Soil management and environmental sustainability of crop-livestock systems

Manejo de suelos y sostenibilidad ambiental de los sistemas agrícola-ganaderos

Manejo de solos e sustentabilidade ambiental de sistemas agropastoris

Editor

José Terra
Instituto Nacional de Investigación Agropecuaria, Treinta y Tres, Uruguay.

Correspondence

Fernando García Préchac, *gauchogp@gmail.com*

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García Préchac, F.[1]

[1]*Universidad de la República, Facultad de Agronomía, Departamento de Suelos y Aguas, Montevideo, Uruguay.*

Abstract

Uruguay experienced an expansion of the cropped area in the last decades motivated by market conditions: price of grains, differences in the relative land value, and regional tax policies. This change affected the crop-livestock production system, mainly in soil quality and system sustainability.

The available information on soil erosion and organic carbon content (SOC) allowed to validate the models USLE/RUSLE and CENTURY, which demonstrated the advantages of crop-pasture rotations compared to continuous cropping. No-till represented an outstanding advance, by reducing mechanical tillage. The drop in soil organic carbon was correlated with a productivity decrease, mainly due to the lower availability of nutrients and limitations in the physical properties of the soil. The Global Soil Alliance of FAO highlights the three most important threats on sustainable soil management: erosion, loss of organic carbon, and nutrient imbalance.

The main public policy in Uruguay is the application of the Law of Soil and Surface Water Conservation. The principal measure is that cropping cannot present erosion estimates above the official tolerance for the dominant soil used. It became mandatory in 2013, and currently, 96% of the obliged area has complied with the presentation of the plans, covering 1.6 Mha.

In 2018, a proposal for the Environmental Plan for Sustainable Development based on agroecology elements was generated from the Environmental Ministerial Office. Crop-pasture rotations include varied plant and animal production, and comply with most agroecology elements, minimizing erosion and maintaining or recovering SOC.

Keywords: crop-livestock sustainability, sustainable soil management guides (FAO-UN), models of erosion and organic carbon, soil degradation, public policies for sustainable development

Resumen

Uruguay experimentó en las últimas décadas una expansión del área agrícola motivada por condiciones de mercado en el precio de los granos, diferencias en el valor relativo de la tierra y políticas impositivas de la región. Este cambio afectó el sistema de producción agrícola-ganadero, principalmente en la calidad de los suelos y la sostenibilidad de los sistemas.

La información disponible sobre erosión y contenido de carbono orgánico (COS) del suelo permitió validar los modelos USLE/RUSLE y CENTURY, que demostraron tempranamente las ventajas de las rotaciones de cultivos y pasturas frente a la realización de cultivos continuos. La siembra directa significó un destacado avance, al reducir el laboreo mecánico. La caída en carbono orgánico de suelos se correlacionó con una caída de productividad, debido principalmente a menor disponibilidad de nutrientes y limitaciones en las propiedades físicas del suelo. La Alianza Global por los Suelos de la FAO destaca, sobre manejo sostenible de los suelos, las tres amenazas más importantes: erosión, pérdida de carbono orgánico y desbalance de nutrientes.

La principal política pública en Uruguay es la aplicación de la Ley de Conservación de Suelos y Aguas Superficiales con fines agropecuarios. La disposición principal es que la realización de cultivos no arroje estimaciones de erosión por encima de la tolerancia oficial para el suelo dominante utilizado. Comenzó a ser obligatorio en 2013, y al presente el 96 % del área obligada ha cumplido con la presentación de los planes, ocupando unas 1,6 Mha.

En 2018 se generó desde el Gabinete Ministerial Ambiental una propuesta del Plan Ambiental para el Desarrollo Sostenible con base en los elementos de la agroecología. Las rotaciones de cultivos y pasturas incluyen producción vegetal y animal, con variantes dentro de cada una, y cumplen con la mayoría de los elementos de la agroecología, minimizando la erosión y manteniendo o recuperando el COS.

Palabras clave: sostenibilidad agrícola-ganadera, guías de manejo de suelo sostenible (FAO-UN), modelos de erosión y carbono orgánico, degradación de suelos, políticas públicas de desarrollo sostenible

Resumo

O Uruguai experimentou nas últimas décadas uma expansão da área agrícola motivada pelas condições do mercado no preço dos grãos e no valor relativo da terra e nas políticas fiscal na região. Essa mudança afetou o sistema de produção agropecuária principalmente na qualidade dos solos e na sustentabilidade dos sistemas.

As informações disponíveis sobre erosão e teor de carbono orgânico do solo permitiram validar os modelos USLE / RUSLE e CENTURY que demonstraram antecipadamente as vantagens da rotação de culturas com pastagens em comparação com o cultivo contínuo. O plantio direto representou um avanço notável na redução do

preparo do solo. A queda no carbono orgânico do solo foi correlacionada com uma queda na produtividade, principalmente devido à menor disponibilidade de nutrientes e limitações nas propriedades físicas do solo. A FAO Global Soil Alliance destaca as três ameaças mais importantes ao manejo sustentável do solo: erosão, perda de carbono orgânico e desequilíbrio de nutrientes.

A principal política pública do Uruguai é a aplicação da Lei de Conservação de Solos e Águas Superficiais para fins agrícolas. A principal disposição é que os cultivos não produzam estimativas de erosão acima da tolerância oficial para o solo dominante usado. Começou a ser obrigatório a partir de 2013 e, atualmente, que 96% da área obrigada cumpram a apresentação dos planos, ocupando cerca de 1,6 Mha.

Em 2018, foi gerada a partir do Gabinete Ministerial do Meio Ambiente uma proposta de Plano Ambiental para o Desenvolvimento Sustentável, com base nos elementos da Agroecologia. A rotação de culturas com pastagens inclui a produção de plantas e animais, com variantes em cada uma e cumprem a maioria dos elementos da agroecologia, minimizando a erosão e mantendo ou recuperando a COS.

Palavras-chave: sustentabilidade agropecuária, Diretrizes de Manejo Sustentável do Solo (FAO-ONU), modelos de erosão e carbono orgânico, degradação do solo, políticas públicas para o desenvolvimento sustentável

1. Introduction

In the first decade of the XXI century, there was a very important increase in the annual cropped area in Uruguay, which changed from around 0.5 Mha of predominant wheat crops, to 1.6 Mha of predominant soybean crops. This was caused by market conditions: mainly the high price of soybean at global level, high tax burden on soybean exports decreed by Argentina, and the low relative price of land in Uruguay compared to neighboring countries.

This very important and rapid change was not accompanied by local experimental data that would allow us to know the consequences of soybean predominance on soil quality, and the sustainability of the new land used and the technology employed. Long-term results were available on soil erosion and organic carbon content, allowing validation of the USLE/RUSLE and CENTURY models. These long-term experimental results, comparing soil use and management systems that did not include soybean, since it was not an important crop, clearly demonstrated the advantages of crop-pasture rotations compared to continuous cropping. Moreover, the results of all soil use systems were clearly superior when reducing or eliminating mechanical tillage for no-till.

In the absence of experimental data regarding the effects of soybean cultivation, in 2004 erosion estimates and evolution of organic carbon content (SOC) were carried out with USLE/RUSLE, and CENTURY, respectively. These estimates led us to conclude that: 1) soybean monoculture systems would not be sustainable without additional coverage during winter; 2) the double annual wheat-soybean crop presented erosion estimates on the edge of tolerance, but would lose soil carbon content in the medium and long term, and 3) soybean cultivation could be part of sustainable crop-pasture rotations, both in terms of erosion and soil organic carbon content.

2. Experimental and productive results published after 2010

Between 2009 and 2010, a study by the National Institute for Agricultural Research, La Estanzuela[(1)], compared the content of SOC down to 15 cm deep in 108 farms in the main agricultural region of Uruguay, against undisturbed soils below fences, and it found an average reduction of 20%.

In the annual presentation of results of the Uruguayan Federation of Groups CREA (FUCREA) in 2011, results[(2)] were presented by producers of hundreds of farms showing that best wheat and soybean yields decreased over time when pastures changed to continuous agriculture. Ernst and others[(3)] analyzed four-year wheat production data from FUCREA, using an innovative methodology to separate the effects of different variables, and found that the age of the farm in continuous cropping after pastures caused loss of productive potential, mainly in climate-limiting years. Ernst and others[4] reported that, up to around five years after pasture, the drop in productivity was mainly due to less nutrient availability, particularly nitrogen, and that after more years other properties of the soil, presumably physical, become limiting.

A recent publication by Berreta-Blanco and others[5] analyzed the evolution of the properties of soil samples received by the laboratory of INIA La Estanzuela, between 2002 and 2014, and found a drop of approximately 20% of SOC, along with lower content of interchangeable bases and lower soil pH. When SOC falls, the cation-exchange capacity falls, which determines the loss of bases and, consequently, the acidification of the soils. This is the empirical verification of the predictions with models carried out in 2004 and confirms, in terms of soil quality, that the evolution of predominantly continuous cropping systems, based almost only on soybeans, is not sustainable. Ernst and others[4] also indicate this in terms of productivity, separating soil quality effect from other agronomic factors, such as increased pressure from weeds, pests, and diseases, which are characteristic of cultivating the same crop in the same place every year (monoculture).

3. International recommendations and commitments on sustainable soil management

In 2012, FAO created the Global Soil Partnership (GSP)[6], made up of 200 countries, and many more NGOs. Its objective is the sustainable management of the world's soils. This organization is scientifically advised by a technical panel (ITPS) made up of acknowledged scientists, proposed by governments, and selected by seven regional groups that cover the whole world. The author of this note integrates it since 2015 representing Latin America and the Caribbean.

The main initial work of the ITPS was the *Report on the State of the World's Soil ResourcesI*[7], published in December 2015. 200 scientists from 60 countries collaborated on this report. Ten threats to the world's soils were identified, the three most important being, on a global scale and in decreasing order, erosion, loss of organic carbon, and nutrient use imbalance. The remaining are not global threats but are very important problems in some regions: salinization, contamination, acidification, loss of biodiversity, compaction, flooding, and disappearance of soils under construction. It is noteworthy that this report showed that in the world's soils the content of SOC is more than three times that of all vegetation on earth and atmosphere; therefore, it is not possible to think about mitigating global warming without the sustainable use and management of soils. Likewise, it was found that 25% of the planet's biodiversity lives in the soil.

The document's recommendations to counter the three main threats are: 1) to minimize soil disturbance, avoiding mechanical tillage; 2) to improve and maintain the organic protective soil cover using cover by residues and cover crops; 3) to cultivate a wide range of plant species, both annual and perennial, in associations, sequences, and rotations that may include trees, bushes, pastures, and crops; 4) to sensibly manage crop and pasture fertilization with industrial and organic fertilizers, as well as all other agrochemicals. Based on this study, the GSP asked the ITPS to prepare the Voluntary Guidelines for Sustainable Soil Management, adopted by the FAO[8], and recommended it for compliance with the Sustainable Development Goals of the UN, approved in 2015. The first two recommendations are almost equivalent to “no-till”, for which the use of herbicides is necessary. In this regard, GSP commissioned ITPS high-level scientific opinion on the effect of Plant Protection Products (PPP: herbicides, fungicides, and insecticides) on soil biodiversity, and the fulfillment of their ecosystem functions. The document[9], based on an exhaustive review of the bibliography, concludes that to achieve global food security, in particular, considering the expected population growth up to 2050 and the currently available technology, it is not possible to abandon the use of the PPP, due to the productivity loss it would generate. On erosion and runoff control in temperate regions, the document concludes that the benefit of using PPP, in particular glyphosate herbicide, is clearly greater than the risks of its use for soil biodiversity.

4. Status of public policies on the matter

The main public policy in Uruguay is the application of the Law of Conservation of Soils and Surface Waters with agricultural purposes, and its regulatory decrees[10]. The main measure is that cultivation should be done according to a prior plan made by an accredited agronomist, and that, being evaluated by the USLE/RUSLE MODEL, it does not present erosion estimates above the official tolerance for the dominant soil used. It became mandatory in 2013 and in 2014 an estimate of 94% of the obliged area had complied with the submission of the plans. It has increased over the years to more than 96%, covering about 1.6 Mha.

These results caught international attention; regionally, by the Commission of Agriculture of Argentine representatives in 2014, and several provincial governments, like San Luis and Santa Fe. In the global academia, the presidency of the International Union of Soil Sciences (https://www.iuss.org/) invited us to write a chapter of the book published at the last world conference[11] on the role of soils in meeting the United Nations Sustainable Development Goals. Institutionally, FAO invited the country, through its Minister of Livestock, Agriculture, and Fisheries (MGAP), to deliver the inaugural speech at the *Global Symposium on Soil Erosion*, which took place in Rome, in May 2019[12]. Nationally, the Morosoli Institutional Prize of 2014 awarded the three involved in the development and implementation of the policy: MGAP, INIA, and the Agronomy College of the University of the Republic (Fagro-Udelar). The abovementioned chapter of Pérez Bidegain and others[11] details the process of research and development, the policy results, and, particularly, how the use of USLE/RUSLE to achieve tolerable erosion estimates leads to reducing or eliminating mechanical tillage and the use of rotations, mainly of crops and pastures.

In 2018, a proposal for an Environmental Plan for Sustainable Development (EPSD)[13] was generated by the Environmental Ministerial Office (GMA by its Spanish acronym), according to determining legal provisions. It was submitted to public consultations throughout the country, and subsequently to the Advisory Commission on the Environment (COTAMA by its Spanish acronym) of the Ministry of Housing, Territorial Planning, and Environment (MVOTMA by its Spanish acronym). After considering comments and suggestions, the plan was approved by the Environmental National Office in December 2018, and by Executive Decree No. 222/019 of August 5, 2019[14]. The 2.2 objective is to promote productive practices that reduce the environmental impact of agricultural activities, and its goal 2.2.1 are "agricultural practices based on Agroecology elements". Also, in January 2019, Law No. 19.717[15] was approved, which establishes a plan to promote agroecology in urban, peri-urban, and family agriculture. The definition that EPSD will take is then established: Agroecology is "the application of ecological concepts and principles to design and manage sustainable agricultural ecosystems"[13]. According to FAO[16], there are several definitions of *agroecology*, but all of them share the following elements: diversity, synergy, efficiency, recycling, resilience, co-innovation, human and social values, food culture and traditions, responsible governance, and solidarity and circular economy.

The rationale of goal 2.2.1 of the EPSD argues that rotations in particular of crops and pastures comply with most elements of agroecology, in addition to the indicated in terms of minimizing erosion and maintaining or recovering the SOC. Crop-pasture rotations include plant and animal production, with variants within each, making them <u>diverse</u>. Symbiotic nitrogen fixation by pasture legumes increases its availability for the following crops, which is a <u>synergy</u> element, as well as stopping weed, pest, and disease cycles during the pasture period. The above, together with the pastures' use of nutrients such as phosphorous, which usually increase the availability in the soil during fertilized crops, provide <u>efficiency</u>. Grazed pastures <u>recycle</u> potassium; this nutrient is absorbed by roots of perennial pastures, generally deeper than crops, and during grazing, it is returned to the surface in animal droppings, since it is not exported in the animal product. The aforementioned can also be considered as circular economy, together with the fact that the greater SOC content in rotations, apart from improving physical properties and nitrogen availability, also determines greater sulfur availability, a major nutrient that is only provided by the organic matter from soils and has begun to show a response to its application in continuous cropping systems. Because of their diversity, rotation systems are more resilient to changes due to climate or economic conditions of prices of inputs and products. Crop-pasture rotations have been the product of research, transfer, and adoption by producers since mid-1960s. They had been the predominant production systems before the soybean boom described at the beginning; that is, they are the product of co-innovation. Continuous cropping systems lost values and culture of livestock work, which would be recovered with the return to crop-pasture rotations.

The high load of agrochemicals in current continuous cropping systems is of great concern, due to the potential environmental contamination and its consequences. A study in Paysandú by Ernst and Siri-Prieto[17] reports a twelve-year average use of inputs in crop rotations and pastures compared to continuous agriculture. They found that, in their no-till rotations, where pastures only occupied 40% of the time and area, the reductions compared to continuous cropping were 44 and 46% for nitrogenous and phosphate fertilizers, respectively, 42% for glyphosate, 50% for other herbicides, and 48% for fuel and machinery usage time. It can be affirmed that, in crop-pasture rotations where pastures occupy 50% of the time and space, the use of agrochemicals and fossil fuels is reduced by half.

Also, no-till crop-pasture rotations showed similar soil biodiversity indexes to those of natural grassland[18]. Together with spatial dispersion or mosaic, reduced use of agrochemicals, and floral diversity (particularly those of pastures) offer greater possibilities to pollinators.

Two lines of action of EPSD goal 2.2.1 are: "To significantly recover the area of annual crops made in rotation with pastures", and "ensure that the area of annual crops that still use continuous cropping systems in a significant proportion does not include any crop that repeats every year in the same site (monocultures)". In the Responsible Use and Management Plans of MGAP[19], most of them between 2013 and 2014, 61.2% correspond to continuous cropping rotations, and 38.8% to crop-pasture rotations. Therefore, after the approval of the EPSD by the Executive Power, policies must be established to reverse these percentages.

5. Conclusions

Based on models for estimating erosion and organic carbon content, agricultural intensification with soybean as an almost exclusive summer crop, with continuous cropping, abandoning crop-pasture rotations since around 2003 and reaching up to 1.6 Mha per year, even with no-tillage, was estimated to be not sustainable for soil quality. About ten years later, those predictions were confirmed by national experimental information. Both, the model estimates and the experimental results show that cultivating soybeans and other crops in no-till rotation with pastures is sustainable for the soils by minimizing erosion and maintaining high organic carbon content. Such rotations also halve the use of agrochemicals and fossil fuels in the entire production system, as well as offer diversity and spatial mosaic of vegetation that favors pollinators. Furthermore, they comply with almost all the agroecology elements. This was included in the public policies for soil conservation and in the EPSD, which aims to make crop-pasture rotation the predominant agricultural production system in the country once again.

Author contribution statement

The author is the only contributor to the content.

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