Scouting benefits and developing innovations in temperate grassland to sustainable agriculture production

Walter Ayala, Ethel Barrios, Ignacio Macedo, Jorge Sawchik and José Terra

ABSTRACT

Agricultural intensification raises concern about land use and future effects to natural resources. The world demand for grain, meat and forest products is increasing constantly. Changes are occurring at large scale, being a compromise for policy makers to contribute to identify opportunities to readdress the productive scenario. There is available technology to reduce impacts, without restricting necessarily productivity. Grasslands provide a large series of economical and ecological benefits to the agricultural systems, being the literature exhaustive in examples. Ley-farming and cover crops technologies are good examples of environmentally sound soil management practices. The society is also worried about an improper use of the natural resources involved. The drastic increase in the grain crops area leaded by soybean in Uruguay, determined that the government implemented Sustainable Soil Use and Management Plans, based on erosion estimation using the USLE-RUSLE model adapted locally by research conducted over more than 50 years on a series of long term experimental platforms. There is an opportunity for this type of local innovative initiatives to be widely diffused, adopted or adapted. In essence, grasslands will continue playing a key role in maintaining a sustainable production.

Key words: Agriculture intensification, Cover crops, Land use regulations, Ley- farming

Introduction

The Southern Cone of South America is well recognized, among other temperate regions around the world, because of its conditions of natural and improved grasslands to provide support to an efficient livestock production. However, the recent increase in the world grain demand a significant soil use change from grasslands for livestock to cropland for grains. In 2008, South America contributed with 40% of the increase in world cropping area (Montossi *et al.*, 2008). This process has been leading by soybean cultivation, supported by market demands and prices, especially associated with the economic development in Asian countries.

This scenario determined important land use changes from grasslands to croplands increasing the demand for fertile soils, a higher land intensification, agriculture expansion to non-traditional areas and raise in land and renting prices among other effects. Livestock production maintained its contribution, based on the intensification in beef demand and prices. However, pastoral lands for livestock production are being reduced, raising the use of marginal areas.

Brazil, Argentina and Uruguay, and more recently Paraguay and Bolivia are examples of these changes in the agricultural sector that determined strong investments in logistic, infrastructure, equipment and also human resources support.

In Uruguay, the area of soybean increased from 9000 hectares in 1998 to 1.321.000 hectares in 2014 (Souto, 2014), being the main row crop in the cropping system area. There is no doubt that agriculture impacts at different levels, from environmental issues to social development. The purpose of this paper is to analyze some benefits that grasslands provide to the agricultural sector of Uruguay, to mitigate land use change impacts on natural resources and to develop integrated and sustainable productive systems.

a) Defining the problem

In Uruguay, continuous cropping systems evolved to simplified rotations with low crop diversity based on a high frequency of soybean that threat, sustainability of agricultural systems. Despite that no-till was fully adopted, there are concerns on: a) sustainability of soil quality, b) negative nutrients balance, c) level of soil residues and erosion risk during winter, d) reduction or elimination of perennial pastures in the rotation, e) charge of agrochemicals, f) contamination of water sources, g) increase pests and weeds incidence.

Risk of soil erosion in more fragile Mollisols like those prevalent from the East region, showed important differences associated with the type of cultivation (Terra and García Prechac, 2001). When double cropped (2 annual crops per year) with conventional tillage, soil losses were 8.5 times higher than a soil with a natural grassland cover (Table 1). In rotation system that included two years crop and four year pastures under no-till, soil losses were similar to the observed in a natural grassland.

Under no-till, soil losses are being reduced because soil residue cover contributes to reduce rainfall effects. Puentes (1981) cited by García Prechac (1992) defined the level of tolerance for most agricultural soils in 7 t/ha/year. Other effects of continuous cropping systems are associated with reduction in crop yields (Díaz, 2006), decline in soil fertility and soil physical properties. These conditions improved when ley-farming was introduced (Fig. 1).

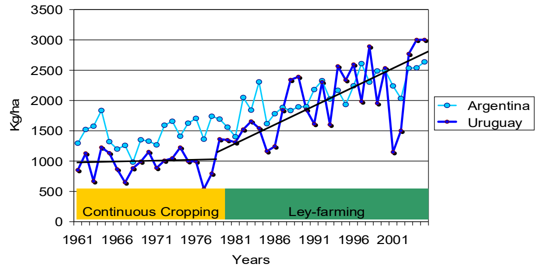

Fig. 1. Average wheat yield in Argentina and Uruguay and dominant agricultural system in Uruguay from 1961 to 2004 (Díaz, 2006).

b) Ley-farming benefits

Ley-farming is the system characterized by the integrating in time and space livestock and grain crop production through a crop-pasture the rotation, achieving the largest potential benefits on sustainability (Diaz, 2007). The integration of annual grain crops with pasture phases of different length improves soil conditions as soil structure or fertility, and contributes to reduce the incidence of pest and diseases. It is well described in the world, the potential benefits of these practices, in terms of: a) improved soil quality, b) reduction of erosion and land degradation, c) improved pest and diseases control, d) integration of livestock and crop production and e) diversification in income opportunities.

Díaz (2006, 2007) demonstrated the value of ley-farming systems in Uruguay, despite that grain market prices and food demand resulted in the intensification of agriculture in many opportunities (García Prechac *et al.*, 2004),

Table 1. Annual soil erosion rates (Mg ha^{-1}) in 4 different soil conditions, (adapted from Terra and García Prechac, 2001).

Period	Bare soil	Natural grassland	Rotation 2-4 No-till	Double cropping Reduced tillage
Av. 1993-1999	85,3	1,8	1,7	15,6

being the consequence the reduction of diversified systems. Their long term stability is highly dependent on the prices relationships between grain and livestock products. In many cases, when soybean prices are high, large companies rented land areas with 2-3 years contract, being possible to achieve greater profitability of continuous cropping compared with beef fattening processes. Many farmers, and particularly land owners, are more interested to develop integrated systems, including an intensive livestock production.

Soil organic carbon (SOC) is recognized as the single most important soil quality indicator. In a long term experiment in Uruguay SOC loss in continuous crops with conventional tillage was 421 kg ha^{-1} yr^{-1} after 40 years, representing 46% of the original SOC content (Moron, 2003). Comparatively, in a crop-pasture rotation (3 years annual crops – 3 years of pasture) SOC and Total nitrogen content were maintained. Phosphorus balance was negative under continuous cropping and positive under the three year pasture phase.

Terra and Macedo (2015), evaluating other long term experiment in Uruguay found that, after 20 years, SOC was 28% lower in continuous cropping (26,9 g kg^{-1}) compared with the same crops rotated with two or four years pastures, even under no till. In a system

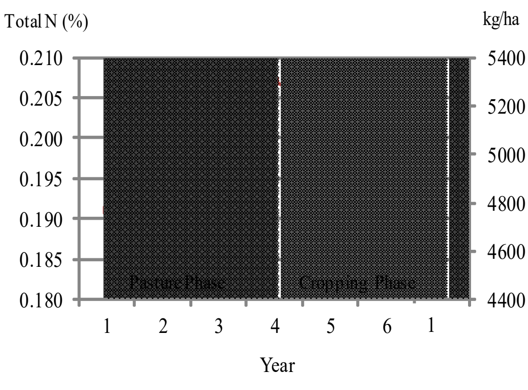

Fig. 2. Soil Nitrogen dynamics through a 3-year pasture and a 3-year cropping phase (Morón, 2003).

with a 3-year pasture phase and 3-year crop phase soil nitrogen dynamics shows an increase during the pasture phase and a decline under cropping, returning to the initial state (Fig. 2).

Grain crop productivity after 40 years was higher in a continuous cropping system with fertilization (system 2) compared with the same rotation without fertilization (system 1). When a pasture phase was included (system 5), crop productivity increased in wheat, sorghum and barley. Sunflower yields were always poor and less variable among systems.

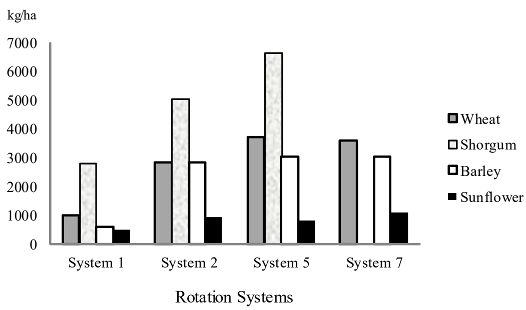

Fig. 3. Annual grain crop productivity after 40 years of soil management with different rotation systems (System 1 = continuous cropping without N&P; System 2 = continuous cropping with N&P; System 5 = 3 year cropping - 3 year pasture rotation; System 7 = 1 year pasture - 2 years grain field crops). (Morón, 2003).

c) Cover crops benefits

Cover crops, also called catch crops or green manure, are grown to provide a series of benefits to cropping systems. Including cover crops in rotations may provide some benefits such as: a) improved soil protection and reduced soil erosion, b) reduction of N and other nutrient losses, c) capacity to catch nutrients from the soil, d) increase N inputs through biological nitrogen fixation by legumes, e) maintain or increase SOC, f) improve soil structure, g) reduce weeds, pathogens and pests, and h) increase in biological biodiversity (Thorup- Kristensen *et al.*, 2003).

Table 1. List of species and cultivars tested as a winter cover crops in two regions of Uruguay (East and South West) and main benefits provided in terms of biomass accumulation, early soil cover, biological nitrogen fixation and improved soil physical properties.

Genus	Species and cultivars tested	Biomass accumulation		Early soil cover	Biological nitrogen fixation	Soil physical properties
		East	South West			
Legumes	*Trifolium resupinatum* LE 90-33	+	++		++	
	Trifolium alexandrinum INIA Calipso	+	++		+++	
	Trifolium subterraneum Goulburn		+		+	
	Trifolium subterraneum Bindoon		--		+	
	Trifolium vesiculosum Sagit	+	++		+++	
	Trifolium michelianum	+	++		+	
	Trifolium pratense LE 116	--	++		+++	
	Ornithopus sativus	--	++		+	
	Ornithopus compressus	--	++		+	
	Medicago scutellata sava	--	++		+	
	Medicago truncatula	--	++		+	
	Vicia sativa Barril	+	++		+	
	Vicia villosa Amoreira	+	++		+	
	Lupinus luteus Cardiga	+++	--		+++	
	Lupinus luteus Mister		--		+	
Grasses	*Lolium multiflorum* INIA Cetus	+++	--	+++		+
	Lolium multiflorum Camaro	--	++	+++		+
	Avena strigosa Calprose Azabache	+++	--	++++		+
	Avena sativa 1095a	--	++	++		+
Cruciferous	*Raphanus sativus* Brutus	+++	++	+		++
	Raphanus sativus Reset	++	+	+		++
	Raphanus sativus CCS-779	++	--	+		++

Note: — represents no data, no symbol in biomass production represent less than 2,5 t DM/ha, each + represents 2,5 t DM/ha. For soil cover nitrogen fixation and soil properties each mark (+) that are more suitable

Based on that principles, a series of cultivars and species of grasses, legumes or cruciferous were evaluated in Uruguay based on their capacity to improve soil cover, biological nitrogen fixation capacity or soil physical properties (Barrios *et al.*, 2015).

During the last five years more than 20 winter cover crops options were tested to evaluate their adaptation (Table 1).

In general, legumes produced lower biomass than grasses and cruciferous, being lower in less fertile environments like the East region of Uruguay, affecting consequently the potential of biological nitrogen fixation (Table 1). Legumes also exhibited less early growth and did not express the full production potential because they were terminated in early spring for land bed preparation. In contrast, grasses provide good levels of biomass production and soil cover at early stages. Cruciferous species offer higher biomass accumulation and the chance to improve soil properties based on their root system. However in some heavy soils with poor drainage, the bulbs development was limited.

Cover crops production had larger productivity differences between years rather than genus or species (Table 2). In a high fertile environment like the South west of Uruguay, biomass production tend to be higher mainly based on the performance of legumes and grasses.

Table 2. Biomass production of different cover crops species from early autumn to early spring in two regions during 3 years (adapted from Barrios *et al.*, 2015 and J. Sawchik *et al.*, *pers. commun.*).

Region	Genus (n)	Biomass (DM, Mg ha^{-1} yr^{-1})		
		Average	Maximum	Minimum
Eastern	Legumes(6)	2.9 ±1.8	7.6	1.1
	Grasses (2)	3.8 ±2.1	8.9	1.8
	Cruciferous (3)	4.3 ±2.5	8.6	1.0
South West	Legumes (5)	3.7 ±1.4	6.2	1.5
	Grasses (2)	4.1 ±1.7	6.9	2.1
	Cruciferous(2)	4.4 ±1.8	6.9	1.6

Cover crops take nitrogen from soil, contributing to reduce nutrient losses. However, nitrogen uptake has large variations as a consequence of growth rate, climatic conditions or soil nitrogen availability. In the experiments mentioned, only nitrogen concentration of aboveground biomass was measured (Table 3), despite that roots in general represent around 50% of total biomass but with a lower nitrogen tissues concentration (Thorup-Kristensen *et al.*, 2003).

Nitrogen uptake by aboveground biomass was not enough to cover subsequent nitrogen extraction by grain production (Table 3). Assuming that legumes nitrogen fixation is being 50-75% of nitrogen uptake and at least 50% is absorbed, nitrogen balance in systems that include legumes as a cover crops tend to be neutral. Using species like grasses or cruciferous, balance is negative being more important other aspects like soil cover o physical structure (Sawchik *et al.*, 2012). Nitrogen release in the field is associated to the type of cover crops, because biomass needs to be discomposed by soil microbes to make nutrients available for the next crop. A high carbon/nitrogen ratio in the biomass will cause a net reduction in nitrogen availability for the following crop, demanding additional fertilization.

In a three years experiment, maintaining the same cover crops, there were no effects on soybean yield and inconsistent effects in sorghum yield (Table 4). The historical low use of this soil with row crops could explain the reduced effects observed.

d) Uruguayan Policy: The Plan Land and Use Management

Recently, the Ministry of Agriculture and Fisheries of Uruguay (MGAP, 2015) implemented a national soil use and conservation plan, that regulates cropping rotation systems based on soil erosion rates estimations and other key soil quality indicators. Erosion problems increased with

Table 3. Nitrogen tissues concentration (NTC), nitrogen biomass uptake (NBU), nitrogen grain soybean uptake (NSU) and extracted Nitrogen by grain/nitrogen biomass uptake ratio (NSU/NBU) from aboveground biomass of cover crops.

Genus (n)	NTC (%)	NBU (N kg ha^{-1} yr^{-1})	NSU (N kg ha^{-1} yr^{-1})	NBU/NSU (%)
Cruciferous (3)	1.63	92	181	51
Grasses (2)	2.05	106	178	58
Legumes(6)	3.07	105	169	62
Control - not sown (1)	2.63	55	174	32

Table 4. Soybean and sorghum grain production under different cover crops for three years comparing two methods for cover crop establishment (oversown previous crop harvest or direct drilling after crop harvest), Barrios *et al.*, 2015.

	Soybean (kg ha^{-1})		Sorghum (kg ha^{-1})
Cover crops	**2012-2013**	**2013-2014**	**2014-2015**
Raphanus sativus Brutus	2690	2792	5219 a
Raphanus sativus Reset	2537	2967	5288 a
Raphanus sativus CCS-779	2537	3077	4945 abcd
Lolium multiflorum INIA Cetus	2742	2975	5095 abc
Avena strigosa CALPROSE Azabache	2750	2895	5098 abc
Trifolium vesiculosum Sagit	2743	3147	4550 bcde
Vicia sativa Barril	2672	3014	--
Vicia villosa Haymaker	--	--	4505 cde
Trifolium resupinatum LE 90-33	2614	2886	4266 e
Lupinus luteus	2648	2813	5014 abc
Trifolium alexandrinum INIA Calipso	2803	3020	5171 a
Trifolium subterraneum	2569	3235	4390 de
Control (not seeded)	2509	2903	5114 ab
Oversown	2655	2892	4948
Direct drilling	2648	3062	4828
Sowing method	0.9084	0.1005	0.3256
Cover crops	0.3463	0.3673	0.0040
Sowing method x Cover crops	0.6398	0.9248	0.2624
General mean (kg/ha)	2652	2977	4888
LSD (cover crop, kg/ha)	--	--	596

Note: Different letters showed significant differences in each column (Least significant difference 5%).

the "agriculture boom", leaded by the intensification of continuous cropping with soybean in traditional agriculture areas and the expansion of agriculture to non-traditional and more fragile soils. The plan defines a soil use and management capacity and erosion tolerance for the farm, being an instrument to regulate soil use and conservation. In practice, each farmer, planting individually more than 100 hectares, must submit a Plan of Land use and Management, prepared by a certified agronomist. This plan includes a soil map describing the different productive units and the crop rotation plan for each one. The annual erosion tolerance is approximately 7 t ha^{-1} yr^{-1} , based on the data generated using the Universal Soil Loss Equation (Renard *et al.*, 1991; Wischmeier and Smith, 1960), which was calibrated in our conditions. The project started with a pilot phase in 2011. Additionally a series of actions are being taken to fully implement this plan at national scale: a) update soil survey of the country; b) develop more research in areas of carbon and nitrogen modeling; c) a guide to good farming practices, d) training of agronomist to elaborate plans.

Conclusions

A series of benefits provided by pastures and cover crops were reviewed, presenting conclusive information about alternatives to maintain a sustainable agriculture production. The Land and Use Management Plan initiative described, is an innovative public policy at national scale to regulate soil use and prevent inappropriate agricultural practices. The integration of livestock and agricultural production give the opportunity to include a pasture phase in cropping rotations and achieve profitability and sustainable soil use.

References

Barrios, E., W. Ayala, I. Macedo and J. Terra. 2014. Cultivos de cobertura en esquemas agrícolas: resultados 2012-2013 y 2013-2014. INIA Serie Actividades de difusión No. 735, p. 26-28.

Barrios, E., W. Ayala, I. Macedo, and J. Terra. 2015. ¿Qué opciones de cultivos de cobertura se disponen para integrar a los esquemas agrícolas en la Región Este?. INIA Treinta y Tres, Serie Actividades de difusión No. 748, p. 13-16.

Díaz, R. 2006. La intensificación agrícola en el Cono Sur y los desafíos de la sostenibilidad. In: Aportes de la Ciencia y Tecnología al manejo productivo y sustentable de los suelos del cono sur. IICA/PROCISUR. pp. 11-20.

Díaz, R. 2007. Ley-farming systems in temperate South America agriculture in Uruguay: a case study. In: *International Symposium on integrated crop livestock production*. Curitiba, Brasil, 20 p.

García Prechac, F. 1992. Propiedades físicas y erosión en rotaciones de cultivos y pasturas. INIA, Investigaciones Agronómicas 1 (I): 127-140.

García Préchac, F., O. Ernst, G. C. Siri-Prieto, and J. A. Terra. 2004. Integrating no till in livestock/crop-pastures rotations in Uruguay. *Soil Tillage Research* 77: 1-13.

MGAP. 2015. http://www.cebra.com.uy/renare/planes-de-uso-y-manejo-de-suelos/ Consulted September 18, 2015.

Montossi, F., W. Ayala, and R. Díaz. 2008. The Challenges of Cropping and Forestry Intensification on Grassland Livestock Production Systems: The Uruguayan Case. XXII International Grassland Congress/VIII International Rangeland Congress , Hohhot-China. Proceedings: Multifunctional Grassland in a Changigng World pp. 5-13

Morón, A. 2003. Principales contribuciones del experimento de rotaciones cultivos-pasturas de INIA La Estanzuela en el área de fertilidad de suelos (1963-2003). In : Simposio 40 años de rotaciones . Editores: Morón, A. y Díaz, R. INIA La Estanzuela, Colonia, Uruguay. Serie técnica no. 134. pp. 1-7.

Renard, K. G., G.R. Foster, G.A. Weesies and J.R. Porter. 1991. RUSLE: Revised universal soil loss equation. *Journal of Soil and Water Conservation* 46 (1): 30-33.

Sawchik, J., M. Perez Bidegain and C. García. 2012. Impact of winter cover crops on soil properties under soybean cropping systems. In Agrociencia, Special Issue, ISTRO 2012. pp. 288-293.

Souto, G. 2014. Oleaginosos y derivados. Situación y perspectivas. In Anuario 2014. *OPYPA: análisis sectorial y cadenas productivas , temas de política, estudios*. pp. 147-164.

Terra, J. and F. García Préchac. 2001. Siembra directa y rotaciones forrajeras en las lomadas del este: Síntesis 1995-2000. INIA Treinta y Tres, Serie técnica No. 125. 99 p.

Terra, J., W. Ayala, G. Cantou, E. Barrios and C. Cardozo. 2013. Cultivos de cobertura en esquemas agrícolas: resultados preliminares. INIA Treinta y Tres, Serie de actividades de difusión 713. Cap. 9. 4 p.

Terra, J. and I. Macedo. 2015. Twenty years no-till pasture rotation systems impacts on soil organic carbon. Abstract. In Proceedings ISTRO 2015. 1p.

Thorup-Kristensen, K., J. Magid, and L. Stoumann Jensen. 2003. Catch crops and green manures as biological tools in nitrogen management in temperate zones. *Advances in Agronomy* 79: 227-302.

Wischmeier, W.H. and D.D. Smith, 1960. A Universal Soil Loss Equation To Guide Conservation Farm Planning. In. 7th International Congress of Soil Science , Madison., U.S.A: 418-425.