Sustainable intensification in crop-livestock systems

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Abstract

Extensive livestock production is the main animal source food system in the Pampas and Campos sub-regions in South America. Beef cattle and sheep convert forage biomass that humans cannot eat into nutrient-dense human-edible foods (meat and milk) and valuable co-products (wool). However, diverse global pressures are acting on Pampas systems including increasing demand for protein sources (food security), climate change, environmental footprint, and competition for land. The integration of small areas of pasture-crop rotations is an alternative for increasing efficiency and sustainable intensification of agroecosystems based on natural grasslands. Rotations led by improved pastures increase the carrying capacity and productivity of traditional Pampas systems, and include crop production (soybean, rice) as an opportunity for farm diversification and resilience. Therefore, mixed crop-livestock systems can feed more people in terms of calories and protein than what is possible with specialized systems. The higher carrying capacity in the area under the rotation may allow less intensive grazing management in larger areas of native grasslands reducing threats to biodiversity. Some of the integrated management practices in crop-livestock systems are perennial pastures to mitigate soil organic carbon losses during cropping, biological nitrogen fixation by legumes, grazing cover crops, crop residue grazing, dual-purpose crops, and harvesting grain and hay for livestock feed. Also, complementary crop and livestock production systems facilitate more efficient nutrient cycling and self-sufficient systems promoting the circular economy concept as a strategic approach toward system sustainability. Key to understanding the potential of mixed crop-livestock systems are productive, environmental, economic, and social factors that determine their performance, as well as trade-offs among them. Development, implementation, maintenance, and analysis of long-term crop-livestock platforms research provides science-based information to address complex biological systems, and to implement innovative public policies at national scale to regulate soil use and to prevent non-sustainable agricultural practices.

Introduction

The Pampas and Campos region comprises parts of Argentina and Brazil and the whole of Uruguay (Modernel *et al.,* 2016). It has different subregions defined by vegetation communities, soils, and landscape characteristics (Baldi and Paruelo 2008). The expansion of the agricultural area under continuous cropping and livestock overgrazing of native grasslands are two of the main concerns compromising the sustainability of the Pampa and Campos biome (Medan *et al.,* 2011; Oliveira *et al.,* 2017; Tiscornia *et al.,* 2019). Cultivation of soybean was the most important reason for land use change in the XXI century causing a decline in the area available for livestock. However, cattle numbers remained relatively stable indicating that cattle stocking rates increased in native grasslands areas and decreased in areas dominated by crop production (Modernel *et al.,* 2016). Recoupling livestock and cropping pathways into integrated crop-livestock systems (ICLS) provides an opportunity to achieve sustainable intensification and protect grasslands from conversion to permanent cropland (Smart et al., *in press*) or overgrazed areas. The objective of this short paper is to review key results of the 'Palo a Pique' long term experiment and to discuss the synergy between ICLS and native grasslands in enhancing the sustainability in the Pampa and Campos biome in South America.

Materials and Methods

Data shown in the present paper corresponds to a long-term crop-livestock experiment established in 1995 in Treinta y Tres (Uruguay) at the National Institute of Agricultural Research (INIA) 'Palo a Pique' research unit (33°15'54.4"S 54°29'28.1"W). The dominant soils are Typic Argiudols with low to moderate soil fertility (1.5 to 2.0% soil organic carbon content (SOC), mass base, in 20 cm depth), occupying a landscape of gently sloping hills where the erosion risk is moderate to high (Terra et al., 2002). The experiment evaluates four different soil use intensities (rotations) with different combinations of pastures and crops under no-till technology (Terra et al., 2006; Rovira et al., 2020). The rotations are: (i) continuous cropping without pastures (CC), (ii) short rotation (SR, two years crops and two years of red clover-based pastures), (iii) long rotation (LR, two years crops and four years of white clover-based pastures), (iv) permanent improved white clover-based pasture (PP) without crops. Each phase of the rotations was represented by a paddock of 6 ha, which was the experimental unit (EU), totaling 12 EUs. Although all phases of the rotations were present at the same time, there were no synchronic replications of each phase. Pastures and forage crops are subjected to direct grazing by growing and finishing Aberdeen Angus cattle.

Results

After 20 years of running the experiment (1995-2015), no soil organic carbon (SOC) differences were found between rotations that included pastures (SR and LR), but they had 21% greater SOC than CC. In addition, SR and LR had lower SOC than PP, while a SOC decreasing trend of 12% was observed in PP compared to the original undisturbed soil under native grasslands located next to the experimental site (Terra and Macedo, 2015). No differences were found in crop yield between the different crop–livestock rotations, averaging (± s.d.) 2499 ± 888, 4871 ± 1758, 2771 ± 1158, and 1569 ± 479 kg/ha for soybean, sorghum, wheat, and oat, respectively, across rotations in the period 2005-2016.

From the animal production standpoint, average liveweight gains (± s.d.) for the first four years of the experiment were 485±151 (CC), 527±61 (SR), 484±82 (LR), and 338±103 (PP) kg/ha per year. In the same period, average forage production was 8.5, 10.2, 9.1, and 7.9 t DM/ha per year for CC, SR, LR and PP, respectively, allowing an animal carrying capacity of 951, 726, 722, and 480 kg LW/ha/year for CC, SR, LR, and PP, respectively (Terra and García-Préchac, 2001). During similar period (1992-2004) and in the same research unit, forage production of native grasslands averaged 3.4 t DM/ha per year, with a seasonal distribution of 35%, 26%, 11%, and 28% in summer, autumn, winter, and spring, respectively (Bermudez y Ayala, 2005). The annual production of the year with the highest production (2002) was three times greater than the production of the year with the lowest production (2004) (5.2 and 1.2 t DM/ha, respectively). For an average year, livestock production in native grasslands ranged between 118 and 145 kg LW/ha/year at a stocking rate between 300 and 420 kg LW/ha (Ayala and Bermudez, 2005).

Discussion

In the Pampas and Campos region the area occupied by grasslands has been reduced by the expansion of soybean. When crops are introduced, rotation with pastures is one of the most basic principles to achieve a sustainable farming system. Here, we describe a large-scale, long-term experiment evaluating four different pasture-crop rotations integrated to livestock production. After 20 years of the experiment, results showed a significant SOC reduction under no-till CC relative to the other rotations containing high proportion of perennial pastures in their cycles. Terra et al. (2006) suggested that the higher content of SOC in pasture-based rotations was related to the greater biomass partitioned to the root systems compared to CC. Recently, evaluating the four rotations using sophisticated models suggested that perennial pastures underpin soil C and nitrogen (N) cycling in crop rotations by maintaining soil C closer to saturation (Pravia et al., 2019). Similar results were obtained in Argentina, where a minimum of 3 years of pastures maintained soil properties within acceptable limits and meet the goals of sustainable intensification in pasture-crop rotations (Studdert et al., 1997).

One of the main features of the experiment is that all paddocks were subjected to direct grazing by beef cattle in a rotationally grazing system adjusting the stocking to pasture conditions. The stocking rate and intensity of grazing determines the amount of residual biomass which is a key parameter for the sustainability of the system. Residual biomass after grazing not only influence animal performance but also represents a physical barrier to compaction through animal trampling, influencing soil aggregation and water dynamics, while avoiding runoff and soil losses from erosion (Carvalho et al. 2018). In Argentina, Fernández et al. (2011) found that the inclusion of livestock to graze cover crops and perennial pastures in ICLS did not produce deterioration of soil physical conditions; although soil penetration resistance was slightly increased within the first 7.5 cm. However, shallow compaction of the topsoil may develop after years of no-till seeding, even in the absence of grazing (Lavado and Taboada, 2009).

Pastures in ICLS increased 2.5 times the forage production and doubled the animal carrying capacity compared to native grasslands. As a result, LW production in pasture-crop rotations more than tripled compared to LW production in native grasslands. Production intensification is one way to reduce carbon footprint per animal and per hectare (Kanter et al., 2016). In Uruguay, Picasso et al. (2014) found that for every 10 kg increase in productivity (kg LW/ha/year), carbon footprint decreases by 1.2 kg CO2e/kg LW and 36 kg CO2e/ha. Increasing productivity can lower environmental impacts by spreading baseline emissions in higher animal outputs and by reducing the cattle age at slaughter, which also produces more food on less land area (Sánchez Zubieta et al., 2021). In addition to increase LW production, ICLS provide product and economic diversification though grain harvesting during the cropping phase of the rotations which can be sold or used to feed the animals within the system.

Native grasslands are key partners of ICLS. Coupling strategic and small areas of pasture-crop rotations with larger areas of grasslands increases farm sustainability by reducing the risk of conversion to continuous agriculture (Smart et al., 2020) and overgrazing of grasslands (Lemaire et al., 2015).Temperate pastures composed by grasses (i.e. tall fescue, annual cover crops) and legumes (i.e., lotus, red and white clover) in ICLS supply high-quality forage during winter when production is reduced in grasslands, usually dominated by native C4 species (Modernel et al., 2016). This complementary can alleviate overgrazing of native grasslands usually grazed by animals all year around at a relatively constant stocking rate, although its forage production shows large seasonal variation. On the other hand, livestock can be moved to grasslands when the area under the pasture-crop rotation has limited carrying capacity due to conjunctural (i.e. excessive soil moisture in winter) or structural (i.e. area under fallow or recently seeded in autumn and spring) factors inherent to ICLS. To avoid spread of introduced species from pasture-crop rotations to grasslands areas via cattle feces, it is recommended to have a transient or buffer area where cattle can graze for few days before starting to graze the natural pasture area. The role of native grasslands in ICLS is clearly a topic that merits further research.

In conclusion, strategic areas of pasture-crop rotations integrated to livestock grazing are not the problem but part of the solution to protect vast areas of native grasslands from continuous agriculture and overgrazing. Increasing overall productivity while reducing its environmental footprint and conserving the biodiversity in ICLS represents a great challenge due to specific trade-offs among productive, socioeconomic and environmental goals (Latawiec et al., 2014). This poses a major research challenge in identifying and facilitating sustainable farming systems in the Pampas and Campos region. Research platforms, as the 'Palo a Pique' long-term experiment, play a key role to provide scientific data supporting sustainable pathways of intensification.

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