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Material and Energy Demand for Soybean Production in Argentina

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Abstract

Since the 1990s, Argentina's agriculture suffered great transformations due to the use of GM soybean. This crop has been transferred from the most fertile area of the country, Pampa, to areas with greater environmental fragility like Chaco. The agricultural model is highly dependent on external inputs, and while there is qualitative information about the process called "sojización", quantitative studies of the demand for materials and energy of soybean in Argentina at local level have not yet been done. The objective of this study is to evaluate such demand and determine which inputs are those with higher loading of materials and energy using MFA (Material Flow Analysis) and Embodied Energy Analysis (EEA), respectively. The results indicate that the greatest demand is abiotic mass, and, within it, the loss of topsoil is the most important. The total amount of material inputs required by soybean production was 6.6 kg/kg of soybean. The greatest value is the abiotic mass, with 3.91 kg/kg of soybean, followed by water, with 2.44 kg/kg of soybean. Extrapolating the obtained data in the study area, we can roughly estimate the material and energy consumption in the entire country. For example, agrochemical use by soybean was one third of the total used in Argentina during the analyzed campaign (2009-2010). In terms of embodied energy, each kg of soybean requires 0.02 kg of oil equivalent, i.e. 9.68E+05 J/kg of soybean. According to our results, 25% of energy consumption in the agricultural sector of Argentina is solely due to soybean production. Over the course of recent decades it was shown that the industrial agricultural system, highly dependent on supplies and materials, is not a solution to the problems of food shortages, but rather, it is the cause of many of them, as well as the cause of significant impacts on the environment and humans.

1 Introduction

Nowadays, we can state that agriculture is one of the human activities that has transformed most the environment. It usually involves strong processes of change in the landscape and energy flow, and a significant loss

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of biodiversity (Pengue, 2005). Of the 500,000 years of human history, until 500 years ago most people were still living by hunting, fishing and gathering. Only in the last 300 years, agriculture and livestock became the main way of food source. And until about 70 years ago, these activities were practiced with few inputs (Solbrig and Morello, 1997; Sarandón, 2002).

In the late 1940s, in Mexico, a group of scientists financed by the Rockefeller Foundation conducted a series of experiments to obtain, by crossing, new varieties of wheat and corn. This time and place is suggested as the birth of the "Green Revolution" (Beltran, 1971). The proposal involved the use of genetic varieties of higher performance, combined with irrigation and massive use of chemical fertilizers, pesticides, herbicides, tractors and other heavy machinery. The aim was to increase world food production, and although the quantitative results have been very important, impacts on the environment have been still greater (Azcárate, 1991; Sarandón, 2002; Pengue, 2005, 2008; Ceccon, 2008). In most agricultural settings, management practices are often evaluated based on their economic benefits with less attention given to the environmental and public health perspectives (Udeigwe et al., 2015).

In the 1990s a "new" Green Revolution, or industrial agricultural model arises, which basically refers to the production of commodities with large capital investment in genetically modified seeds (mainly soybean), machinery, agrochemicals (fertilizers, pesticides, herbicides), significant use of fossil fuels, need of little labor and presence of new social actors such as sowing pools, contractors, rentiers, etc. (Pengue, 2005; Ceccon, 2008). Global soybean production rose from 143 to 227 Mtons between 2000 and 2010 among major producers (Argentina, Brazil, China and the US; FAOSTAT, 2013) (Lathuillière et al., 2014).

In the last decades of the twentieth century, an economic reorientation begun in Argentina. It is based on the adoption of pampean crops (sunflower, sorghum, wheat, corn and then soybean) to the detriment of livestock, resulting in the process called agriculturization. In the late 90s, the phenomenon called “pampeanization” begins (Morello et al., 2007). “Pampeanization” refers to the process of transferring the technology package and production practices of the Pampas region to other areas (Pengue, 2005), generally marginal as the Chaco region, with the assumption that they operate in the same way on both sites, regardless of environmental conditions, which are very different, and therefore also their impacts are different. This transfer was based on the release of the first genetically modified organism in Argentina: transgenic soybean resistant to glyphosate herbicide, which is why it is also called "sojización" (Pengue, 2005). The technological package was wide spread due to continued increase in no-tilling practices, further integration of transgenic crops together with herbicides, implementation of precision tools supported by geo-referencing, and resulting yield increases (Rótolo et al., 2014). The use of this GM crop brings with it a huge demand for inputs of which the industrial agricultural model depends.

The higher production levels per unit of land or labor in the agriculture sector allowed for a dramatic increase in the global population, a related decrease in arable land per capita, and a movement of the work force away from agricultural production. One additional factor is the role of energy prices; relatively high prices for oil and natural gas have consequences, primarily on fertilizer use and transport (IAASTD, 2009). Therefore, considering the materials and energy, the new technology applied to agriculture is highly demanding.

There is a lot of qualitative information about these phenomena, but so far, a study has not been done describing quantitatively soybean production in Argentina regarding materials and energy demanded by the technology package of soybean crop al local level. We propose to estimate the amount of materials mobilized and commercial energy use by the soybean crop in farms located in chaco-pampean plain. This is the area of the country where the greatest amount of soybeans is grown.

1.1 Social Metabolism

Economic and human development relies on the throughput of materials and energy to support production and consumption processes, which produce waste and emissions as by-products (Schandl et al., 2016). Social Metabolism is the theoretical framework that explains the physical relationship between society and nature (Fischer-Kowalski, 1998; 1999), or, in other words, it is a concept applied to investigate the relationships between social and natural systems. The biological concept of metabolism, the process by which an organism stores (anabolism) and consumes (catabolism) energy to perform its vital functions, can also be applied to social systems, which need to extract matter and energy from the surrounding environment to survive, generating wastes that are returned to the environment.

Changes made by humans on their environment are of enormous magnitude since the socioeconomic metabolism produces significant pressure on the environment. For example, it is estimated that the volume of materials that are moved annually for the construction of roads, housing, mining, infrastructure, etc., is 57,000 Mt/year (million tons), almost three times higher than the sediments transported by the world rivers to the ocean in a year (Douglas and Lawson, 2000). Through agricultural activity alone, humans have displaced about 20,000 Gt of soil through cropland erosion over the history of civilization. It represents a volume of 8000 km^3, an amount sufficient to cover the entire Earth landscape to a depth of around 6 cm. Perhaps more importantly, it represents huge amounts of continental erosion over extremely short durations of geologic time (Wilkinson et al, 2007). These authors states that humans actually are the most important geologic agents, and annually displace 75 Gt of soil. For example, some studies (Pimentel et al., 1995; Pimentel and Skidmore, 2004; U.S. Department of Agriculture, 1994) indicate that rates of soil loss from United States croplands exceed those of soil formation by over an order of magnitude, implying that current agricultural practices are far removed from sustainable levels (Wilkinson, 2005).The global economy now uses three times as many resources as biomass, fossil fuels, metal ores and construction minerals than it did four decades ago (Schandl and West, 2010; Steinberger et al., 2010). This continuous growth in use of materials (including energy carriers), land and water cannot be sustained (Hirschnitz-Garbers et al., 2016).

Based on the work of Ayres (1989), when the use of the "industrial metabolism" notion was introduced, economic statistics considered only flows from nature which had an economic value (iron, wood, etc.). But Schmidt-Bleek (1993) suggested that this analysis excluded the bulk of removed material displaced by the humans to produce goods and services, among which was agriculture erosion, mining and earthworks for infrastructure construction. For this reason, the concept of "ecological rucksack" (Schmidt-Bleek, 1992) was coined, which refers to the hidden flows of resources required to obtain a substance or manufacture of a product, and which are not part of the product and do not have an economic value (Hinterberger et al., 2003; Carpintero, 2005).

1.2 Research Objectives

The objective of this research was to evaluate the contribution provided by the environment, measured as the amount of required materials and energy, to the process of soybean production in Argentina. Accounting of material and energy flows is done through a Material Flow Analysis (MFA) and an Embodied Energy Analysis (EEA), respectively. Most of the investigations using the MFA and EEA analyze the national economies of countries because the data can be obtained directly from published official statistics, while studies at regional or local level (as in the case of this research) are very few, due to the fact that availability of data at the local level is much lower (Hinterberger et al., 2003).

2 Materials and Methods

2.1 Study areas

Two Argentine agricultural localities were selected, one in the Pampas region (Rojas, Buenos Aires Province) and one in the Chaco region (Charata, Chaco Province) (see Figure 1). Both locations represent a sample of the characteristics of soybean production in Argentina; each region has distinctive features. For this reason the results can be extrapolated to the entire country to roughly estimate the material and energy consumption.

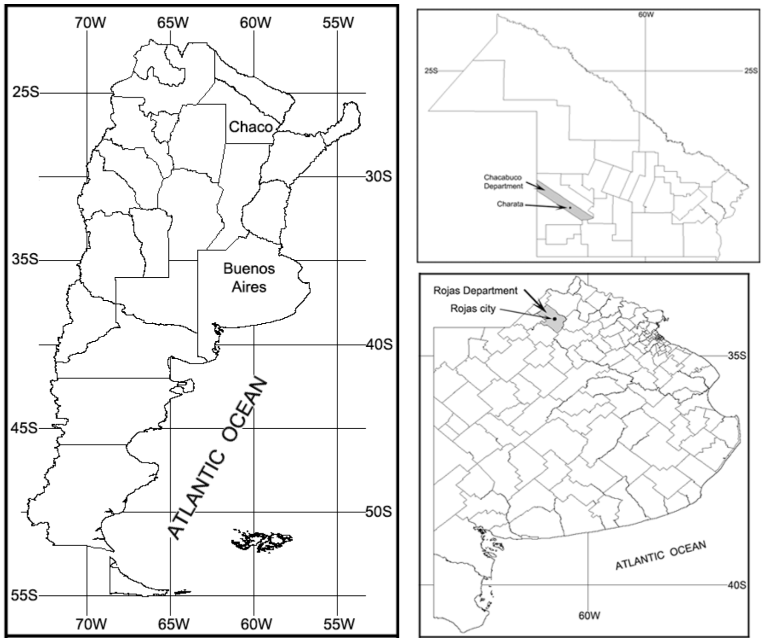

Fig. 1. Maps of Argentina, Chaco and Buenos Aires provinces with the study area departments. The maps, updated to August 2015, are prvided by the National Geographic Institute (http://www.ign.gob.ar/sig) referenced in geographic coordinates, using the Reference System WGS 84 and 07. POSGAR Framework (EPSG Code: 4326).

Rojas is located in the Pampa Ecoregion. In this area, grassland is the predominant natural vegetation. Since the advance of industrial agriculture with the introduction of GM soybean (*Glycine max*) in the late 90s, the continuous application of glyphosate (the herbicide for which genetically modified soybean is resistant), has removed all relicts of natural vegetation (Matteucci, 2012). The climate is humid subtropical, with rainfall throughout the year (Morello and Matteucci, 1997). Average annual rainfall varies between 1000 and 1200 mm. The Rolling Pampa, the main agricultural area in the pampa ecoregion, has the best quality soils of the ecoregion, with a distinctly agricultural natural potential (Matteucci, 2012). The Pampas Region has been the country's center of commodities production for more than 200 years, and currently contributes 93% of soybean (Rótolo et al., 2014).

Charata is in Chaco province and it is located inside the Dry Chaco Ecoregion. In the Dry Chaco the rainfall is very irregular and the annual average varies between 650 and 900 mm (Morello, 2012). Although this rainfall allows rainfed agriculture, water is a limiting factor and drought years are not rare. Since Charata is located on a plain of fluvial and aeolian origin, soils are suitable for agriculture. Until the 90s, cotton was the main crop, but at that time, soybean production begins to expand. This expansion was responsible for large environmental, social and economic changes. Originally, the natural vegetation was tall open forest, interspersed with savannah interrupted by shrub patches and highly flammable forest patches. Today, the landscape is very anthropized, formed by a matrix of agricultural plots with patches of degraded forests (Morello, 2012).

2.2 Material Flow Analysis (MFA)

Material Flow Analysis aims at assessing the environmental disturbances associated with removal or diversion of matter flows of its natural ecosystem paths. When expanding the scale of investigation, we realize that each flow of matter supplied to a process has been extracted and processed elsewhere. Additional matter is moved from place to place, processed and then disposed of to supply each input to the process (Franzese et al., 2013). In MFA, the manufactured products require more materials over their production chain than contained in their final forms (Lettenmeier et al., 2009). In general, raw materials, water and air extracted from natural system are inputs to the social-economic system. In it they are transformed into products and are finally transferred back to the natural system as outputs (waste and emissions) (Schmidt-Bleek, 1993; Hinterberger and Stiller, 1998; Hinterberger et al., 2003; Bargigli., 2004; Bargigli et al, 2004a). This type of analysis contributes to increase the efficiency in the use of resources by reducing the used volumes of matter (Moncada, 2006).

In this method, Material Intensity Factors (MIF) obtained from tables available in published papers and web databases, are multiplied by each input to the system, in order to obtain the total amount of abiotic matter, water, air and biotic matter directly or indirectly required to provide each of these inputs to the system (Ascione et al., 2008; Franzese et al., 2013). That is, all data provided by farmers are entered in a Table in the "Value" column, multiplying each by the MIF obtained from literature. A high value indicates that the MIF product or service being analyzed has a high material intensity i.e., large amounts of material must be diverted from natural patterns in order to generate it (Spangenberg et al., 1998).

Material demands of the individual inputs are then summed up in each column (material inputs are divided into 4 categories: biotic and abiotic materials, water and air). These total masses indicate the amount of materials used for soybean production per hectare. Finally, the corresponding MIF of soybean production are calculated from the yield value. A list of MIFs can be found on the website of Wuppertal Institute (www.wupperinst.org), together with the proposal of other sources for these intensities.

2.3 Embodied Energy Analysis (EEA)

The International Federation of Institutes for Advanced Study (IFIAS) defined Energy Analysis as the process of determining the "commercial energy" (mainly fossil fuel) required directly and indirectly to allow a system to produce a specified good or service (IFIAS, 1974; Herendeen, 1998a,b; Agostinho and Siche, 2014). It focuses on fuels and electricity, fertilizers and other chemicals, machinery, and assets supplied to a process in terms of the oil equivalent energy required to produce them (Agostinho and Ortega, 2012; Franzese et al., 2009), expressed in energy units per physical unit of good or service delivered (for instance, MJ per kg of steel). In this method, all the material and energy inputs to the system are multiplied by appropriate oil equivalent factors (g/unit), and the cumulative embodied energy requirement of the system's output is then computed as the sum of the individual oil equivalents of the inputs, which can be converted to energy units by multiplying by the standard calorific value of 1 g of oil (41860 J/g oil). The chosen cumulative indicator is the so-called "gross energy requirement" (GER), expressing the total commercial energy requirement of one unit of output in terms of equivalent joules of oil (Ulgiati, et al, 2010; Spinelli et al., 2012; Ulgiati et al., 2006; Ascione et al., 2008; Cavalett, 2008). GER of a product refers to the depletion of fossil energy, and therefore all process inputs of material and energy which do not require the use of fossil and fossil equivalent resources are not accounted for. Resources provided for free by the environment, such as topsoil and spring water, are not accounted for by EEA. Human labor and economic services are also not included in most evaluations (Franzese et al., 2009). Thus, summing up the embodied energy values of all input flows in all process steps, the total energy invested into the process, i.e. the total energy cost of the product through energy cropping, is obtained (Fahd et al., 2010). Embodied Energy Analysis quantifies the contribution of the investigated process to fossil energy resources depletion (Franzese et al., 2013), and provides useful insights about energy efficiency of the system (Cavalett, 2008).

In short, Embodied Energy analysis provides two main indicators: Gross Energy Requirement (GER) and Energy Return on Investment (EROI). While the first one is concerned with the Embodied Energy required to produce a unit of product, for instance J/kg, J/m^3, J/L, and so on, the second is an efficiency indicator that shows the ratio of all the Embodied Energy obtained to the energy supplied (J_{out}/J_{in}) (Agostinho and Pereira, 2013). EROI is obtained by dividing the amount of energy obtained per hectare (energy content of soybean) by the total energy invested in one hectare of crop.

We worked with small or medium scale production systems. The time window is one year, with reference to the 2009-2010 campaign. This research was conducted at the local level, in order to know in details the system flows. The scale of analysis is the parcel planted with soybean, and the information was gathered through semi structured surveys. Although in almost all visited production units two or three crops were rotated, this research was focused on soybean production, as it is the major crop in terms of occupied surface at both locations.

3 Results and Discussion

3.1 Material Flow Analysis

In Table 1 an average of material flows is presented. In the last row the values of total mass used are shown. For calculations see Appendix.

Table 1. Material intensities of soybean in chaco pampean plain (kg ha^{-1}-yr^{-1})

	Item	Unit	Value	Abiotic MIF	Abiotic mass	Water MIF	Water mass	Air MIF	Air mass	Biotic MIF	Biotic mass	Refs. for MIFs
1	Loss of topsoil	kg	1.70E+04	0.66	1.12E+04	0.30	5.10E+03	0.00	0.00E+00	0.04	6.80E+02	[a]
2	Fuel (gas oil and gasoline)	kg	25.95	1.36	3.53E+01	9.70	2.52E+02	0.02	5.19E-01	0.00	0.00E+00	[b]
3	Electricity	kW/h	5.76E+00	1.55	8.93E+00	66.73	3.84E+02	0.54	3.11E+00	0.00	0.00E+00	[e]
4	Water for agro-chemical spray (underground)	kg	4.00E+02	0.01	4.00E+00	1.30	5.20E+01	0.00	0.00E+00	0.00	0.00E+00	[e]
5	Seeds	kg	6.90E+01	4.71	3.25E+02	4.94	3.41E+02	0.05	3.45E+00	0.24	1.66E+01	[c]
6	Phosphate (PO_4)	kg	4.30E+01	3.44	1.48E+02	23.30	1.00E+03	1.29	5.55E+01	0.00	0.00E+00	[e]
7	Fungicides and Insecticides	kg	9.00E-01	1.10	9.90E-01	0.00	0.00E+00	0.00	0.00E+00	0.00	0.00E+00	[d]
8	Herbicides	kg	4.6	1.10	5.06E+00	0.00	0.00E+00	0.00	0.00E+00	0.00	0.00E+00	[d]
9	Agricultural machinery (steel)											
	Tractors	kg	0.91	9.32	8.48E+00	81.90	7.45E+01	0.77	7.00E-01	0.00	0.00E+00	[e]
	Harvester	kg	1.07	9.32	9.97E+00	81.90	8.76E+01	0.77	8.24E-01	0.00	0.00E+00	[e]
	Seeder	kg	0.13	9.32	1.21E+00	81.90	1.06E+01	0.77	1.00E-01	0.00	0.00E+00	[e]
	Sprayer machine	kg	0.32	9.32	2.98E+00	81.90	2.62E+01	0.77	2.46E-01	0.00	0.00E+00	[e]
	OUTPUT											
10	Soy (dry matter)	kg	2995	3.91	1.17E+04	2.44	7.32E+03	2.15E-02	6.44E+01	0.23	6.97E+02	This study

MIF References: [a] By definition; [b] Wurbs et al., 1996; [c] Franzese et al., 2013; [d] Cavalett, 2008; [e] Wuppertal Institute, 2014 (http://wupperinst.org/uploads/tx_wupperinst/MIT_2014.pdf).

From the yield data provided by the interviewed producers the average soybean production per hectare in the year under study was 2995 kg, so we can determine how much material would be needed to produce 1 kg of grain. Thus, MIF values for soybean are obtained and the total values of each mass used and the MIF calculated from the total yield are shown in the last row of Table 1. Therefore, adding all Material Intensity Factors, the total material demand was 6.6 kg per 1 kg of soybean.

Within the category "Abiotic Mass", the main contribution corresponds to the net loss of topsoil with 95.7%, as in "Water Mass" where loss of topsoil accounts 70%, following by phosphate with 13.7% and electricity with 5.25%. In the case of "Air Mass" the greatest contribution is phosphate with 86.2%, following by seeds with 5.4%. Finally, the "Biotic Mass" also has the soil as the most important item, representing 97.6%. It is important to remark that scientific literature usually provides poor data on the biotic impact factor as this impact factor is not considered in most studies (Franzese et al, 2013). The greatest value is the abiotic mass, with 3.91 kg/kg of soybean, followed by water, with 2.44 kg/kg of soybean. Within the categories of Abiotic, Biotic and Water, the main contribution is the loss of topsoil by erosion. For each kg of soybean, 5.68 kg of soil are lost. Soil degradation and water erosion, caused mainly by monoculture, also affect the general economy of the region because events such as floods, damage to infrastructure, housing, roads, among others may occur, as a result of lower infiltration of degraded soils and sediments transport (Senigagliesi et al., 1997).

It is important to mention that Charata is a special case because the small and medium farmers do not use fertilizers. Intensive agriculture in the Chaco region is more recent than in the Pampas plain, thus producers do not perceive the need to apply fertilizers yet. Moreover, in the surveys, the interviewees argued that profit margins are small and production is very unstable due to various factors, therefore they do not incur expenditures perceived as unnecessary. The average value in all inputs except with fertilizers was used, and then we used the value of Rojas. The general practice is the application of Phosphate.

The results obtained were compared with the production of soybean in the Toledo River Basin (Brazil) (Franzese et al., 2013). In that paper, Table 11 shows that 4.25 kg of abiotic material, 3.49 kg of water, 0.03 kg of air, and 0.24 kg of biotic materials were used to produce 1 kg of soybean. The total material flow demand resulted in 8 kg/kg of soybean produced. Even though the total materials demand in Brazil is a little greater than in Argentina, an important coincidence with this work is that the topsoil lost by erosion is also the main input to the Abiotic, Biotic and Water impact factors. We also can compare the results with the agriculture in Italy, where soybean production is only about 1.4% of the total agricultural products (http://seriestoriche.istat.it). Focusing on material costs, 1 kg of agricultural product required in Italy in 2010 about 1 kg of abiotic material. Unit water demand dropped from 29.5 kg water per kg of product (Zucaro et al., 2013). Abiotic material is almost four times smaller and water demand is about eight times greater than that required in Argentina. These values reflect the differences between Italian and argentine agriculture, while Italy produces primarily grains, sugar beets, soybeans, meat, dairy products, fruits, vegetables, olive oil, wine, and durum wheat (Zucaro et al., 2013), in Argentine soybean is the main crop.

Our research shows that, for an average of 2995 kg of soybean per hectare, an average mobilization of about 20,000 kg of materials is required. Following the same reasoning, the total production of soybean in Argentina in the 2009-2010 campaign was 52.7 million tons (Bolsa de Cereales, 2010), and required 3.40E+08 tons of materials. Of these, 1.29E+08 tons correspond to water. This huge volume is comparable with 51,600 Olympic swimming pools. Furthermore, a truck carries 25 tons of grain on average (López, 2012), therefore we could imagine that each truck loaded with soybean is accompanied by almost 7 trucks of materials. Of these, 2 and a half would be loaded with water.

The method allows obtaining annual data for the expenditure of materials for soybean production in the country, thus allowing comparisons over time. One can discriminate which parts of the production process has the greatest burden of materials, and efforts could be directed to its reduction. The main destination of the soybean produced in Argentina is the export, and the main receptors are China and the European Union. Here we refer only to the export of grain, since the rest of products (flour, oil, biodiesel, etc.) require additional industrial processes, with more use of materials, which account is not the objective of this research. From 52.7 million tons produced in the analyzed campaign 13,616,000 tons of grain (26%) were exported (DIAR-DIAS, 2011). The exported grains represent 77,339 tons of soil lost that year. Regarding the amount of water contained in the grains (13%) (de Dios, 1993), nearly two million tons (1,770,080 tons) would be exported. Finally, soybean extracts soil nutrients. Eighty percent of Nitrogen assimilated by the soybean occurs through biological N fixation (Smaling et al., 2008), and the rest is extracted from soil. Elemental concentrations in soybean were obtained from Cunha et al. (2010) and Cruzate & Casas (2009): 59.2 kg N/ton, 5.5 kg P/ton, 18.8 kg K/ton, 2.6 kg Ca/ton and 2.8 kg S/ton of soybean leaving the field (Lathuillière et al, 2008). Therefore, in the analyzed period, about 564,247 ton of nutrients were exported. The importing countries do not pay for these losses, and are not losing these valuable resources in their territories. Money does not measure a large set of free environmental services, which are embodied in the exchanged resources and goods, and therefore it is unsuitable to assess the existence of unfair trade and unbalanced resource flows (Bargigli et al. 2004b).

Commercial crop production is highly dependent on the utilization of agricultural pesticides (*i.e.*, any chemical applied to control weeds, insects, plant disease, and rodents) (Udeigwe et al., 2015). We estimated the total amount of agrochemicals (fungicides, insecticides and herbicides) applied in the campaign analyzed (2009-2010) in the country; which is an important information given their particular danger. According to the Integrated Agricultural Information System of Ministry of Agriculture, Livestock and Fisheries (www.siia.gov.ar), we know that 18,130,799 ha in total were harvested. According to the producers interviewed, an average of 5.5 kg of agrochemicals was applied per ha; thus, a total of 99,720,000 kg was applied in Argentina only to soybeans, in this campaign. The release of these huge amounts of biocides has inevitable impacts on the environment, among which we can mention:

1- **Contamination of water bodies:** there is evidence of contamination of water for human consumption by agrochemicals and fertilizers (Winchester et al., 2009). The CONICET Report (2009) about glyphosate says that the high dependence on herbicides of agricultural systems leads to the possible accumulation of residues in soil and in groundwater.

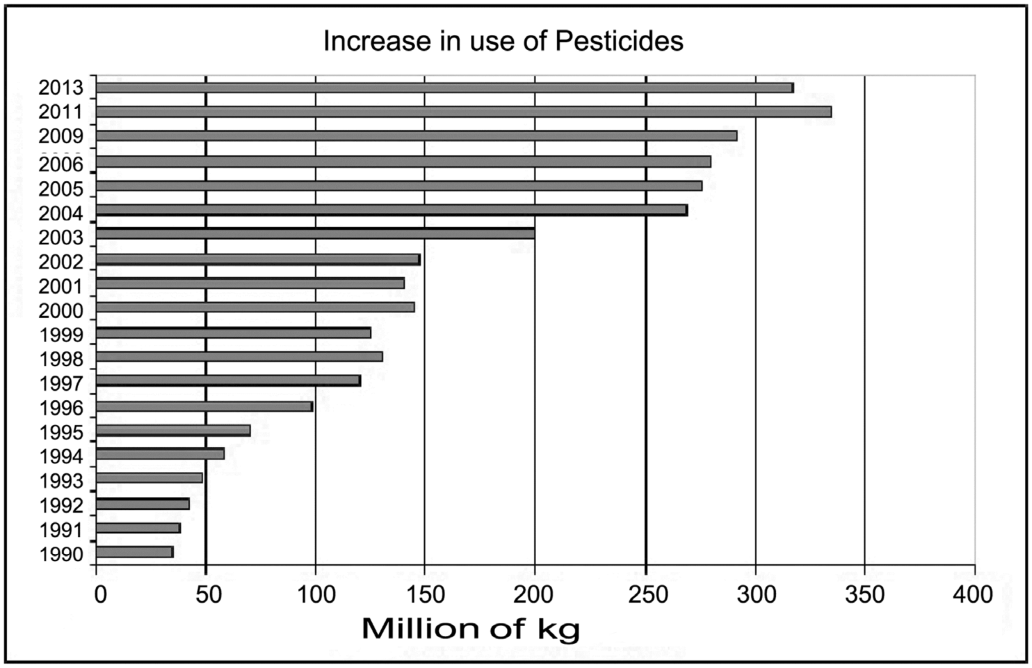

Fig. 2 Amount of pesticides used between 1990 and 2013 in the whole country. Source: Data from the Chamber of Agricultural Health and Fertilizers (CASAFE), data processed by University Network Environment and Health (REDUAS, 2013).

2- **Increasing reliance on agrochemicals**: The application of this type of input is extremely widespread and today agriculture is almost inconceivable without the contribution of agrochemicals (Sarandón, 2002). In 20 years, from 1991 to 2012, while the cultivated grain and oilseed area increased by 50%, from 20 million to 30 million hectares (Oliverio and Lopez, 2010), consumption of pesticides grew from 39 million to 335 million kg/year, which represents an increase of 858% in the volume used (see Figure 2). According to our results, soybean requires approximately one third of the total amount of chemicals applied to all crops cultivated in the country.
Agrochemicals mainly affect the rural population that uses them and people who live near fumigated fields, generating terrible consequences on their health, but also on the flora and fauna that receive increasing amounts of products designed to kill, "weeds" (any other plant that is not crop cultivated), arthropods, fungi, mites, etc. On the other hand, there are vertebrates feeding on arthropods which may contain traces of these pesticides. For example, birds are very sensitive to organophosphate insecticides and carbamates (Woodbridge et al., 1995; Canavelli and Zaccagnini, 1996; Goldstein et al 1996, 1999; Zaccagnini, 1998). The main route of pesticides entrance to the bird's body is through ingestion of food that has been exposed to toxic (Bernardos and Zaccagnini, 2008, Mineau, 2002). We should also take into account the effects on people who consume sprayed products, who even living far from the field, may have traces of chemicals in the blood (for more on this topic see the "Campaña Mala Sangre" by the BIOS NGO and the "Detox Campaign" by WWF).

3- **Development of resistance:** the emergence of resistance in 200 species was documented for the World (Heap, 2011), and some examples are in Argentina: *Sorghum halepense, Loliumperenne, Loliummultiflorum* and *Echinochloacolona* are resistant to glyphosate. This implies that increasing amounts of product or mixtures of more potent chemicals are applied. The same happens with insects, mites, etc. In addition, the indiscriminate use of pesticides causes the disappearance of natural predators and increases the probability of occurrence of new and more vigorous pests (Sarandón, 2002).

The material flow accounting relates the socio-economic metabolism to sustainability because it allows systematic monitoring of natural resource physical flows through the phases of the production process. However, the emphasis only on the amount measured in tons of flows does not mean neglecting the qualitative aspects of environmental impact, such as the toxicity of some flows even if provided in small amounts (Carpintero, 2005). Matthews et al. (2000) noted that “Aggregate indicators of material flows at national level should not automatically be interpreted as direct indicators of environmental impact. A ton of iron is not equivalent to a ton of mercury. [...] However, aggregate indicators are useful measures to determine the potential of physical flows impact on nature”. With regard to industrial agriculture, it is important to note that a ton of water is not the same as a ton of agrochemicals, but the total accounting of the materials used is a valid starting point for understanding the total requirements of soybean production. It is possible to supplement the information provided by the MFA considering the following items (Schmidt-Bleek, 1993):

1- The amount of land used for industrial, agricultural or forestry activities. This is very important to recognize that the amount of available land surface on the planet is limited. The indicator that counts for this is the "ecological footprint", which also includes the land area required to capture the greenhouse gases produced by the use of energy in all the steps of production (Wackernagel and Rees, 1996).

2- The environmental toxicity of circulating materials. MFA is necessary to combine with a quantification of ecotoxicological risks generated by the materials used in the process, since the impacts on human health and ecosystems generate new circulations of materials. For example, in the case of agricultural systems, the large amount of agrochemicals used causes diseases and disorders in the human population, which must be addressed in hospitals, and this in turn generates higher costs of materials. In addition, the consequences of toxic substances on ecosystems are very difficult to measure, but they very likely lead to greater circulation of energy and materials, either to mitigate or remedy them.

3- The chances of a species survival are related to the intensity of land and resources use, and this is directly connected to biodiversity, which is not accounted for by the MFA approach. The use of materials by the economy of a society is somehow related to the extinction of species. This last point has been linked to the processes of "genetic erosion" driven by agricultural modernization (Toledo 1998).

3.2 Embodied Energy Analysis

In Table 2 the energy flows are presented. The main contributions to the soybean production system were fuel (54.7%), phosphorous fertilizer (23.6%) and seeds (10.6%).

Table 2 Embodied Energy Analysis for chaco pampean plain (kg ha^{-1}-yr^{-1})

	Input	Units	Flow	Oil eq. (kg oil/unit)	Total oil demand (kg oil eq)	Total energy demand (J)
1	Fuel	kg	26.0	1.23[a]	3.20E+01	1,34E+09
2	Electricity	J	2.08E+07	6.97E-08[b]	1.45E+00	6,07E+07
3	Seeds	kg	6.90E+01	0.09[b]	6.21E+00	2,60E+08
4	Phosphate (PO_4)	kg	4.30E+01	0.32[a]	1.38E+01	5,78E+08
5	Fungicides	kg	3.80E-01	1.27[b]	4.83E-01	2,02E+07
6	Insecticides	kg	5.00E-01	1.27[b]	6.35E-01	2,66E+04
7	Herbicides	kg	4.60E+00	2.17[b]	9.98E+00	4,18E+05
	Agricultural machinery					
8	Tractors	kg	0.91	1.91[c]	1.74E+00	7.28E+07
9	Harvester	kg	1.07	1.91[c]	2.04E+00	8.55E+07
10	Seeder	kg	0.13	1.91[c]	2.48E-01	1.04E+07
11	Sprayer machine	kg	0.32	1.91[c]	6.11E-01	2.56E+07
	OUTPUT					
12	Soy (dry matter)	kg	2995	0.023[d]	6.89E+01	2.88E+09

References for oil equivalents: [a] Ulgiati, 2001; [b] Cavalett, 2008, [c] Franzese, 2013, [d] This study.

Based on Table 2 we calculated the following indicators:

Table 3 Embodied Energy Analysis indicators

Indicators	Values
GER (J/kg)	9.68E+05
Oil equiv (kg oil eq/kg soybean)	0.02
GER (J $ha^{-1}yr^{-1}$)	2.90E+09
Oil equiv (kg oil eq $ha^{-1}yr^{-1}$)	5.99E+01
EROI	17.6

If for each kg of soybean 0.02 kg of oil were used, 1.05 million tons of oil equivalent (Mtoe) were required in 2009-2010, considering the total soybean production in Argentina. The National Energy Balance (http://www.energia.gov.ar/contenidos/verpagina.php?idpagina=3366) made by the Ministry of Energy and Mining, reports that the agricultural sector consumed a total of 4.45 Mtoe that year. According to the results obtained in this study, 25% of consumption in this sector is solely due to soybean production. The total energy consumed in Argentina in the 2009-2010 period was 53.7 Mtoe, thus 2% corresponds to soybean production.

In this study we are only accounting for the energy used on the farm and upstream, and we are not incorporating transport analysis of grains once they leave the farm, with its corresponding fuel consumption. There are some areas cultivated with soybean in Argentina that can travel up to 1200 km. In the case of Chaco province the average distance is 745 km to Rosario (departure point for export). A standard truck carries 25 ton of grain (López, 2012) and spend 0.4 l of diesel/km (Calzada y Matteo, 2012). In the analysed period the total soybean produced in Chaco(https://datos.magyp.gob.ar/reportes.php?reporte=Estimaciones) was 1,550,860 ton. As we state before, the grain export is about 26% of production, thus 403,224 ton were carried in 16,129 trucks. The transport fuel consumption was 5.4 Mtoe.

One of the proposals that emerged from the increasing need to reduce the consumption of materials and energy was the so-called "dematerialization" (Schmidt-Bleek, 1993). This means reducing the environmental burden while maintaining the standard of living, by introducing functionally equivalent goods that have reduced material intensities (dematerialized goods) on the market. Dematerialized technologies should produce more units of service with a constant or decreasing amount of materials. The concept of dematerialization requires further analysis. To this purpose we can turn to the "Jevons Paradox" (Polimeni, et al., 2008), which states that the relationship between inputs and outputs, i.e. efficiency in the use of a resource, leads in the medium or long term, to an increase in the use of resources rather than to a reduction. Jevons (1865) raised this issue in relation to the use of coal as fuel, whose increased engine efficiency led to higher coal total consumption, both in the established uses as in the expansion of the potential uses of coal in human activities (Giampietro and Mayumi, 2008).

Just as the Jevons Paradox can be applied to resource consumption in general, we can also apply it to agriculture. For example, the Green Revolution was proposed as the solution to world hunger as result of doubling food production efficiency. Yields are actually now much bigger, but it has been shown that the problem of hunger is also associated in large part to inequitable distribution and the impossibility of a large segment of the world population to access the food market (Ceccon, 2008). According Beltran (1971), the Green Revolution has almost exclusively benefited a minority of large farmers with high economic level, who are the only ones that can perform the required high investments and take risks. They are also the only ones to influence prices, to obtain new inputs and to enjoy transport facilities, storage and distribution. And therefore, they are the ones who achieve spectacular results and “reap the abundant fruits of the Green Revolution”.

4 Conclusions

The MFA and EEA methods can be used as a direct measure of the exploitation of natural resources (soil excavation, water extraction, biotic material degradation, etc.) and, from the point of view of the precautionary principle, as an indirect measure of environmental impact (ecosystem stress, local climate changes, biodiversity loss, etc.).

The results show that, regardless the natural conditions of the region, the impact caused by material and energy consumption in soy production is very important, because the agricultural production uses a huge amount of resources, of which the heaviest cost corresponds to the loss of soil through erosion. To the oil equivalent required for soybean production that needed for transport to the market or ports should be added. The fuel spent only in transport of Chaco's soybean was more than that consumed by the entire agricultural sector that year. These results imply a huge negative impact and also show the need to take into account the externalities generated by the industrial agricultural model, which can only be sustained through the exploitation of resources that nobody is paying. The recommendation that arises from our results is a transition to a more diversified agriculture, in space and time. This agriculture should be based on the use of local resources and ecosystem features, enhancing ecological processes and functions, avoiding losses of the system and promoting recycling, minimizing dependence on external inputs. In socioeconomic terms, the need of agriculture for food production to satisfy demands of the local population rather than export-oriented commodities is evident. The MFA and EEA help to decide where efforts should be directed to build an agriculture that takes into account the nutritional needs of people, minimizing its impact on the health of humans and ecosystems.

Over the course of recent decades, it was shown that the industrial agricultural system, highly dependent on supplies, materials and energy is not a solution to the problems of food shortages, but rather, it is the cause of many of them, as well as the cause of significant impacts on the environment and humans. For this reason, the proposal for the future is a study of alternative production systems based on ancestral farming practices, adapting the models used to the specific realities of this kind of farmers.

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Appendix

Notes of Table 1

1. Loss of topsoil

Erosion rate = 1.70E+03 g $(m^2)^{-1}$ $year^{-1}$ (Cavalett, 2008)

Net loss of soil = (cultivated area, m^2) (erosion rate, g $(m^2)^{-1}$ yr^{-1}) = 1.70E+07g ha^{-1} yr^{-1}

Organic Matter content in the soil (wet) = 4% (Albanesi et al., 2001; Odum, 1996)

Number of OM (wet) = (1.70E+ 07 g $(m^2)^{-1}$ yr^{-1}) (0.04) = 6.80E+05 g $(m^2)^{-1}$ yr^{-1}

Water content of the OM = 30%

Dry OM lost by erosion = (6.8E+05 g $(m^2)^{-1}$ yr^{-1}) (0.7) = 4.77E+05 g $(m^2)^{-1}$ yr^{-1}

Energy content of the OM = 5.4 kcal/g dry matter (Franzese et al., 2013)

Energy loss = (4.77E+05 g $(m^2)^{-1}$ yr^{-1}) (5.4 kcal/g) (4186 J/kcal) = 1.08E+10 J ha^{-1} yr^{-1}

2. Gasoline

Gasoline consumption: 0.75 kg ha^{-1} yr^{-1} (average field data)

3. Gasoil

Seedtime consumption: 8.4 l/ha (Publicarg.com)

Crop consumption: 8.55 l/ha (Publicarg.com)

Pulverization Consumption (1 fungicides application + 3 insecticides applications + 2 herbicides applications): (1 l/ha) (6 passes) = 6 l/ha (data obtained in this investigation)

Truck consumption: 7 l ha^{-1} yr^{-1} (average field data)

Total annual fuel consumption: 8.4 l/ha + 8.55 l/ha + 6 l/ha + 7 = 30 l ha^{-1} yr^{-1}

Diesel density = 0.84 kg/l (www.energypiagroup.com)

Total annual consumption of diesel = (0.84 kg/l) (30 l/ha/yr) = 25.95 kg ha^{-1} yr^{-1}

4. Electricity

Monthly average consumption among respondents producers = 0.48 kWh/ha

Annual consumption (0.48 kWh/ha) (12) = 5.76 kWh ha^{-1} yr^{-1}

5.Spray Water consumption

Annual average consumption among respondents producers = 67.3 l/ha

Total passes of the spray machine: 6

Total water consumption = (67.3 l/ha) (6) = 0.40 m^3 ha^{-1} yr^{-1}

6. Seeds

Seed mass used: 6.90E+01 kg ha^{-1} yr^{-1} (Cavalett, 2008, Franzese et al., 2013). Producers expressed no desire to provide this data for a conflict related to the payment of royalties to seed companies.

7. Fertilizers

The producers interviewed reported they use phosphate. We taking into account only the average amount of active ingredient, reported on the labels.

8, 9 and 10. Agrochemicals (fungicides, insecticides and herbicides)

The producers interviewed reported name and quantity of each product used. We taking into account only the average amount of active ingredient, reported on the labels.

11. Agricultural Machinery

The values used for each type of machine come out of Agrianual 2010

Description	Weight (kg)	Life spam (h)	Hours used (kg ha^{-1} yr^{-1})	Ref. for hours used	Machinery used up (kg ha^{-1} yr^{-1})
Tractor tires 90cv	3870	10000	1.20	Agrianual, 2010	0.46
Tractor tires 120cv	4920	10000	0.67	Agrianual, 2010	0.33
Tractor tires 65cv	2580	10000	0.45	Agrianual, 2010	0.12
Harvester	16400	10000	0.65	Agrianual, 2010	1.07
Seeder	1500	8000	0.67	Agrianual, 2010	0.13
Agrochemical Sprayer	2140	8000	1.20	Agrianual, 2010	0.32

Source: Franzese et al., 2013.

Energy content of soybean production

According the Istituto Nazionale di Ricerca per gli Alimenti e la Nutrizione, 1 kg of soybean possess 17010 kJ. Then, for 2995 kg/ha we obtained 5.09E+10 J ha^{-1} yr^{-1}.