# Long-term effect of different agricultural soil use and management systems on the organic carbon content of Uruguay prairie soils.

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## Background information

Uruguay continental area is 16.99 Mha, located between 30-35˚ S and 53-58˚ W. Annual average precipitation is 1100 mm (± 200 mm); mean annual temperature is 24˚C in summer and 12˚C in winter. The country belongs to the Río de la Plata Grasslands Physiographic Unit (Paruelo et al. 2001), that still occupy 65% of the territory. Topography is gently rolled; dominant slopes are 3-6%, with some flat plains and areas with more than 8%; mean altitude over the sea level is 140 m. In Soil Taxonomy, the most important soils are Molisols and Vertisols, but there are significant areas of Alfisols, Ultisols, Inceptisols, Entisols and Histosols.

Durán (1998) calculated the Uruguayan soils organic carbon (SOC) content, using the national general soil map (1:1 million scale, 99 mapping units). Values came from sampling and analyzing 200 profiles, mostly undisturbed soils. Therefore, his information represents the country potential SOC content. Durán results indicate that down to 1 m depth, soils of the country continental area can hold 2.3 Pg of SOC, with a mean value of 13.4 $kg.m^{-2}.m^{-1}$. This is 17% above the world average of 11.5 $kg.m^{-2}.m^{-1}$ (Eswaran et al., 1993 and 1995, cit. by Durán, 1998). It should be pointed out that the area occupied by the mapping units dominated by Molisols and Vertisols, representing 30.6% of the country, have SOC content from 15 $kg.m^{-2}.m^{-1}$ to 20 $kg.m^{-2}.m^{-1}$ and more. Also, 40-45% of these soils SOC is in the upper 20 cm of the profile.

Until mid XX Century agricultural use was continuous crops (CC) with conventional tillage (CT), being wheat the main crop, with several tillage operations and low crop residues return. This generated important erosion rates and soil degradation, affecting around 30% of the country surface by mid 60s, in the most productive soils areas (Cayssials et al., 1978, cit. by Durán and García Préchac, 2007). An actualization at the end of the XX Century (Sganga et al., 2005, cit. by Durán y García Préchac, 2007), showed the same proportion of affected territory (30.1%), separating the following categories: Slight 18.3%, Moderate 9.9%, Severe 1.3% and Very Severe 0.6%.

By mid 60s, there was a general adoption of crop-pasture rotations (CPR), cropping 3-4 years followed by other 3-4 years of seeded grass and legumes pastures for direct grazing. This change, even with CT, resulted in important erosion rate reduction and SOC content recovery during the pasture CPRs periods (Garcia Préchac et al., 2004). During the 90s no-till (NT) substituted CT; this, together with the CPRs, improved even more soil conservation (García Préchac et al., 2004).

Beginning the XXI century a new cropping intensification started, resulting in less pasture duration in the CPRs or even its elimination, generating a great increment of CC area. This dramatic change was due to new agricultural enterprises of great scale, generating structural changes in land size, tenure, and operational management (Arbeletche et al., 2010). Soybean became the new leading crop, growing its area from almost nothing (around 10 kha by 1999) to 1.4 Mha in 2014.

This took Uruguay without experimental data of it consequences on soils, because soybean was not previously important. Thus, models (USLE/RUSLE to estimate erosion, and CENTURY to estimate SOC) were used (Clérici et al., 2004, cit. by García Préchac et al., 2004; Morón, 2009). Their predictions indicated that CC with NT soybean monoculture is not sustainable due to its erosion rate and loss of SOC. Including winter cover crops or double annual cropping of soybeans and wheat could reduce erosion close to Tolerance (Typically 7 $Mg.ha^{-1}.year^{-1}$), but not the loss of SOC. Sustainability could be achieved with CPR-NT systems, producing erosion rates similar to the ones under natural grasses and keeping or modestly increasing SOC content.

## Experimental results

There are three long-term experiments in Uruguayan Argiudols, comparing soil use and management alternatives. The oldest started in 1962 in the Experimental Station INIA-La Estanzuela (lat…Long). Soil is a Typic Argiudol, Silty Clay Loam, 2.2 % SOC original content in 0-20 cm depth; site slope is 3.5%. Results during the period of CT soil management were reviewed by García Préchac et al. (2004). Figure 1 presents all SOC data, including the period after switching to NT management in 2007.

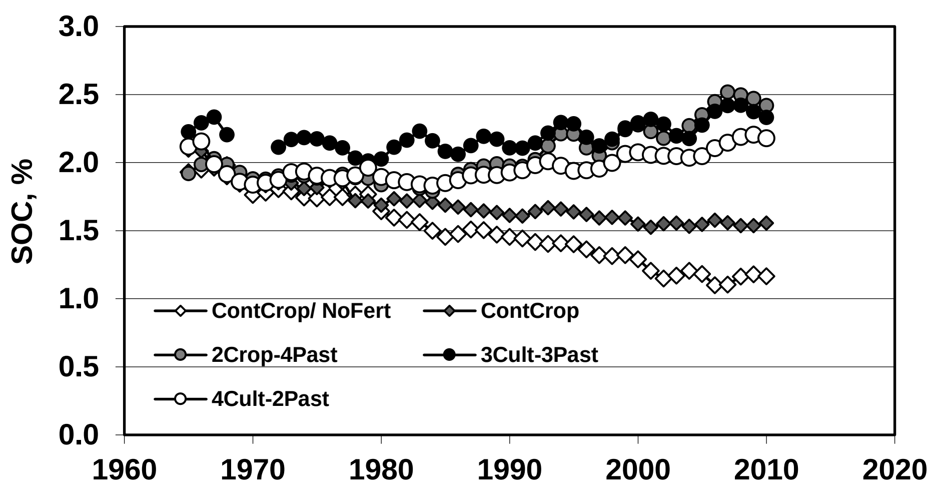


Figure 1. Percent gravimetric SOC content at 0-15 cm depth of the Typic Argiudol in the long-term rotation experiment in INIA-La Estanzuela (Quinke et al., 2012).

SOC decrease in CC with no N and P fertilization was continuous over time, being it last value 45% of the original. But in CC with N and P fertilization the evolution reached a steady state around 72% of the original. SOC content was always higher in the CPRs, and more with longer time under pasture and less under crops. The most important result is that with CT during 47 years, or with NT from 2008, SOC content in the CPRs did not differ of the original one.

Other experiment started in 1994 in the Experimental Station EEMAC, Faculty of Agronomy-Univ. of Uruguay (Lat Long). Soil is a Typic Argiudol, Clay Loam, with 3% gravimetric SOC original content. The site differs from La Estanzuela in its slope that is less than 1%. Treatments are CC or CPR (3 yrs. crops-3 yrs. pasture), combined with CT or NT. SOC content was determined at 0-15 cm depth after one rotation cycle of the CPR and discussed in a review (García Préchac et al., 2004). Results indicated that the lowest SOC content was under CC with CT, but there were no significant differences between the other treatments (CC-NT, CPR-NT and CPR-CT). These results were confirmed in later measurements, after two cycles of rotation (Ernst and Siri-Prieto, 2009; Salvo et al., 2010). This last work evaluated a variant introduced in 2000, consisting in splitting the plots during the cropping cycle to contrast planting soybean or sunflowers versus sorghum or corn in summer. The difference between the quantity and quality of the C3 vs. C4 crops residues was significant, with more SOC under the second ones. Lack of erosion in this experiment, due to low slope grade, is the explanation given for no significant difference between the treatments with NT, in particular, between CC-NT, CPR-NT, and even CPR-CT. SOC physical fractionation and $^{13}C$ studies at different depths (Salvo et al., 2014) found that SOC dynamics during the experimental time was mainly in the particulate fraction (POM-C), in which occurred 63% of the losses, meanwhile there were no significant differences in the mineral associated organic C (MAOM-C). After 9.5 years, only 14.5% of the SOC in the 0-18 cm layer was young C, being the largest proportion incorporated no deeper than 6 cm. Only 17% of the plant residues were incorporated in the topsoil. Estimated half life of C in the 0-18 cm depth was 28 years, but it varied from less than 5 years for POM-C to 400 years for MAOM-C.

The third experiment is in the Experimental Unit INIA-Palo a Pique (Lat. Long.) , in an Abruptic Argiudol, Silty Loam, with 1.7 % SOC original content in 1995. Experimental area is 72 ha, with 6 ha experimental units (Terra and García Préchac, 2001). All soil management is NT. Soil uses contrasted are: 1) CC: annual winter oats and ryegrass directly grazed, and Sorghum or Moha in summer for silage or hay; 2) short rotation (SR): two years idem CC and two years pasture; 3) long rotation (LR): two years idem CC and 4 years pasture; 4) permanent pasture (PP): regenerated natural pasture over seeded with perennial legumes. After 8 years, SOC and particulate organic carbon (C-POM, 53-2000 µm) were determined at 0-15 cm depth (Terra et al., 2006). LR increased SOC by 19% compared to CC (31.8 $Mg.ha^{-1}$); no SOC differences were found between LR, SR and PP. Plots under pastures had 14% higher SOC than plots under crops (33.7 $Mg.ha^{-1}$). Crops rotated with pastures in LR and SR, had 5% more SOC than crops in CC (31.8 $Mg.ha^{-1}$). Pastures of 3-4 years had 33% more SOC than 1-2 years pastures (34.4 $Mg.ha^{-1}$). The lowest and greatest C-POM were in CC and in 3-4 years pastures of LR (8.2 and 12.6 Mg $C.ha^{-1}$, respectively). The paper concludes that CPR-NT systems including long-term seeded pastures of grasses and legumes preserved SOC content, even in high biomass extractive systems.

## Conclusions

Long-term experimental results confirmed the majority of models predictions, except the possible long-term increase of SOC in CPR-NT. The majority of the results showed no significant changes of this use and management compared with the experimental original SOC contents.

Results showed that CC-NT with predominance of grasses instead of soybean or sunflower in the cropping sequence, could arrive not only to control erosion but also to keep SOC content close to the original. Changes in SOC content under the different NT systems were detected close to soil surface. This could be due to the predominant over-ground origin of the residues. SOC changes were detected in the particulate fraction with low time of residence.

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