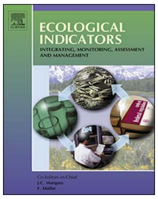
Ecological Indicators 83 (2017) 328–337

Contents lists available at ScienceDirect

Ecological Indicators

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



Original Articles

Trade-off assessments between environmental and economic indicators in cropping systems of Pampa region (Argentina)

Diego O. Ferraro[a,b,*], Mercedes Gagliostro[a,b]

[a] IFEVA, Universidad de Buenos Aires, CONICET, Facultad de Agronomía, Av. San Martín 4453 (C1417DSE), Buenos Aires, Argentina
[b] Universidad de Buenos Aires, Facultad de Agronomía, Departamento de Producción Vegetal, Cátedra de Cerealicultura, Av. San Martín 4453 (C1417DSE), Buenos Aires, Argentina

ARTICLE INFO

Keywords:
Sustainability indicators
Agriculture
Tradeoff
Emergy
Ecotoxicity

ABSTRACT

An overall sustainability assessment should include changes in the economic return, the social benefits and the human intervention on the biophysical resources in order to highlight potential trade-off or synergies among them. In this work, we studied the performance of 36 cropping systems (CS) of the Pampa region, Argentina, which include three different crops, three increasing levels of technology adoption in four contrasting site conditions. For each CS, we simultaneously assessed 1) the ecosystem energy flow using the emergy synthesis; 2) the pesticide ecotoxicity using a simple dose-response model; and 3) the economic profit, in order to evaluate the influence of crop identity, technological level, and site location on the indicators values as well as to detect potential trade-offs between indicators. Results revealed that maize crop entailed the most sustainable indicator profile by exhibiting relative high emergy return, low non-renewable emergy use, low pesticide ecotoxicity, and high gross income. In addition, results showed a significant trade-off between economic profit and ecotoxicological risk in the CS studied. Further studies should be conducted for including more contrasting indicators in order to explore the potential trade-off among other ecosystem components as a promising way to identify sustainable crop management regimes for different production zones.

1. Introduction

Agricultural systems are ecosystems human-modified in order to obtain a product that generates a profit. However, recently it arose the idea of a potential trade-off between

productivity-enhancing technical change (i.e. agricultural intensification) and the maintenance of ecosystem integrity (Müller and Burkhard, 2010). Consequently, it led to a demand of analytic tools that can measure progress toward a broad range of social, environmental and economic goals (Reed et al., 2006). However, these goals should be clearly identified and the indicators should be goal-oriented for allowing course corrections. Despite the complexity of economic, ecological, and social aspects of agroecosystems, the economic performance is readily assessed using the economic return. However, when the ecological counterpart is assessed the multiplicity of both components and process entails a significant compromise between relevance and feasibility (Bockstaller et al., 2009). This compromise leads to find both robust and ecologically sound indicators to complement with the economic return indicators. The use of energy can be used as an indicator of both structural and functional integrity in agroecosystems due to, like any biological system, they are subject to the basic laws of physics, such as energy exchange and the resulting thermodynamic balances (Bakshi, 2002). Although thermodynamics are required to obtain a proper understanding of the physics underlying biological systems, economics, and the environmental sciences are useful complements for understating the path towards more sustainable agricultural systems. Thus, the use of energy-related analysis should be considered as one tool amongst several quantitative approaches that should be employed to study agricultural systems. The components of this "sustainability toolkit" (Hammond, 2007) would also include environmental assessments and cost-benefit analysis. In this work, we assessed the thermodynamic, environmental and the economic outcome of the most frequent cropping systems in the Pampa region (Argentina) in order to evaluate their performance as well as to highlight any potential trade-off among components. The energetic performance of the cropping systems analyzed was assessed using the emergy synthesis (Odum, 1996; Zhang et al., 2007; Zhang et al., 2012; Wu et al., 2014). This is an energy evaluation method and specifically, emergy is defined as "the total amount of available energy of one kind (most often of the solar kind) that is used up directly or indirectly in a process to deliver an

---

[*] Corresponding author at: Cátedra de Cerealicultura, Facultad de Agronomía, Universidad de Buenos Aires, Av. San Martín 4453 (C1417DSE), Buenos Aires, Argentina.
E-mail address: ferraro@agro.edu.ar (D.O. Ferraro).

http://dx.doi.org/10.1016/j.ecolind.2017.08.020
Received 11 January 2017; Received in revised form 31 July 2017; Accepted 4 August 2017
Available online 18 August 2017
1470-160X/

output product, flow, or service" (Odum, 1996). Thus, emergy accounting is a measure of the past and present environmental support to a process, and it allows to explore the interplay of the natural ecosystem and human activities (Franzese et al., 2009). For analyzing one of the direct environmental effects we assessed the ecotoxicological risk associated with the pesticides used in each cropping system (Ferraro et al., 2003) in order to understand some potential effect on both insects and mammal diversity. Finally, the cropping systems were evaluated in terms of economical profit using historical economic data. The study was conducted in four locations located in the Pampa region of Argentina, each one representing different environmental cropping conditions. In this region, some issues regarding sustainability have recently arisen; among these are concerns that sustainability may be hampered by the replacement of mixed grazing–cropping systems with permanent agriculture mainly based on soybean crops, and that the impacts of increasing productivity by increasing inputs could derive in critical trade-offs between various economic and ecological services (Viglizzo and Frank, 2006; Rositano and Ferraro, 2014). As a measure of this intensification process, the pesticide consumption in the studied area increased from 6 million kilograms in 1992–32 million kilograms in 2012 (Solis et al., 2016). More recently, the cases of herbicide resistance in the study area (Valverde, 2007) contributed to increase the environmental load due to chemical compounds (Matin Qaim, 2005). Based on these antecedents, the main goal of this work is to conduct a comprehensive multiple assessments of the most conspicuous cropping systems of the Pampa region (Argentina), including the economic, and the environmental performance.

2. Materials and methods

2.1. Study site

The cropping systems analyzed in this work are located in the Pampa region (Argentina). The Pampa is a fertile plain originally covered by grasslands, which during the 1900s and 2000s was transformed into an agricultural land mosaic by grazing and farming activities (Soriano et al., 1991). However, since 1990 the traditionally mixed grazing–cropping systems were being replaced by permanent agriculture. The most frequently cropped soils in the region are Mollisols, developed from eolian sediments of the Pleistocene era, with dominantly udic and thermic water and temperature regimes, respectively (Moscatelli et al., 1980). We assessed the cropping system performance in four typical agricultural locations: 1) Pergamino, 2) Balcarce, 3) Villegas, and 4) Gualeguay. Pergamino (33°53′00″S; 60°34′00″O) is located in the Rolling Pampas, the most productive subregion of the Pampa where annual cropping is concentrated (Hall et al., 1992). The predominant soil is a typical Argiudolls (Soil-Survey-Staff, 1999) and the annual rainfall averaged 950 mm. Balcarce (37°49′00″S 58°15′00″O) is considered representative of the predominant land uses in the southeast part of the Pampa Region. It includes part of the Flooding Pampas, mostly a cattle-breeding area dominated by lowlands with small differences in topography, soil quality, problems of salinity, water drainage and flood risk (Barral and Oscar, 2012). Predominant soils can be used for cultivated crops and pasture implantation, with an average annual rainfall of 700 mm (Viglizzo et al., 2004). Villegas is located to the west of the province of Buenos Aires (35° 02′00 "S; 63° 01′00" W), in the sub-region of the Sandy Pampa. Predominant soils with an aptitude for agricultural and livestock use, classified as typical Hapludolls (Soil-Survey-Staff, 1999). Soils with good depth and good drainage alternate with soils with hardened horizons, which limit the root development of plants. It is a sub-humid zone, with an average annual rainfall of 700 mm (Viglizzo et al., 2004). Finally, Gualeguay (33° 09′ 00"S; 59° 20′00" W) belongs to the southeast sub-region of Entre Ríos. The representative soils are the vertic Argiudolls, developed on colluvium-alluvial materials that are suitable for tillage, with a moderate risk of water erosion (Mantel and van Engelen, 1997). The average annual rainfall is 900 mm (Viglizzo et al., 2004).

2.2. Cropping systems: management description and crop yield simulation

Our analysis was restricted to 36 cropping systems (CS) that derived from a full combination of three crops, three incremental level of technological adoption and four site locations. In the four site locations described above, we selected the three most frequent crop systems in the Pampa region: (1) the wheat/soybean double cropping (W/S); (2) maize cropping (M), and spring soybean cropping (S). Within each crop, we defined three incremental technological level (TL): low (L), average (A) and high (H). The incremental technological level entails increasing input usage (e.g pesticides, fertilizers, yield potential due to genotype constraints). TL characterization was built by using several sources (BOLCER, 2015; Margenes_Agropecuarios, 2015). The scarcity of reliable data sources of the average crop yield for the whole set of CS led us to explore the outcome of these alternative management strategies by simulating crop yields into the Decision Support System for Agrotechnology Transfer (DSSAT) package (Jones et al., 2003) that has been calibrated for the studied locations (Mercau et al., 2007). The advantage of using crop simulations models is that they are able to capture climate-management interactions in a process-based structure as well as the simulated a representative average yield value using long-term weather records. Crop simulation models focus on how weather (especially temperature and the amount of radiation intercepted by the crop) and genetic characteristics affect potential yield, given a specified management scheme. DSSAT need many auxiliary inputs such as daily weather variables and soil characteristics in addition to crop genetics and management conditions. There are four types of input data to the DSSAT model: weather, plant, soil, and management. The weather input data are the daily sum of global radiation (MJ $m-2$), daily minimum and maximum air temperatures (°C), and the daily sum of precipitation (mm). Plant parameters and physiological characteristics are given in the form of genetic coefficients, which describe physiological processes such as development, photosynthesis, and growth for individual crop varieties in response to soil, weather, and management during a season (He et al., 2010). Soil inputs describe the physical, chemical, and morphological properties of the soil surface and each soil layer within the root zone. The management information includes planting density, row spacing, planting depth, irrigation, application of fertilizer and they were representative of the most frequent situation of each the cropping systems of the selected site locations. The average crop yield value from 1971 to 2008 historical weather record period was used as the representative crop yield for each CS. Factors associated with management and weather, however, are limited to plant-water supply and plant-nitrogen supply (Ghaffari et al., 2001) excluding important factors such as weeds, diseases, and pests. Therefore, we empirically adjusted the attainable crop yield (van Ittersum and Rabbinge, 1997) resulting from DSSAT simulations in order to model actual crop yield. Local data of simulated versus observed crop yield were used for obtaining the adjusting coefficients (attainable to actual yield) at each TL for each crop species (Mercau et al., 2001; Satorre et al., 2005; Mercau et al., 2007)

2.3. Indicator description

2.3.1. Emergy based-indicators (ELR and EYR)

A typical diagram of the crop production system is presented in Fig. A1 in supplementary materials. The diagram illustrates the boundary, main components, and interactions. Inputs of the crop production system can be categorized into four types as shown in that diagram: (1) local renewable resources (R), such as sunlight, rain, and the wind, (2) local non-renewable resources (NR), such as net loss of topsoil, (3) purchased materials (M), such as mechanical equipment, purchased diesel, chemical fertilizers, seeds and pesticides, and (4) purchased services (S), such as labor, and technical management (Tao et al.,