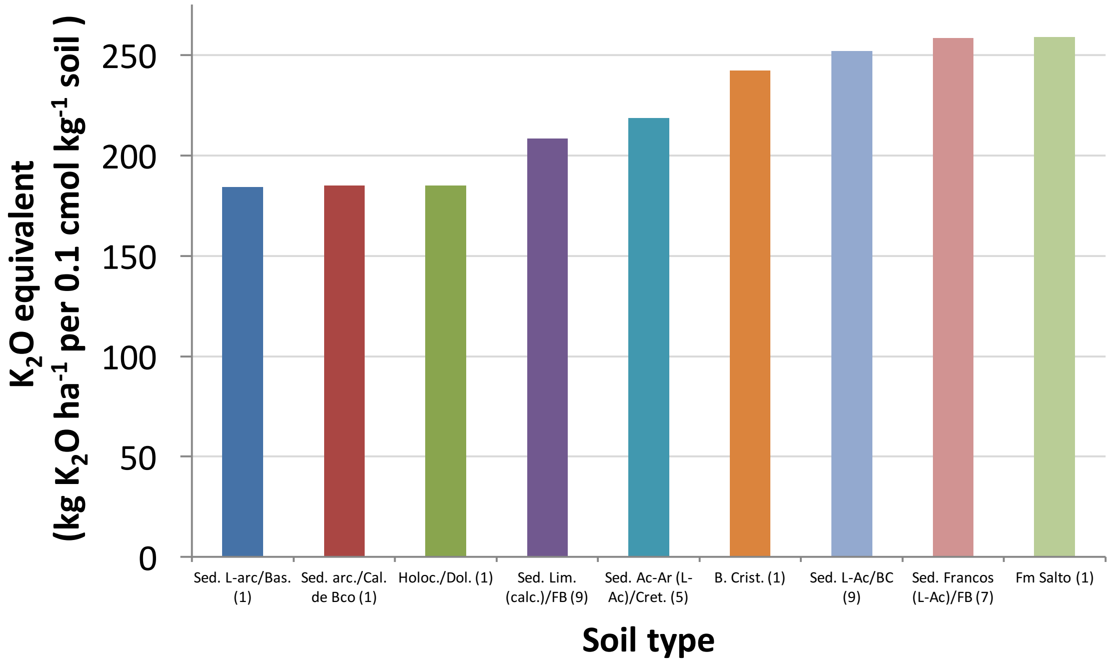

Fig. 5. Rate of K_2O equivalent (kg K_2O ha^{-1} per 0.1 cmol kg^{-1} soil) for different soil types of Uruguay under controlled incubations. Source: Barbazan et al. (2011).

3. Potassium release from maize and soybean residues and temporal variation of STK (Barbazan et al., 2011)

Quality and management of crop residues, may affect K distribution with soil depth, and it should be considered by soil survey/sampling and fertilizer recommendations. Work by Barbazan et al. (2011) showed that STK varied at different depths depending on K release from crop residues (**Fig. 6**).

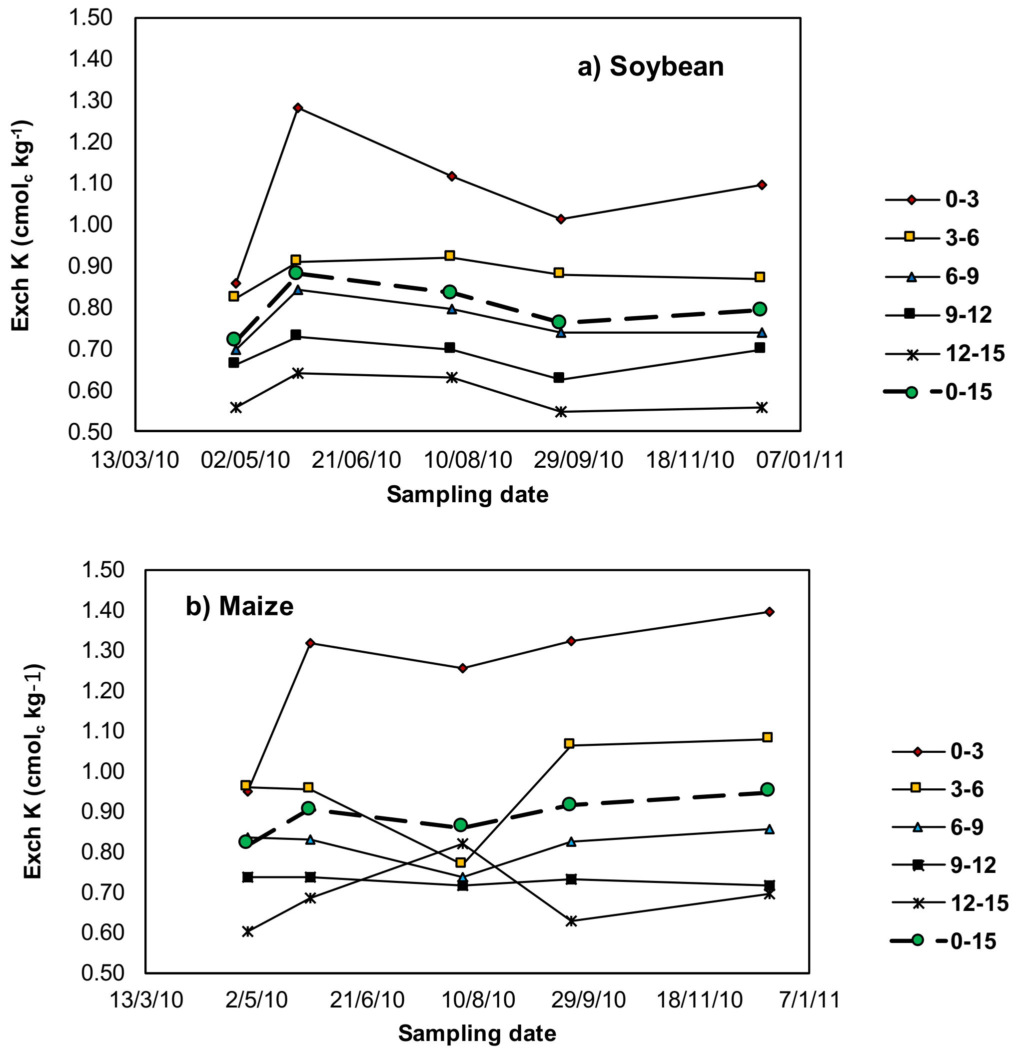

Fig. 6. Temporal variation of exchangeable K (Exch K, STK) after harvest of a) soybean and b) maize according to soil depth (cm). Adapted from Barbazán et al. (2011).

4. Survey of commercial soybean fields (Bordoli et al., 2012)

Bordoli et al. (2012) evaluated nutrient deficiencies of 178 commercial fields widely distributed around the country, using soybean as indicator crop. During the 2009/10 and 2010/11 cropping seasons, a nutritional soil and plant survey was conducted, collecting soil and leaf samples at the R1-R2 soybean growth stage. Soybean yields ranged from 511 to 5435 kg ha^{-1}. In 23% of the fields, STK, measured as exchangeable K, was below 0.30 cmol kg^{-1}. The concentrations of K in leaves for all the samples was of 2.03% (±0.53). The more frequently deficient nutrients were P, K, and N, with 42%, 39%, and 13% of the fields with concentrations in leaves below the critical concentrations (**Fig. 7)**. The results show that the actual soybean productivity could be partially affected by K deficiencies, suggesting that K corrections need to be considered in the nutritional management program for each crop production system.

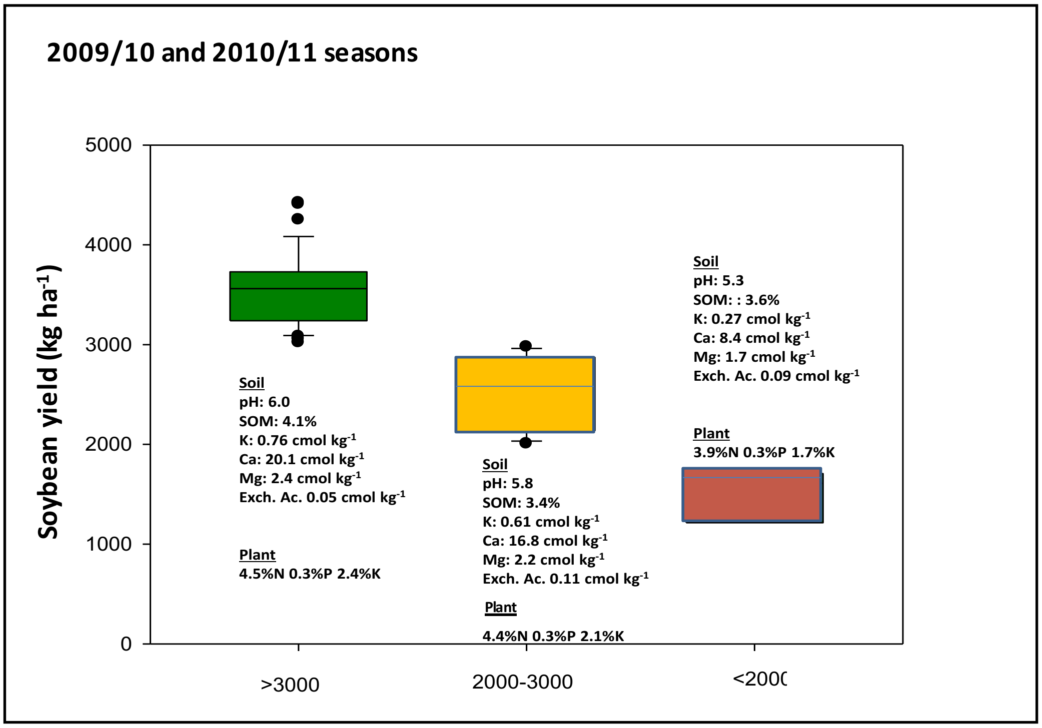

Fig. 7. Soybean grain yields according productivity and relationship with soil and plant variables. Median (thin center line), and percentiles (10, 25, 75 and 90) for yield. Adapted from Bordoli et al. (2012).

5*. STK determination in moist samples (Barbazan et al., 2013)*

STK determination is usually carried out in dry samples at the soil testing laboratories. Research by Barbagelata and Mallarino (2013) has shown improved soil test calibration when STK is determined in field-moisture condition (moist) samples. Barbazan et al. (2014, unpublished) have observed similar results evaluating soil samples from field experiments at Uruguay. **Fig. 8** shows that STK would be overestimated when determined in dry samples at the low STK range. This would be one possible cause of the poor calibration observed in some datasets.

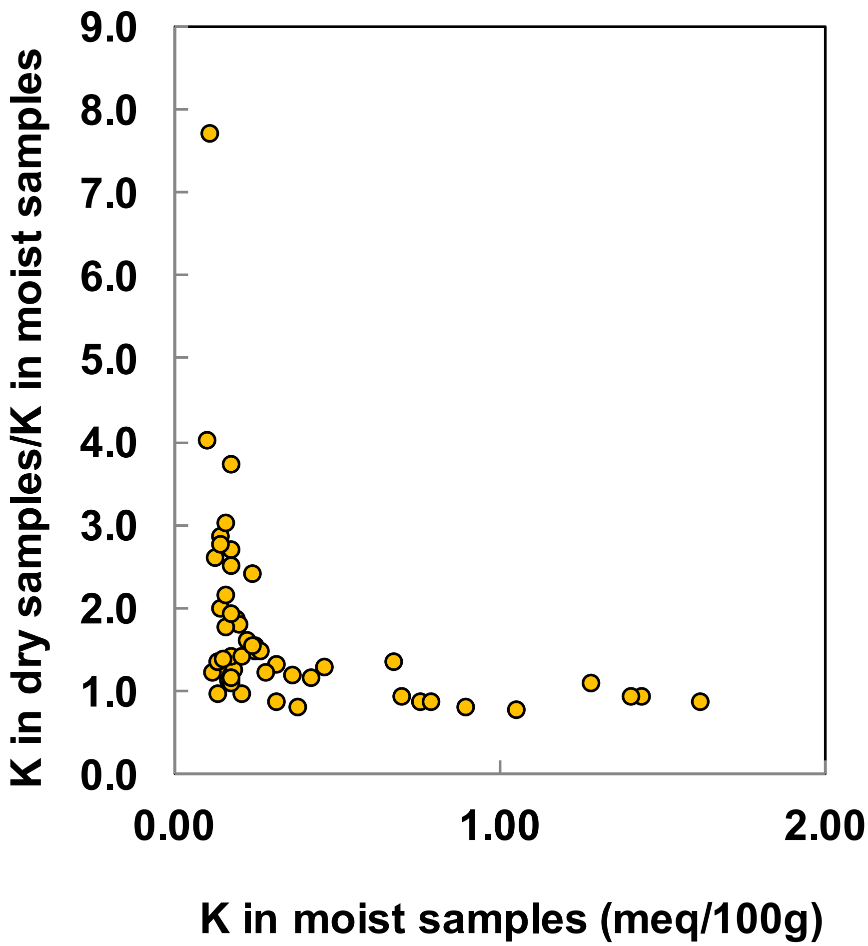

Fig. 8. Relationship between the STK in dry samples/STK in moist samples with STK in moist samples.

6. Evaluation of non-exchangeable K fractions (Na-tetraphenylborate extraction) improved the correlation between STK and yield response (Nuñez, 2014).

Nuñez (2014) evaluated the sodium tetraphenylboron- (NaTPB) extraction, a method that allows the quantification of plant-available non-exchangeable K. The NaTPB method showed a superior estimation of plant-available K and a stronger relationship with soil K balance than the ammonium acetate extraction because of its capacity to extract exchangeable K plus a proportion of nonexchangeable K which is available to plants (**Fig. 9**). The NaTPB method is considered promising to estimate soil K reserves and to monitor K evolution in soil.

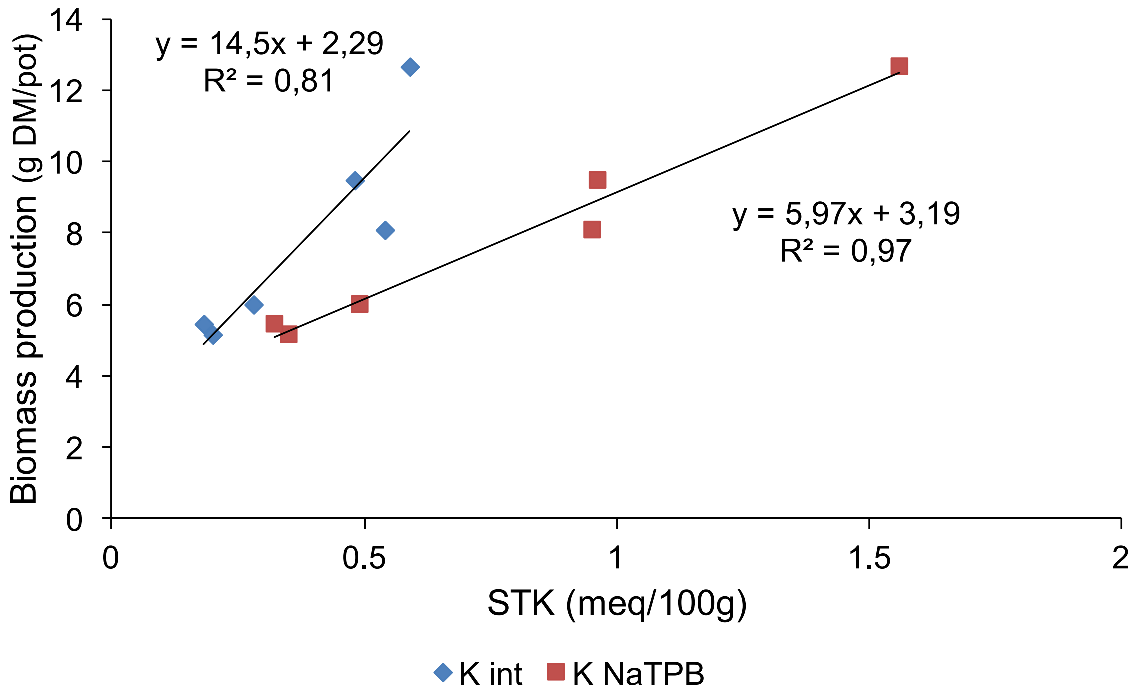

Fig. 9. Relationship of dry matter production with exchangeable K and K extracted with NaTPB. From Nuñez (2014).

7. Variability of STK and relationship with response to potassium fertilization in soybean: edaphic and topographic properties association with crop response (Coitiño, 2016)

Work by Coitiño (2016) looked to: (i) quantify soybean crop response to potassium (K) fertilization in variations of the soil K supply near the exchangeable K (STK) critical level; (ii) study associations between soybean crop response to K fertilization and other soil and topographic properties; (iii) study crop response to K fertilization temporal variation; and (iv) identify zones within the field with different crop response to K fertilization. A strip fertilization experiment was installed during two years (2012 and 2013) in the same field under soybean crops. Spatial variation analysis allowed to identify zones within the field using STK in 2012 in a cluster analysis (**Fig. 10**). STK in sites without K fertilization was 0.46 cmol kg^{-1} in 2012, and 0.40 cmol kg^{-1} in 2013. Differences between years in soil K supply impacted in early K deficiency symptomatology, early dry weight and K nutritional level in reproductive stage. There was significate yield response to K fertilization only in 2013, yield response was different between zones. Responses to K fertilization were related to STK. No other additional properties were identified to complement the interpretation of the soil K test and to explain more exactly crop response to fertilization.

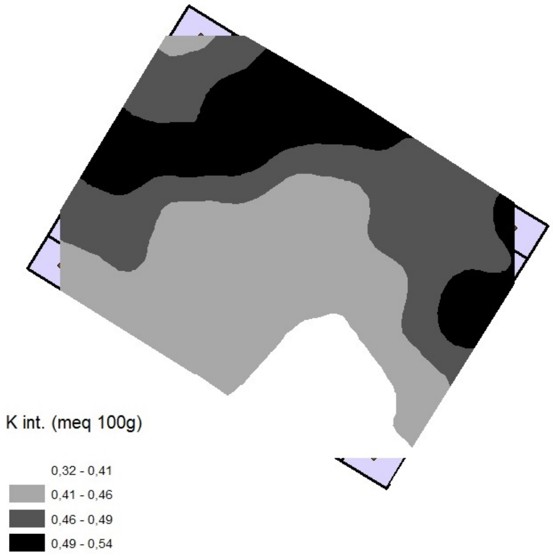

Fig. 10. Soil test K (STK, exchangeable K) map for the long-term experiment located at La Manera farm at Paysandú (Uruguay). Source: Coitiño (2016).

Final considerations

Results from research in the last years have largely contributed to the increase in K_2O importations at Uruguay which have gone from 9,000 t in 2003 to 146,000 t in 2013 (**Fig. 11**).

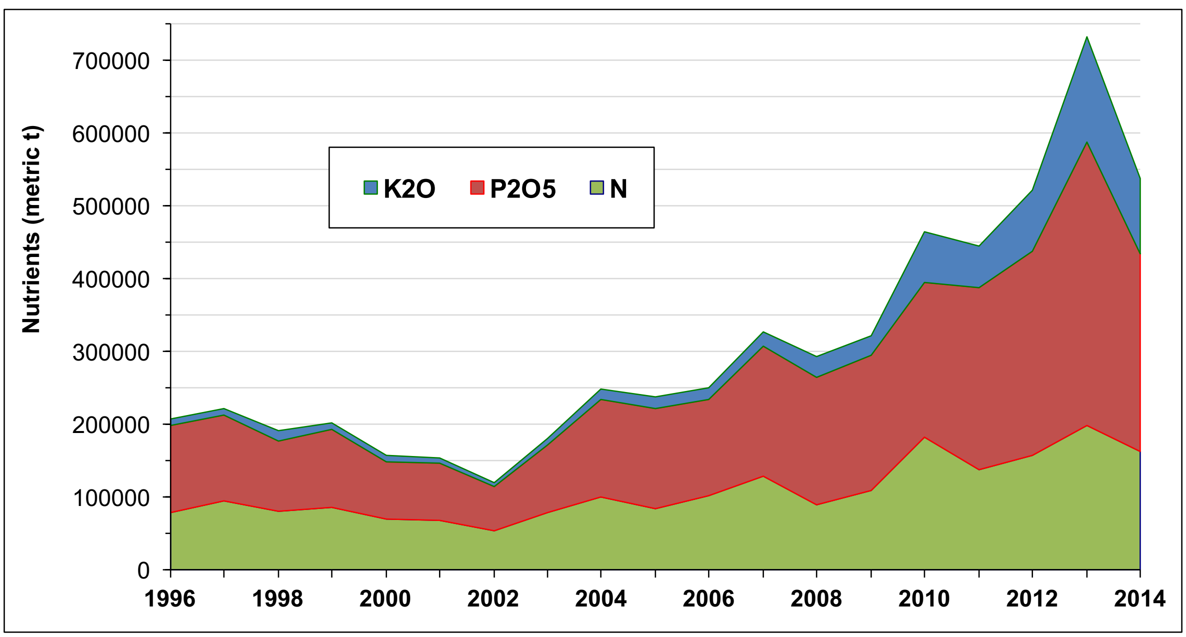

Fig. 11. Nutrient importations at Uruguay in the 1996-2014 period. Based on DIEA-MGAP (2015).

Future research and experimentation will have to focus on the relationship of K dynamics with soil mineralogy and physical properties, and with changes in cropping systems and soil management history in the medium and long term. These studies would be useful to improve K fertilization guidelines. Potassium use efficiency depends on understanding of K dynamics in the soil-plant system, as well as of crop and soil responses to soil fertility management.

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