Agriculture, Ecosystems and Environment 190 (2014) 70–79

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Integrated crop-livestock system in tropical Brazil: Toward a sustainable production system

Julio C. Salton[a,*], Fabio M. Mercante[a,b], Michely Tomazi[a], Josileia A. Zanatta[c], Germani Concenço[a], Wiliam M. Silva[a], Marciana Retore[a]

[a] Embrapa Western Agriculture, Dourados, MS, Brazil
[b] CNPq Researcher, Brazil
[c] Embrapa Forestry, Colombo, PR, Brazil

ARTICLE INFO

Article history:
Received 4 March 2013
Received in revised form
30 September 2013
Accepted 30 September 2013
Available online 24 October 2013

Keywords:
Soybean
No-tillage
Soil quality
Savanna
Pasture
Brachiaria
Crop rotation

ABSTRACT

Performance of soil management systems was initiated in 1995 in a field experiment in Dourados, MS, Brazil, with the following systems: CS – conventional tillage; NTS – no-tillage; ICLS – integrated crop-livestock with soybean (*Glycine max* (L.) Merr.) and pasture under no-till, rotating every two years, and PP – permanent pasture. Pastures (*Brachiaria decumbens*) were grazed by heifers with stocking rate adjusted to constant supply of forage. The hypothesis was that rotation of crops and pastures would be more efficient and present beneficial effects to the environment. More complex and diversified production systems may exhibit synergism between components to result in better soil physical structure, greater efficiency in use of nutrients by plants, greater accumulation of labile fractions of soil organic matter, greater diversity and biological activity in soil, and lower occurrence of nematodes and weeds. Better soil conditions in ICLS allowed greater resilience; over the years of assessment soybean and pasture yields were less affected by drought and frost. The ICLS was very efficient, accumulating soil C and reducing emissions of greenhouse gases. Soil quality was improved in integrated systems with larger number of components and greater interaction between these components (ICLS) compared to simple systems. Based on soil attributes, we affirmed in this long-term study that the ICLS system is agronomically and environmentally efficient and sustainable.

1. Introduction

To intensify the production of food, fiber, and energy, production systems are constantly being reformulated to increase production efficiency, protect the surrounding environment, and/or promote ecological recovery. With the expansion of soybean cultivation, the degradation of large areas due to cattle grazing, and low livestock productivity (especially during the winter) in tropical Brazil, agricultural systems that integrate grain production and livestock grazing could be advantageous to both farmers and the environment. Integrated crop-livestock systems could make it possible to reconcile the recovery of pasture productivity with greater crop stability (Sulc and Tracy, 2007; Carvalho et al., 2010).

Integrated crop-livestock systems have been adopted in several regions of Brazil. Due to the unique climatic, economic, and structural characteristics of each region, however, these production systems are arranged in various ways that differ in the species sequence, implementation details and rotation phases between crop and livestock farming (Salton et al., 2008; Balbinot et al., 2009; Carvalho et al., 2010). In general, the adoption of integrated systems is beneficial by reducing pasture degradation (Kluthcouski and Stone, 2003). The benefits of integrated systems include increased soil fertility due to the accumulation of organic matter (Salton et al., 2010), improved nutrient cycling (Flores et al., 2008; Carvalho et al., 2010), increased fertilizer efficiency (Assmann et al., 2003), and better soil aggregation (Salton et al., 2008). Integrated systems also favor a more biologically active edaphic environment compared to other cropping systems (Silva et al., 2011). Similarly, crop fertilization improves both pasture productivity and livestock performance indexes (Carvalho et al., 2010). Rotation of crops with livestock can also help to break pest, disease, and weed cycles, thus reducing production costs, increasing economic and environmental outcomes (Lazzarotto et al., 2009; Martha Junior et al., 2011), and reducing the environmental risk posed by the proliferation of agrochemicals (Vilela et al., 2008).

Accumulation of organic matter and improvements of soil chemical, physical, and biological properties suggest that integrated systems will reduce the environmental impact of agricultural production, mitigate greenhouse-gas (GHG) emissions, maintain or increase crop yields, improve water and nutrient usage

* Corresponding author. Tel.: +55 6734169748; fax: +55 6734169721.
E-mail addresses: julio.salton@embrapa.br, jcsalton@yahoo.com.br (J.C. Salton).

0167-8809/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2013.09.023

(Franchini et al., 2011), and enhance environmental resilience by promoting biological diversity and improving soil quality (Anghinoni, 2007).

However, integrated systems must be designed differently across the large continental extent of Brazil. We compiled the results of a long-term experiment in Dourados, Mato Grosso do Sul, Brazil to assess the performance of simple and complex agricultural production strategies. Soil attributes and grain and beef production were monitored. Other agronomic and environmental features, such as weed dynamics and GHG emissions, were also monitored. We tested the hypothesis that a 2 year rotation of no-till crop and livestock production is more efficient and environmentally beneficial than less-complex systems, including both conventional and no-till systems. In this work, results of several reports during this long-term experiment were pooled through multivariate principal component analysis to infer about the efficiency and sustainability of integrated systems.

2. Materials and methods

2.1. The Dourados experiment

A field experiment was initiated in 1995 at the Embrapa Western Agriculture station in the city of Dourados, Mato Grosso do Sul, Brazil (22°16′56.08″ S and 54°48′17.17″ W).The soil at this site is an Oxisol (kaolinitic with clay, silt, and sand contents of 630, 215 and 155 g kg^{-1}, respectively). The regional climate is classified as Cwa: a mesothermal, humid climate with hot summers and dry winters. The 25-ha experimental area was divided into plots where the following systems were used: a conventional system (CS) consisting of a soybean (*Glycine max* (L.) Merr.) monoculture followed by oats (*Avena strigosa* Schreb. or *Avena sativa* L.) under conventional soil tillage using a disk harrow every growing season; a no-till system (NTS) using a crop rotation including soybeans and corn (*Zea mays* L.) grown during the summer and wheat (*Triticum aestivum* L.), oat or turnip (*Raphanus sativus* L. var. oleiferus Metzg.) as cover crops, without soil tillage; an integrated crop-livestock system (ICLS) rotating every two years between crop species (soybean and oat) and pasture grass (*Urochloa decumbens* syn. *Brachiaria decumbens* Stapf) under no-till cultivation, with pastures grazed by heifers whose stocking rate was adjusted to ensure a constant forage supply of approximately 7% of body weight; and a permanent pasture (PP) consisting of *B. decumbens* grazed according to the same management strategy used in the ICLS.

During experiment planning of this long-term trial, we envisioned the type of data to be collected. Since the area had homogenous soil and environmental conditions, we decided that large plots (2–4 ha per treatment), would make possible collection of all types of system data while allowing superposition of a geostatistical layer grid for use of geoprocessing tools. All soil and plant samples were collected using this grid of equidistant points spaced 30 m apart (Fig. 1). This design also facilitated mechanical operations like planting, harvesting and cattle management, while resembling management adopted in large, commercial production areas.

NTS was divided into three subplots (NTSa, NTSb, NTSc) to account for different crops in the rotation. Every summer, two plots were planted with soybean, while the third was planted with corn; in winter, oat, wheat and turnip were used, according to the sequence oat/soybean/wheat/soybean/turnip/corn. ICLS was divided into two subplots (ICLSa, ICLSb) aiming to have cattle raising and grain crops in the same year with rotation between crop and livestock every two years. Soybean fertilization was based on replacing nutrient exportation in the grain of the crop, by applying 20 kg ha^{-1} of P_2O_5 and 20 kg ha^{-1} of K_2O per ton of grain. For corn and wheat, an average of 100 kg ha^{-1} of N per cropping cycle was applied as urea; cover crops (oats and turnips), as well as pastures, were not fertilized. Lime was applied in 2001 at the soil surface with 2 Mg ha^{-1} of dolomitic limestone. Soybean seeds were inoculated with *Bradyrhizobium* spp. in every planting.

2.2. Soil physical and chemicals attributes

A fixed grid of 242 equidistant points distributed across the experimental area was used for sample collection to measure the physical and chemical attributes of the soil over time. Mean values were calculated and presented with the corresponding standard error (Fig. 1).

2.2.1. Physical attributes

Soil aggregation was determined for monoliths with 10 cm × 10 cm with 20 cm depth that were kept in the shade and manually disaggregated by observing their weak points. Subsequently, all soil samples were air-dried and passed through a 9.52-mm mesh sieve. Following the method of Salton et al. (2008), soil aggregates from each sample were classified by size after both dry and wet sieving. A series of sieves with 4.76-, 2.00-, 1.00-, 0.50-, 0.25-, 0.105-, and 0.053-mm openings were used. After agitation, soil aggregates remaining in each sieve were weighed. Values obtained from dry and wet sieving were used separately to calculate mean weight-diameter (MWD). The ratio of the wet MWD to the dry MWD is the aggregate stability index (ASI).

2.2.2. Chemicals attributes

Every two years, the 0–5-, 5–15-, and 15–30-cm soil-depth levels were sampled for chemical analyses. Concentrations of exchangeable bases [calcium (Ca) and magnesium (Mg)], phosphorus (P), and potassium (K) were measured based on Silva (1999). Total, organic, and inorganic P concentrations were measured by the ignition method (Saunders and Williams, 1955), in which samples were incinerated at 550 °C for 1 h to analyze total P and not incinerated to analyze inorganic P. Total and inorganic P were then determined photocolorimetrically at 725 nm, and organic P was obtained as the difference between these two values.

2.2.3. Soil organic matter contents and quality

Soil organic matter (SOM) and its fractions were monitored over time in soil samples obtained from the sampling grid and depths described in Section 2.2.2. Total organic carbon in soil (TOC) was expressed in terms of its content (g kg^{-1}) and storage (Mg ha^{-1}) in each soil layer. These calculations took into account the soil density values [C content (%) × soil density (g cm^{-3}) × layer thickness (cm)].Carbon concentration was quantifying by dry combustion(TOC Analyzer –VCPN SSM-5000A, Shimadzu Corp, Japan). The carbon-retention rate of soil was calculated from the total C storage at the beginning of the experiment and measured periodically until 10 years.

The amount of C in the particulate organic carbon (POC) fraction was determined through physical granulometric fractioning according to the method of Cambardella and Elliott (1992). First, a 20-g soil sample was dispersed in 80 mL $(NaPO_3)_6$ at 0.5% and sieved through a 0.053-mm mesh sieve. Next, the mass and C concentration of the residue were determined, yielding the carbon concentration (g kg^{-1} soil) of the POC fraction. For samples collected in 2004, densimetric physical fractioning was used to obtain the free-light fraction (FLF), occluded-light fraction (OLF), and heavy fraction (HF) of the SOM. This method employs ultrasound dispersion in sodium polytungstate $[Na_6(W_{12}O_{40}H_2)\cdot H_2O]$ dissolved in distilled water and adjusted to a density of 2.0 g cm^{-3}. These procedures were described by Boeni (2007), who also determined the amounts of organic matter present in different types