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Agronomic and environmental impacts of pasture–crop rotations in temperate North and South America

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ABSTRACT

Agriculture has become increasingly specialized in response to political, regulatory, sociological, and economic pressures to meet market demands of an ever-larger food and fiber processing sector. However, there is a growing concern with specialized agricultural systems, because of increasingly negative responses on the environment from declining soil quality to eutrophication of water bodies and enhanced greenhouse gas emissions. Literature from North and South America was reviewed that showed (i) strong positive production outcomes of crops grown following pastures, (ii) enhancement of soil organic matter with perennial pastures, particularly in the surface soil, (iii) improvement in water infiltration and water quality, and (iv) synergies between crop and livestock systems in system-wide evaluations of production and environmental quality. Therefore, agricultural soils would benefit from the re-introduction of perennial grasses and legumes into the landscape (i.e. temporally and/or spatially) by regaining soil organic matter and strengthening their capacity for long-term productivity and environmental resiliency.

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1. Introduction

Agriculture has become increasingly specialized in industrialized countries in response to political and economic pressures to meet market demands of an ever-larger food and fiber processing sector (Russelle et al., 2007; Hendrickson et al., 2008). In the USA, specialization has been accompanied by a dramatic decline in the number of farms from >6 million in 1920 to <2 million in 2009 and an amazing increase in productivity (Hanson and Hendrickson, 2009). Large family and non-family farms now account for >75% of agricultural sales; in 2007, the largest 2% of farms were responsible for 59% of total farm sales (NRC, 2010). However, nearly 65% of farmers in the USA also worked off the farm and 40% worked more than 200 days per year at an off-farm job, primarily to obtain sufficient income and employer-subsidized health insurance (USDA-NASS, 2009). Livestock production has changed, too. Compared with many small, diversified family farms in 1950, today there are larger specialized row-crop and/or concentrated animal feeding operations (CAFOs) (Singer et al., 2009).

In Uruguay (and similarly in most of the Southern Cone of South America – including Argentina and Chile), the total number of small crop and livestock farms has declined sharply in the last 20 years (DIEA, 2012). In the dairy sector, based mostly on annual forage crops and permanent pastures, the number of farms and land declined 12 and 15%, respectively, in the last decade. However, milk production per unit area increased 32%, mainly due to the adoption of new technologies, an increase in stocking rates, and change in feed composition (DIEA, 2011). The same trends have also been observed on crop farms. Large agricultural enterprises that operate throughout the Southern Cone region are responsible for almost 70% of the grain crop area and production (DIEA, 2011). Most of the farmers involved in family farms now lease machinery operations or other services to new agricultural operators, while others sold or rented their farms. Although an increase in productivity has occurred for different cash grain crops in the last 30 years in the Southern Cone (Saavedra, 2011), much of it has been at the expense of a smaller diversity of products from farms, of which many are now devoted to soybean monocropping, resulting in susceptibility to perturbations from changing markets and climate (Viglizzo, 1986; Viglizzo et al., 1995, 2011).

Kirschenmann (2009) and Steiner et al. (2009) expounded that the contemporary food system in the USA has become entrenched in an era of cheap energy, an assumed stable climate, and a business environment, in which negative environmental and social costs have been externalized without penalty or assumed responsibility. Industrialization and concentration of agriculture have increasingly revealed how food is produced in a way that homogenizes the landscape, widens the chasm between rich and poor, can fuel an epidemic of obesity, is seemingly insensitive to animal welfare,

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and has become environmentally degrading (Pollan, 2006; Kenner, 2008; Ikerd, 2009). Individual and societal decision making is beginning to recognize these concerns (Halloran and Archer, 2008).

Specialized agricultural systems that simplify ecosystems and their processes can result in cumulative negative effects on the environment that are manifested in (Russelle and Franzluebbers, 2007):

- water contamination with excessive nutrients, pesticides, and pathogens;
- sinking groundwater levels due to high demand and competition from a variety of stakeholders, including specialized crop production;
- rising greenhouse gas concentrations from soils depleted in organic matter;
- dysfunctional soils that have become exhausted from excessive tillage, salt accumulation, and pesticide inputs; and
- loss of family farms and rural infrastructure.

In contrast, conservation systems that integrate crops and livestock could provide opportunities to vigorously capture ecological interactions to make agricultural ecosystems more efficient at cycling of nutrients, rely more on renewable natural resources, and improve the inherent functioning of soils, while achieving acceptable or improved economic returns for the farmer (Franzluebbers, 2007; Russelle et al., 2007; Franzluebbers et al., 2011). Furthermore, diversifying agricultural production enterprises utilizes labor more efficiently for many on-farm tasks (Hoagland et al., 2010).

Although it is more ecologically efficient to consume calories and protein from crops than from meat, and although some livestock production systems have contributed to environmental degradation, livestock can utilize crops and residues not suitable as food and fiber for humans (Russelle et al., 2007), as well as transform plant-bound nutrients into readily mineralizable substrates through passage in the rumen to improve soil fertility (Whalen et al., 2000; Bulluck et al., 2002). In addition, conservation-oriented integrated crop–livestock systems can provide multiple environmental benefits (Schiere et al., 2002; Franzluebbers, 2007; Sulc and Tracy, 2007).

Four modes of agriculture have been described (Schiere et al., 2002):

- low external input agriculture, in which demand is adjusted to resource availability and greater labor and skills are necessary to increase production;
- expansive agriculture, where land is abundant;
- high external input agriculture, in which demand for output or profitability determines input levels, sometimes leading to environmental degradation; and
- new conservation agriculture, in which production goals are matched with the resource base to achieve both profitability and environmental benefits.

Agriculture in the post-European colonization period of the USA was initially of the expansive mode – when land in the east became worn out after years of use with no inputs and declining soil organic matter, farmers traveled westward to explore new ground (Triplett and Dick, 2008). United States Congress responded to the massive degradation of land and displacement of people during the Dust Bowl of the 1930s with the Soil Conservation Act of 1935. With full implementation of the industrial revolution in agriculture following World War II, synthetic fertilizers and pest control strategies heralded an age of impressive increase in staple food production and global trade of high-value commodities (Tilman et al., 2002).

Land use in the Argentinean Pampas changed from a vast grassland without large herbivores prior to Spanish settlement in the 16th century to grassland with numerous cattle and horses until the end of the 19th century and more recently vast conversion to crop cultivation since the 20th century (Lavado and Taboada, 2009). Agriculture in Uruguay and Argentina has experienced unique shifts during the past century. In the 1950s and 1960s, annual crops (one crop per year) were planted with long (>2 months) fallow periods. This fallow allowed dramatic soil erosion and soil degradation to occur. In the 1970s with strong advice from New Zealand, N and P fertilizers and some soil conservation practices began to take place. This slowly led to the adoption of crop–pasture rotations, resulting in improved soil quality, enriched biodiversity, reduced fuel costs, and other benefits (Díaz-Rosselló, 1980; García-Prechac et al., 2004). There was also an increase in productivity through adoption of improved seed genetics. Adoption of no-tillage systems throughout the region in the 1990s shifted agricultural production systems from crop–pasture rotations to continuous cropping with no tillage. Most livestock production was relegated to marginal soils, while cropping intensified (i.e. increase in number of crops per year on a parcel of land). Since the turn of the 21st century, a dramatic increase in area under soybean [*Glycine max* (L). Merr.] has occurred throughout the region, leading to less diversified cropping systems. In Uruguay, small-grain cereals are still very important and a double cropping system [e.g. wheat (*Triticum aestivum* L.)/soybean] is prevalent in other parts of the Southern Cone region. However, soybean is now the dominant crop. Meanwhile, cost of land in the whole region has increased, e.g. 10-fold increase in some areas. This change has restricted accessibility to land for other production systems, like the dairy sector. Overall though, Uruguay still has >70% of land under natural grasslands.

In the temperate Pampas of Argentina, the area covered by grasslands and pastures decreased from 65% to 55% in the first decade of the 21st century (Viglizzo et al., 2010). According to the National Agriculture Census (INDEC, 2012), ~8 Mha of pastures were converted to cropping (mainly soybean) from 1988 to 2002 in this region. Livestock grazing on pastures shifted to subtropical areas of Argentina, and calves have become more often fattened in feed lots (Paruelo et al., 2005; Viglizzo et al., 2010). With less land devoted to long-term pastures and grasslands in recent decades, cattle have become fattened increasingly with grain supplements, forage reserves, agricultural residues, or directly in feed lots.

With recent emphasis on biomass harvest for renewable energy technologies, agriculture can be expected to provide an even wider range of beneficial ecosystem services to society, other than the traditional role of food production. It is within this context that integrated crop–livestock systems hold enormous potential for achieving agricultural sustainability in the Americas. Emphasis on renewable energy technologies is also important in the Southern Cone region, but the situation is somewhat different among various countries. Uruguay still has a large supply of forest products and the government has put greater emphasis on other renewable technologies, instead of biomass crops. Part of the soybean grain production in the region is being processed for biofuel production.

2. Ecosystem services from grasslands

Natural grasslands have historically provided a sustainable and resilient land cover rooted down by a variety of grasses and forbs. Such stable ecosystem structure provides a plethora of essential ecosystem services, notably efficient water and nutrient cycling, balanced gas exchange with the atmosphere, stable climate regulation, abundant food and feed production, and a diversity of cultural and esthetic opportunities and experiences (Franzluebbers, 2012). Carbon in grasslands is stored predominantly below-ground in soil organic matter (Parton et al., 1988; Burke et al., 1989). In the long term, grazing by herbivores can have important consequences on