Comment on: "Back to the future? Conservative grassland management can preserve soil health in the changing landscapes of Uruguay" On the risks of good intentions and poor evidence.

José Paruelo [1,2,3], Luis López Mársico[2], Pablo Baldassini [1,3], Felipe Lezama[4], Bruno Bazzoni[3], Luciana Staiano[3], Agustin Nuñez[1], Anaclara Guido[2], Cecilia Ríos[2], Andrea Tommasino[2], Federico Gallego[2], Fabiana Pezzani[4], Gonzalo Camba Sans[2], Andrés Quincke[1], Santiago Baeza[4], Gervasio Piñeiro[3,4] and Walter Baethgen[5].

1. Instituto Nacional de Investigación Agropecuaria. INIA - La Estanzuela. Colonia, Uruguay
2. Instituto de Ecología y Ciencias Ambientales. Facultad de Ciencias, Universidad de la República. Montevideo, Uruguay
3. LART-IFEVA and Facultad de Agronomía, Universidad de Buenos Aires, CONICET, Buenos Aires, Argentina.
4. Departamento de Sistemas Ambientales, Facultad de Agronomía, Universidad de la República, Montevideo, Uruguay
5. International Research Institute for Climate and Society (IRI), Columbia University, Palisades, NY, United States.

Correspondence to: José Paruelo (angie@email.com)

Abstract. In this article we make comments on some methodological issues and on the general approach of the paper "Back to the future? Conservative grassland management can preserve soil health in the changing landscapes of Uruguay" by Ina Säumel, Leonardo R. Ramírez, Sarah Tietjen, Marcos Barra, and Erick Zagal, Soil 9, 425–442, https://doi.org/10.5194/soil-9-425-2023. We identified various design and methodological problems that may induce potential misinterpretations. Our concerns are of three different types. First, there are aspects of the study design and methodology that, in our opinion, introduce biases and critical errors. Secondly, the article does not put forth any novel propositions and ignores extensive local literature and aspects that are central to the interpretation of the data Finally, we are concerned about the possible interpretations of a study, generated from institutions based on developed countries with not the participation of local scientists from the Global South in the design of policies and development of non-tariff barriers for South American countries.

1 Introduction

The article "Back to the future? Conservative grassland management can preserve soil health in the changing landscapes of Uruguay" written by Ina Säumel, Leonardo R. Ramírez, Sarah Tietjen, Marcos Barra, and Erick Zagal in Soils 9, 425–442, https://doi.org/10.5194/soil-9-425-2023, analyzed a set of soil parameters that describe the chemical conditions of the first 10 cm of 101 sampling areas under different land uses and land cover. Upon thorough examination, several deficiencies and considerations were discerned within the article that warrant attention, as they have the potential to give rise to erroneous or misleading interpretations.

2 Our main criticisms

We have identified various design and methodological concerns that may induce potential misinterpretations. Given the sensitive nature of soil degradation, the potential ramifications of drawing conclusions based on insufficient evidence could lead to misguided interpretations and subsequent actions. Our concerns are of three different types. First, there are aspects of the study design and methodology that, in our opinion, introduce biases and critical errors. Secondly, the article does not put forth any novel propositions and ignores extensive local literature and aspects that are central to the interpretation of the data Finally, we are concerned about the possible interpretations of a study, generated from institutions based on developed countries with no the participation of local scientists from the Global South (something that is called "parachute science" and related with scientific neocolonialism practices; see Nakamura et al., 2023), in the design of policies and development of non-tariff barriers for South American countries.

2.1.Design and methodological issues

2.1.1. Definition of the sampling site: The concept of a "monitoring site" is critical in this type of study, as the plots are located according to the "site". However, the site is not sufficiently defined in spatial terms in Säumel et al. Which was the universe of sites used to be randomized? Is it a specific area? A basin? A cell of a grid? More information is needed to understand the implications of the study and to evaluate thoroughly the sites considered.

2.1.2. About the sampling scheme: The authors indicate that "randomly selected monitoring sites across the country". Having a randomized design is certainly an advantage. However, no details are given on how this randomization was carried out. This process requires stratification, the definition of a grid, a criterion to discard sites that cannot be accessed, etc. A detail of a possible country-wide stratification alternative is presented in Altesor et al. (2019). In that work, the authors used land cover maps and a 10x10 km grid where 20 cells were drawn. Within each cell, 5 squares of 1x1 km were randomly chosen and in that area two patches belonging to two different natural grassland communities were sampled by Lezama et al. (2019). Those areas corresponded to a MODIS grid pixel (231x231 m), allowing for a clear localization of the sample. Random sampling implies complex logistics of displacements in the field, especially in areas with low road density as in the north of Uruguay. The absence of a description of the design and the coincidence of the location of the sampling areas with the distribution of roads (particularly National No. 5) does not allow us to dispel doubts about possible biases in the collection of samples. The coordinates of each of the sampling sites are also not indicated in the study, although it is stated that they were used to locate the soil groups in the Soil Map of Uruguay at scale 1:1,000,000. Aside from the general design, the authors indicated that “We sampled topsoil three times at each land use at the edges of the plot” (Säumel et al., 2023, p. 427)”. Does this mean 3 samples/plot (so the 280 samples are full of pseudo-replications) or 3 different times? Did they use composite samples or not?

2.1.3. Representativeness of land use types: It is striking that the proportions of land use types sampled in Säumel et al. study differ strongly from those present in Uruguay, particularly if the sample sites were randomly chosen. According to the latest cartographies, both forestry and native forests are overrepresented. Both occupy 12.5 % (2.204.060according to Baeza et al., 2022) and in the article, the samples of these land covers corresponded to 53% of the total. It is also difficult to make inferences about croplands in Uruguay with no samples in the SW region of the country (i.e., the main cropland area), or is at least incomplete (Baeza and Paruelo, 2020). This lack of coverage of the main croplands zone of the country is evident by the low number of samples under annual crop use (see Table 1 in the original manuscript). As an example, the authors only had 15 samples of cropland sites, while during 2015/2016 (when the sampling was conducted), there were 1,289,000 has of summer crops (soybean, maize, and sorghum) (DIEA (2022).

2.1.4. Design of the study: Any study that intends to establish differences associated with land use types from spatial sampling must minimize all sources of variation excluding the factor to be compared (e.g. soil depth, texture, slope, rockiness, water availability, etc.). Two widely used approaches in observational studies are paired sites or block sampling (e.g. Perelman et al., 2019). The article by Säumel et al., compared all different land uses against each other, implicitly assuming that the observed differences were only due to land use types, without controlling with the experimental design other factors that also co-varied in space with land uses (e.g. all riverine native forest are located in lowlands). In addition, normally in a paired design aimed to compare land use effects on ecosystems, it is necessary to document that the paired sites sampled are located in an equivalent topographic position, soil types, etc... There is no evidence that this was done in this study. How did the authors control these types of effects in the study? Does the differences in soil characteristics between tree plantations and native forest (or grasslands) resulted from the effect of the land cover or were the consequence of planting trees on soils defined a priori for this use? The design of the study precludes an answer to these questions. This is not a trivial point because those soils defined as “Afforestation priority” in Uruguay have, originally, low fertility and pH. Actually, the authors recognized the importance of soil heterogeneity: “In addition, the lateral heterogeneity of Pampean soils over short distances makes separating geochemical and anthropic signatures difficult (Roca, 2015)” (Säumel et al., 2023, p. 434) a key point they we consider that they did not properly contemplate.

In addition, the land use trajectories proposed in Säumel et al., are oversimplified into four categories. The authors ignored well known land use sequences in the region such as annual crops—grassland returns, rotations with annual crops and perennial pastures, and the cropping history prior to 1986 (the agricultural peak of the 1950s).

2.1.5. Soil type characterization: The only approach used to characterize the site is the soil map of Uruguay at a scale of 1:1,000,000. This does not allow us to perceive critical edaphic and topographic differences. The soil group in such Soil Map is defined by the dominant soil type at scale 1:1,000,000, among other associated soils in the group. It is well known that the fact that two sites belong to the same soil group does not mean that they have the same soil type (large differences in texture, and other soil properties are common between soils in the same soil group). The assignment of a soil group without any field evidence is, at least, striking given the coarse resolution of the used map. It is surprising that the authors did not evaluate texture to characterize soils at least for two reasons: (i) it is key to give evidence about the comparability between pairs, (ii) it is a property that correlates/explains all other soil properties measured in Säumel et al., from soil organic carbon (SOC) and cation exchange capacity (CEC) to all soil metals. In addition, in the article there is a strong emphasis on CONEAT units. This is a conceptual error because CONEAT units are not a soil type per se: "CONEAT groups are not strictly basic soil mapping units, but constitute homogeneous areas, defined by their productive capacity in terms of beef, sheep and wool (Art. 65 of Law 13695). " https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/politicas-y-gestion/coneat. Again, inside a single CONEAT unit there are normally large variations in soil types and properties.

2.1.6. SOC data: One of the major shortcomings of the paper is the lack of details on the way SOC is reported. First, characterizing SOC changes only from the first 10 cm is, at least, incomplete and risky. Even more, if the particulate and mineral associated fractions of the organic C are not differentiated. Land cover, management, or changes in the relative abundance of plant functional types, may change the vertical distribution of SOC. In fact, within the same land use (native grasslands), paired grazed-ungrazed areas significantly differ in the upper layer distribution of SOC and belowground C inputs (Piñeiro et al., 2009; López-Mársico et al., 2015). Such effects are evident way below 10 cm. Second, the authors reported SOC as a percentage or concentration without indicating if data are on a gravimetric or a volumetric basis. Reporting SOC without considering bulk density precludes any reasonable comparison on an equivalent soil mass (Gifford and Roderick, 2003). No data on bulk density were reported, which is well-known to be affected by land use types evaluated in this work such as afforestation (Hernandez et al., 2016) or crop production and crop-pasture rotations (Rubio et al., 2021). This is particularly critical if only data for the first cm of the soils are reported. SOC stocks would differ dramatically between soils with different levels of compaction and, hence, differing on bulk density. Also, soils under native forests and tree plantations have an upper layer with mixed soil and plant residues ("litter layer"). Were litter layers excluded/included in the sampled soils? Furthermore, the comparisons of C stocks between riparian forests, tree plantations and grasslands made by Säumel et al., are surely biased without standardizing for two of the key factors in determining SOC, C inputs (Net Primary Production) and soil texture (Parton et al., 1994; Schimel et al., 1994; Krull et al., 2001). Riverine forests have a completely different water regime than grasslands or tree plantations and consequently differences in net primary production. Alluvial soils are expected to have profound differences in soil texture compared to upland areas and this will impact dramatically on the SOC saturation level of the soil (Chung et al., 2008; Stewart et al., 2007; Mayzelle et al., 2014; Pravia et al., 2017). The saturation level is largely associated with texture, particularly with the fine soil particles fraction (Hassink, 1997; Feng et al., 2013). However, the study ignores the well-known effects of texture on SOC.

2.1.7. Grasslands categories: Säumel et al., must provide the evidence they have to "... subdivided GL plots according to the intensity of use: (i) undisturbed GLs (without grazing), (ii) partially grazed GLs (with sporadic grazing and low animal charge), and (iii) highly grazed GLs (with high animal charge)" (Note: We assume that "animal charge" means stocking rate). Some of the authors of this reply have been working on grassland ecology in Argentina, Brazil and Uruguay for more than 35 years. We were particularly interested in identifying different grazing situations. Actually, we have compiled a set of ungrazed situations based on an extensive search (Lezama et al., 2014). The sites available were very few. Except for very particular situations, we found it extremely difficult to define the level of grazing intensity in commercial ranches because such information is seldom recorded (but see Lezama and Paruelo, 2022). Aside from how they were defined, it is not clear how the different "categories" of grassland entered into the analysis. However, in the results the authors said that no differences were detected "among different GL subtypes". Several local studies on paired grazed and ungrazed native grasslands have previously showed important changes in SOC stocks that varied according to soil types (Piñeiro et al., 2009, 2010). More recent studies showed that belowground C inputs are heavily impacted by the grazing condition (grazed-ungrazed) (López-Mársico et al., 2023). It is surprising that Säumel et al., ignored the well documented differences among native grazed or ungrazed grasslands: its species composition and vegetation structure. Furthermore, grassland communities of Uruguay have been thoroughly described (Lezama et al., 2019) and mapped (Baeza et al., 2019) in detail, showing that the phytosociological units defined for the country are quite stable under different levels of grazing intensity and degradation (Altesor et al., 2019).

2.1.8. We found the conclusions related to the role of riverine forest soils as a sink for trace metals extremely speculative. This kind of analysis must be performed at the catchment level. No evidence is provided on the location of the data reported, do they correspond to the same basin? Are they physically connected?

2.1.9. Some other issues related to the analysis preclude clear comparisons with previous studies and/or generalizations. For example:

a. "Total P concentration was determined calorimetrically after microwave-assisted digestion with a Unicam spectrometer at a wavelength of 660 nm." (Säumel et al., 2023, p. 429) --- total soil P is not a fertility parameter, as it has a low correlation with P availability.

b. "The pH of our topsoil samples are mainly in the category of very strongly to extremely acidic and is lowest in TPs (Fig. 6), below the means reported so far (Jobbagy and Jackson, 2003; Céspedes-Payret et al., 2012)." (Säumel et al., 2023, p. 433) --- The authors measured pH in $CaCl_2$ ["Acidity was measured by adding calcium chloride (0.01 M) to the samples at a 2.5:1 proportion, and after shaking and 2 h rest, read with a pH meter (HI2550 meter, Hanna Instruments, USA)." (Säumel et al., 2023, p. 427)], while Céspedes-Payret et al. (2012) and Jobbagy and Jackson (2003) measured it in water, so the results are not comparable. The pH measured in water extractions is more common or standard lab analysis in Uruguay (Hernandez et al., 2016; Beretta-Blanco et al., 2019; Grahmann et al., 2020).

2.2.Novelty of the results

2.2.1. The impact of tree plantations and cropping on SOC, CEC, Ca and pH has been extensively reported in articles without the serious problems of experimental design in the study of Säumel et al. (2023). Many of them were cited by the authors and others were ignored. Particularly, there is an extensive literature on the environmental impacts of tree plantations (Jobbagy et al., 2003, 2006; Farley et al., 2008; Berthrong et al., 2009, 2012; among others). There is a general consensus (empirical and theoretical) on the effects of tree plantations on water, SOC, pH and nutrient dynamics in previous well preformed studies. We do not identify anything novel in the results reported by Säumel et al..

2.2.2. The same happens in the case of croplands. In general terms, annual crop production would have negative impacts on soil properties, particularly on SOC and pH and, consequently, on potential fertility (Berhongaray et al., 2013; Wingeyer et al., 2015; Beretta-Blanco et al., 2019; Alvarez et al., 2020; Grahmann et al., 2020; Baethgen et al., 2021; García-Préchac et al., 2022). Focusing on this well-known general pattern and ignoring the local evidence on the heterogeneous impact of the agricultural management on soil properties may generate a simplistic (and in our opinion, erroneous) perception of the environmental performance of agriculture in Uruguay. Let`s be specific, Baethgen et al. (2022) showed that depending on the long-term management (basically the length of the pasture phase of the rotation) in crop productions systems SOC stocks may increase or decrease (for example through a crop-pasture rotational management). More recently, and on a country-wide study, Baldassini et al. (2023) showed that the impact of crop production on SOC is highly variable and, depending on management, annual crops-pasture rotations may have a positive impact on SOC. In summary, truly original studies on the effects of agricultural management on SOC (and soil properties in general) should focus on the effect of specific practices (service crops, crop -pasture rotations, etc.) instead of on the well-known general effect of "agriculture".

2.3.Misleading interpretations and its consequences

2.3.1. We are worried about two recommendations that the authors made in the discussion that go against grassland conservation:

a) the conversion of grasslands into silvopastoral systems

b) the expansion of native forests and the use of native species in tree plantations

There is profuse evidence that planting trees in open ecosystems, such as Uruguayan grasslands, are not a solution for its restoration nor conservation (Veldman et al., 2015; 2019; among others), although these evidences go against popular beliefs, particularly originated in countries originally covered by native forests.

2.3.2. The article included some generalizations that may lead to some serious misinterpretations:

a): "Our topsoil data indicate that carbon sequestration occurs mainly in the topsoils of native riverine forests that cover less than 5 % of Uruguayan territory." (Säumel et al., 2023, p. 435) --- We think that Säumel et al., cannot state that SOC sequestration occurs mainly in the topsoil because: (i) they did not measure SOC stocks or bulk density, (ii) they cannot relate a non-paired, observational study to cause-effect processes (no checking of same soil type besides CONEAT, which includes several soil types), (iii) they did not sample below 10 cm. Moreover, SOC accumulation in riverine areas may result from erosion (natural or anthropic) of SOC formed in upland soils, and therefore correspond to a spatial reallocation of SOC.

b) “Organic carbon content and the exchangeable cations are strongly reduced in the topsoils of GLs, TPs and AC compared to NFs (Figs. 4b, d–h and 5b, d–h).” (Säumel et al., 2023, p. 433). As we stated before the experimental design does not allow to evaluate reductions or changes in soil cations, because it’s an observational study without any explicit control of the other forming factors (in particular parental material and topography that widely differs among Uruguayan soils) that would allow to use a space-for-time substitution approach necessary to relate observed differences to land use changes.

2.3.3. The discussion of the article from Säumel et al. (2023) starts linking the agricultural sector of Uruguay with “Socioeconomic and conventional management practices that drive soil degradation” and the generation of “inputs trap” and “credit or poverty trap””. Even though the characteristics, practices, and structure of the agricultural sector of Uruguay are open to criticism and debate, the article presents no data or evidence to start a discussion about this issue. Aside from the intention of the authors, such comment at the beginning of the discussion may be interpreted as the characterization of the agricultural sector of a country of the Global South by the developed Global North part of the world. The general impression of an independent reader is that soil degradation is widespread in Uruguay, which is not the case, since Uruguay is the country in the region that has the highest area under natural grasslands (Baeza et al. 2022). Moreover, this type of “scientific evidence” on the bad environmental performance of South American countries, spread by scientists of European countries (see i.e. Kerhoe et al., 2020) helps to build non-tariff barriers for primary products and provides excuses to set conditions in international trade agreements. Nevertheless, we strongly agree that Uruguay and other South American countries have major environmental problems. Most of the authors of this reply have been and are involved in documenting, alerting, proposing solutions and/or generating policies in our region, including Uruguay, Argentina, and Brazil (Staiano et al., 2021; Baeza et al., 2022; Overbeck et al., 2022; Paruelo et al., 2022; Gallego et al., 2023; Baldassini et al., 2023; among others). We are also involved in identifying the underlying causes of the environmental problems in the Global South. National debts, lack of commitment of developed countries with environmental agreements, Nature commodification, land grabbing, the role of multinational financial markets in the agricultural sector are some of the factors promoting land use and land cover changes and degradation, and setting limits to country-level policies. Considering all of the above, we want to stress the risks of simplifying a complex problem that involves a myriad of actors and factors, based on what we believe is not solid scientific evidence. An unavoidable step in assessing such complexity would be to interact and with local scientists to have a better perception of the systems and the influence of, at least, some of the factors (biophysical, social, economic, cultural, normative, etc.) responsible of the complexity of the environmental problems. As our academic trajectory document, we believe in science as a global endeavor. We also think that such global construction must be based on building networks including discipline, gender, cultural, and citizenship diversities.

3 Concluding Remarks

There are many urgent issues to solve in Uruguay related to the environmental impacts of the agricultural sector. The nation's social organizations, governmental bodies, and academic institutions are collectively truing to address these critical issues. Amidst this concerted effort, discernible pathways leading toward a more sustainable agricultural landscape can be identified. Uruguay has taken significant strides in this direction, enacting a series of legislative measures designed to safeguard soil erosion and health and promote the principles of Agroecology. In a noteworthy collaboration between the Ministry of Environment (MA) and the Ministry of Livestock, Agriculture and Fishing (MGAP), a pioneering initiative is underway to conceptualize and calculate the Environmental Footprint of the livestock production sector (MA, 2022). Furthermore, an Act for Native Grassland Preservation is currently under discussion in the Parliament (https://parlamento.gub.uy/documentosyleyes/ficha-asunto/158085) and a long-lasting plans on soil erosion has been implemented since 2008 (https://www.gub.uy/tramites/planes-uso-manejo-responsable-suelos). All these efforts include the active engagement and participation of the academic sector. Environmental problems always have a social and political dimension, consequently, scientists must be aware of the consequences of their work in different contexts, sectors, organizations and countries (Sennett, 2008). As Bernardo Houssay, one of the South American Nobel Prices, said “Science has no homeland, but the scientist does” (Stoppani, 2000).

References

Altesor, A., Gallego, F., Ferrón, M., Pezzani, F., López-Mársico, L., Lezama, F., Baeza, S., Pereira, M., Costa, B., and Paruelo, J. M.: Inductive approach to build state-and-transition models for Uruguayan Grasslands, Rangeland Ecol. Manage., 72(6), 1005-1016, https://doi.org/10.1016/j.rama.2019.06.004, 2019.

Alvarez, R., Gimenez, A., Pagnanini, F., Recondo, V., Gangi, D., Caffaro, M., De Paepe, J.L, and Berhongaray, G.: Soil acidity in the Argentine Pampas: Effects of land use and management. Soil Tillage Res, 196, 104434, 2020.

Baethgen, W. E., Parton, W. J., Rubio, V., Kelly, R. H., and Lutz, S. M.: Ecosystem dynamics of crop–pasture rotations in a fifty-year field experiment in southern South America: Century model and field results, Soil Sci. Soc. Am. J., 85(2), 423-437. https://doi.org/10.1002/saj2.20204, 2021.

Baeza, S., Rama, G., and Lezama F.: Cartografía de los pastizales naturales en las regiones geomorfológicas de Uruguay predominantemente ganaderas. Ampliación y actualización, in: Bases ecológicas y tecnológicas para el manejo de pastizales II, edited by: Altesor A., López-Mársico L., Paruelo J. M. FPTA - INIA, Montevideo: 26 – 47, ISBN 978-9974-38-412-5, 2019.

Baeza, S., Paruelo, J.M. Land use/land cover change (2000-2014) in the Rio de la Plata grasslands: An analysis based on MODIS NDVI time series. Remote Sensing 12(3), 381; https://doi.org/10.3390/rs12030381, 2020.

Baeza, S., Vélez-Martin, E., De Abelleyra, D., Banchero, S., Gallego, F., Schirmbeck, J., Veron, S., Vallejos, M., Weber, E., Oyarzabal, M., Barbieri, A., Petek, M., Guerra Lara, M., Sarrailhé, S. S., Baldi, G., Bagnato, C., Bruzzone, L., Ramos, S. and Hasenack, H.: Two decades of land cover mapping in the Río de la Plata grassland region: The MapBiomas Pampa initiative, Remote Sens. Appl.: Soc. Environ., 28, 100834, https://doi.org/10.1016/j.rsase.2022.100834, 2022.

Baldassini, P., Baethgen, W., Camba-Sans, G.H., Quincke, A., Pravia, M. V., Terra, J., Macedo, I., Piñeiro, G., and Paruelo, J. M.; Carbon stocks and potential sequestration of Uruguayan soils. A road map to a comprehensive characterization of temporal and spatial changes to assess Carbon footprint, Front. Sustainable Food Syst., 7, 1045734, https://doi.org/10.3389/fsufs.2023.1045734, 2023.

Berthrong, S. T., Jobbágy, E. G., and Jackson, R. B.: A global meta-analysis of soil exchangeable cations, pH, carbon, and nitrogen with afforestation, Ecol. Appl., 19(8), 2228-2241, https://doi.org/10.1890/08-1730.1, 2009.

Berthrong, S. T., Piñeiro, G., Jobbágy, E. G., and Jackson, R. B.: Soil C and N changes with afforestation of grasslands across gradients of precipitation and plantation age, 22(1), Ecol. Appl., 76-86. https://doi.org/10.1890/10-2210.1, 2012.

Berhongaray, G., Alvarez, R., De Paepe, J., Caride, C., and Cantet, R.: Land use effects on soil carbon in the Argentine Pampas, Geoderma, 192, 97-110, https://doi.org/10.1016/j.geoderma.2012.07.016, 2013.

Beretta-Blanco, A., Pérez, O., and Carrasco-Letelier, L.: Soil quality decrease over 13 years of agricultural production. Nutr. Cycling Agroecosyst., 114(1), 45-55, https://doi.org/10.1007/s10705-019-09990-3, 2019.

Céspedes-Payret, C., Piñeiro, G., Gutiérrez, O., and Panario, D.: Land use change in a temperate grassland soil: Afforestation effects on chemical properties and their ecological and mineralogical implication, Sci. Total Environ., 438, 549–557, https://doi.org/10.1016/j.scitotenv.2012.08.075, 2012. Chung, H., Grove, J. H., and Six, J.: Indications for soil carbon saturation in a temperate agroecosystem, Soil Sci. Soc. Am. J., 72(4), 1132-1139, https://doi.org/10.2136/sssaj2007.0265, 2008.

DIEA. Encuesta Agrícola ‘‘Primavera 2021’’ (Agriculture Survey Spring 2021), Ministerio de Agricultura, Ganadería y Pesca, Montevideo, Uruguay, 2022.

Farley, K. A., Piñeiro, G., Palmer, S. M., Jobbágy, E. G., & Jackson, R. B . Stream acidification and base cation losses with grassland afforestation. Water Resources Research, 44(7), 2008

Feng, W., Plante, A. F., and Six, J.: Improving estimates of maximal organic carbon stabilization by fine soil particles, Biogeochemistry, 112(1), 81-93, https://doi.org/10.1007/s10533-011-9679-7, 2013.

Gallego, F., López-Mársico, L., Tommasino, A., Altesor, A., Casás, M., and Rodríguez, C.: Legacy effects after seven years of afforestation with Pinus taeda in a natural grassland, Restor. Ecol., 31(4), e13865, https://doi.org/10.1111/rec.13865, 2023.

García-Préchac, F., Salvo, L., Ernst, O., Siri-Prieto, G., Quincke, J. A., and Terra, J. A.: Long-term effects of different agricultural soil use and management systems on soil degradation in Uruguay, in: Global Degradation of Soil and Water Resources: Regional Assessment and Strategies Singapore, edited by: Li, R., Napier, T.L., El-Swaify, S.A., Sabir, M., Rienzi, E., Springer, Singapore, 77-92, https://doi.org/10.1007/978-981-16-7916-2_7, ISBN: 978-981-16-7916-2, 2022.

Gifford, R. M., and Roderick, M. L.: Soil carbon stocks and bulk density: spatial or cumulative mass coordinates as a basis of expression?, Global Change Biol., 9(11), 1507-1514, https://doi.org/10.1046/j.1365-2486.2003.00677.x, 2003.

Grahmann, K., Dellepiane, V. R., Terra, J. A., and Quincke, J. A.: Long-term observations in contrasting crop-pasture rotations over half a century: statistical analysis of chemical soil properties and implications for soil sampling frequency, Agric. Ecosyst. Environ., 287, 106710. https://doi.org/10.1016/j.agee.2019.106710,2020.

Hassink, J.: The capacity of soils to preserve organic C and N by their association with clay and silt particles, Plant soil, 191, 77-87, https://doi.org/10.1023/A:1004213929699, 1997.

Jobbágy, E. G., and Jackson, R. B.: Patterns and mechanisms of soil acidification in the conversion of grasslands to forests, Biogeochemistry, 64(2), 205-229, https://doi.org/10.1023/A:1024985629259, 2003.

Jobbágy, E. G., Vasallo, M., Farley, K. A., Pineiro, G., Garbulsky, M. F., Nosetto, M. D., Jackson, R.B, and Paruelo, J. M.: Forestación en pastizales: hacia una visión integral de sus oportunidades y costos ecológicos, Agrocienc. Urug., 10(2), 109-124, 2006.

Krull, E., Baldock, J., and Skjemstad, J.: Soil texture effects on decomposition and soil carbon storage. In Net ecosystem exchange CRC workshop proceedings, 103-110, Citeseer, 2001.

Lezama, F., Baeza, S., Altesor, A., Cesa, A., Chaneton, E. J., and Paruelo, J. M.: Variation of grazing-induced vegetation changes across a large-scale productivity gradient, J. Veg. Sci., 25(1), 8-21, https://doi.org/10.1111/jvs.12053, 2014.

Lezama, F., Pereira, M., Altesor, A., and Paruelo, J. M.: Grasslands of Uruguay: classification based on vegetation plots, Phytocoenologia, 49(3), 211-229, https://doi.org/10.1127/phyto/2019/0215, 2019.

Lezama, F., and Paruelo, J. M.: Regional Assessment of Stocking Rate Effects on Uruguayan Rangelands: A Ranch-Level Study, Rangeland Ecol. Manage., 82, 58-65, https://doi.org/10.1016/j.rama.2022.02.005, 2022.

López-Mársico, L., Altesor, A., Oyarzabal, M., Baldassini, P., and Paruelo, J. M.: Grazing increases below-ground biomass and net primary production in a temperate grassland, Plant Soil, 392, 155-162. https://doi.org/10.1007/s11104-015-2452-2, 2015.

López-Mársico, L., Oyarzabal, M., Altesor, A., and Paruelo, J. M.: Grazing exclusion reduces below-ground biomass of temperate subhumid grasslands of South America: A meta-analysis and a database, Austral Ecol., https://doi.org/10.1111/aec.13304, 2023.

Mayzelle, M. M., Krusor, M. L., Lajtha, K., Bowden, R. D., and Six, J.: Effects of detrital inputs and roots on carbon saturation deficit of a temperate forest soil, Soil Sci. Soc. Am. J., 78(S1), S76-S83, https://doi.org/10.2136/sssaj2013.09.0415nafsc, 2014.

Mello, A. L., Lezama, F., and Baeza, S.: Patrones y controles regionales de la fragmentación de pastizales naturales en Uruguay, Ecosistemas, 32(2), 2534-2534, https://doi.org/10.7818/ECOS.2534, 2023.

Ministerio de Ambiente (MA): Informe sobre la Huella Ambiental Ganadera, October, 2022. Available at: https://www.gub.uy/ministerio-ambiente/sites/ministerio-ambiente/files/documentos/publicaciones/Huella_Ambiental_Ganadera_Informe%2010-2022.pdf

Nakamura, G., Soares, B.E., Pillar, V.D., Diniz-Filho, J.A., Duarte, A.: Three pathways to better recognize the expertise of Global South researchers, NPJ Biodivers 2, 17, https://doi.org/10.1038/s44185-023-00021-7, 2023

Overbeck, G. E., Vélez-Martin, E., da Silva Menezes, L., Anand, M., Baeza, S., Carlucci, M. B., Dechoum, M. S., Durigan, G., Fidelis, A., Guido, A., Freire Moro, M., Rodrigues Munhoz, C. B., Reginato, M., Schütz Rodrigues, R., Rosenfield, M. F., Sampaio, A. B., Barbosa da Silva, F. H., Silveira, F. A.O., Sosinski, E. E., Staude, I. R., Temperton, V. M., Turchetto, C., Veldman, J. W., Viana, P. L., Zappi,D. C., and Müller, S. C.: Placing Brazil's grasslands and savannas on the map of science and conservation, Perspect. Plant. Ecol. Evol. Syst., 56, 125687, https://doi.org/10.1016/j.ppees.2022.125687, 2022.

Parton, W. J., Ojima, D. S., Cole, C. V., and Schimel, D. S.: A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management, Quant. model. soil. forming processes, 39, 147-167, https://doi.org/10.2136/sssaspecpub39.c9, 1994.

Paruelo, J. M., Oesterheld, M., Altesor, A., Piñeiro, G., Rodríguez, C., Baldassini, P., Irisarri, G., López-Mársico, L., and Pillar, V. D.: Grazers and fires: Their role in shaping the structure and functioning of the Río de la Plata Grasslands, Ecología Austral, 32(2bis), 784-805, https://doi.org/10.25260/EA.22.32.2.1.1880, 2022.

Piñeiro, G., Paruelo, J. M., Jobbágy, E. G., Jackson, R. B., and Oesterheld, M.: Grazing effects on belowground C and N stocks along a network of cattle exclosures in temperate and subtropical grasslands of South America, Global Biogeochem. Cycles, 23, https://doi.org/10.1029/2007GB003168, 2009.

Piñeiro, G., Paruelo, J. M., Oesterheld, M., and Jobbágy, E. G.: Pathways of grazing effects on soil organic carbon and nitrogen, Rangel. Ecol. Manag., 63, 109-119, https://doi.org/10.2111/08-255.1, 2010.

Perelman, S. B., Garibald, L. A., and Tognetti, P. M. (Eds.): Experimentación y modelos, Editorial Facultad de Agronomía, Ciudad Autónoma de Buenos Aires, Argentina, 356 pp, ISBN: 978-987-3738-22-7, 2019.

Pravia, M. V., Kemanian, A. R., Terra, J. A., Shi, Y., Macedo, I., and Goslee, S.: Soil carbon saturation, productivity, and carbon and nitrogen cycling in crop-pasture rotations. Agricultural Systems, 171, 13-22, 2019.

Säumel, I., Ramírez, L. R., Tietjen, S., Barra, M., and Zagal, E.: Back to the future? Conservative grassland management can preserve soil health in the changing landscapes of Uruguay, Soil, 9, 425-442, https://doi.org/10.5194/soil-9-425-2023, 2023.

Schimel, D. S., Braswell, B. H., Holland, E. A., McKeown, R., Ojima, D. S., Painter, T. H., Parton, W. J., and Townsend, A. R.: Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils, Global Biogeochem. Cycles, 8, 279-293, https://doi.org/10.1029/94GB00993, 1994.

Sennett, R: The Craftsman. Yale University Press. New Haven, CT. 326 p, 2008

Stoppani, A.O.M.: Bernardo A. Houssay y su tiempo, Anales de la Academia Nacional de Ciencias de Buenos, Buenos Aires, 19-20, 2000

Stewart, C. E., Paustian, K., Conant, R. T., Plante, A. F., and Six, J.: Soil carbon saturation: concept, evidence and evaluation, Biogeochemistry, 86, 19-31, https://doi.org/10.1007/s10533-007-9140-0, 2007.

Staiano, L., Sans, G. H. C., Baldassini, P., Gallego, F., Texeira, M. A., and Paruelo, J. M.: Putting the Ecosystem Services idea at work: Applications on impact assessment and territorial planning., Environ. Dev., 38, 100570, https://doi.org/10.1016/j.envdev.2020.100570, 2021.

Veldman, J. W., Overbeck, G. E., Negreiros, D., Mahy, G., Le Stradic, S., Fernandes, G. W., Durigan, G., Buisson, E., Putz, F. E., and Bond, W. J.: Where tree planting and forest expansion are bad for biodiversity and ecosystem services, BioScience, 65, 1011-1018, https://doi.org/10.1093/biosci/biv118, 2015.

Veldman, J. W., Aleman, J. C., Alvarado, S. T., Anderson, T. M., Archibald, S., Bond, W. J., Boutton, T. W., Buchmann, N., Buisson, E.,...and Zaloumis, N. P.: Comment on “The global tree restoration potential”,Science, 366, eaay7976, https://doi.org/10.1126/science.aay797, 2019.

Wingeyer, A. B., Amado, T. J., Pérez-Bidegain, M., Studdert, G. A., Perdomo Varela, C. H., Garcia, F. O., and Karlen, D. L.: Soil quality impacts of current South American agricultural practices. Sustainability, 7(2), 2213-2242, https://doi.org/10.3390/su7022213, 2015.