Soil carbon and nitrogen dynamics of integrated crop-pasture systems with annual and perennial forages

Maria V Pravia [A], *Armen R Kemanian* [B] *and Jose A Terra* [C]

[A] Instituto Nacional de Investigación Agropecuaria (INIA), Treinta y Tres, Uruguay, www.inia.org.uy
[B] Department of Plant Science, The Pennsylvania State University, University Park, PA. www.psu.edu
[C] Instituto Nacional de Investigación Agropecuaria (INIA), Treinta y Tres, Uruguay, www.inia.org.uy
Contact email: vpravia@inia.org.uy

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Introduction

Increased demand for food and bioenergy crops and the subsequent intensification of crop production creates a challenge for the conservation of natural resources in Latin America and the world. In Uruguay, no-till cash-crop production area has increased from 0.4 to 1.5 million ha in the last decade (DIEA 2011) mostly at the expense of pastureland through expanding grain production to soils with lower land use capability. Production systems based on crop-pasture rotations shifted to a longer annual cropping phase with a shorter pasture phase, or to continuous annual cropping. Long-term experiments in the country have shown that the rotation of annual crops and perennial pastures minimizes soil erosion in tilled systems, maintaining a positive long-term soil carbon (C) and nitrogen (N) balance that contrasts with C and N losses in annual cropping systems (García-Préchac *et al.* 2004). Research and extension on soil conservation in crop-pasture systems have led to a massive adoption of no-tillage practices, reaching about 90% of cash crop area by the 2009 growing season (DIEA 2011). However, the gradual increase in no-till adoption by farm operators has been associated with a dramatic increase in continuous annual cropping to the detriment of the pasture phase of the rotation.

Our overarching question is: What is the impact of an increased frequency of annual crops in the C and N cycling of these systems? The objective of this study was to assess the impact of the pasture phase and cropping intensity on the soil C and N cycling of an Oxyaquic Argiudoll soil of eastern Uruguay using long term field experimental data and a cropping systems simulation model.

Methods

Long-term field experiment

The production systems evaluated consisted on sequence of sorghum (*Sorghum bicolor*)-soybean (*Glycine max*)-pasture contrasting to the pasture phase of the rotation. Three rainfed no-tillage rotational systems had been set up in 1995 at INIA Treinta y Tres (Uruguay, 33°15'44 S, 54°29' W), with the following sequences: (1) Continuous annual cropping (CC) with a winter cover of ryegrass (*Lolium multiflorum* Lam.) for grazing; (2) Short rotation (SR) of 2 yr pasture of red clover (*Trifolium pratense* L.) and ryegrass and two years identical to CC; and (3) Long rotation (LR) with 4 yr of an orchardgrass (*Dactylis glomerata*), white clover (*Trifolium repens* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) pasture, followed by 2 yr identical to CC.

Soil properties and grain yield data

Soil properties and crop yield were measured at field scale plots (3 ha each) after 12 to15 years of rotation. Soil samples consisted of 24 composed samples of 10 cores per field up to 0.15 m depth. Soil samples were analysed for organic C content by dry combustion and infrared detection, according to the laboratory methods described by Burt (1996). Grain yield was recorded and geo-referenced across the fields using a combine equipped with a DGPS (Trimble AgGPS® 132) and an Ag Leader PF3000 yield monitor (Ag. Leader Tech. Inc., Ames, IA). Mixed models (Littell *et al.* 1996) performed with SAS software PROC MIXED (SAS Inst., Cary, NC) were used to analyse measured data.

Integrated crop-pasture systems simulation

The CropSyst model (Stöckle *et al.* 2003) was used to simulate the systems. A complete soil profile description and daily weather data measured at the site were used as inputs for the 15 yr simulation (1995-2009). Sorghum and soybean crop phenology were calibrated manually. Red clover was used as surrogate for the perennial pasture mix LR. Field management practices were simulated as follows. Sorghum (cultivar DK39) and soybeans (cultivar AGT6000) were planted under no-tillage practices on the first decade of November. Forage crops as described for every system were planted on May 20th, after the preceding grain crop was harvested in April. Nitrogen was applied at planting at rate of 22.5 kg N/ha and 15 kg N/ha on sorghum and ryegrass, respectively. Starter fertilizer was applied 50% banded at planting and 50% broadcast on the surface. In sorghum urea was broadcasted at jointing in at a rate of 46 kg N/ha. Sorghum and soybean grain were harvested between March 15th and April 15th of each year.

Results and Discussion

Soil properties and grain production

After 12 years or crop-pasture rotation, cropping systems including perennial pastures had 3 to 6 Mg/ha more soil organic C than continuous annual cropping systems in the top 0.15 m of soil ($P \leq 0.05$). Observed soil organic C average values for CC, SR and LR were 13.6, 16.3 and 18.7

g/kg, respectively. Using default soil organic C turnover parameters in Cropsyst, the model predicts a steady decline in soil organic C that is much larger than that observed. Modifying the parameters to match the soil organic C observed causes acute N stress in sorghum and ryegrass. Sorghum and soybean observed yields were unrelated to soil organic C, and showed pronounced inter-annual variations ($P \leq 0.05$) reflecting variations in water availability during the growing seasons. Average sorghum grain yields for 2006 to 2008 seasons were 8.2, 4.6 and 6.1 Mg/ha, and 2007-2009 soybean 2.1, 3.6, 3.5 Mg/ha, respectively. CropSyst simulations captured weather effects on crop grain yield, although the unusual high sorghum yield observed on 2006 was underestimated.

Nitrogen cycling

According to our simulations, in these low input systems only 40% of the plant available N comes from the fertilizer, while the soil is supplying most of the crop requirements through soil organic matter mineralization. To match soil organic C dynamics, the model forces a reduction in N mineralization that causes a lower than observed N uptake (and N stress). For sorghum, crop N uptake by the end of the season at the observed yield levels is approximately 180 kg N/ha. To achieve that uptake level, the fertilization in the model had to be increased from 68 to 123 kg/ha in the simulations to achieve observed sorghum grain yields. The simulated increase in N fertilization did not increased leaching N losses, and gas losses only increased from 12 to 20 kg/ha. This simulated increase in N fertilization (~55 kg N/ha) can be considered an estimation of the soil N supply derived from crop-pasture rotations in the *short term* that is not accounted for by the default organic matter model dynamics, if the soil organic C is to be preserved. Clearly, part of the benefit of integrating crop-pasture systems is the inclusion of legumes in the pasture phase (Labandera *et al*. 1988; Mallarino *et al*. 1990a, b), yet many questions remain on the components of the N balance for both crop-pasture rotations and annual systems.

Conclusion

Perennial pastures rotating with crops seem to be necessary to preserve soil organic C even under no-tillage in these low-input systems. Based on our results, the short-term cycling of N in these systems is not properly understood or represented in the model. While we have a broad understanding that legumes add N to the system, simulating the observed N uptake patterns in crop-pasture rotations remain challenging. Cleary, this is an area that will benefit from further research.

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