Environmental Evaluation of Transgenic Corn Seed Production in Argentina

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ABSTRACT

Since ancient times, grain seed for sowing has been a precious commodity. Moreover, the rising demand for food to meet the needs of a fast growing population, the trend of natural resources erosion and the inequality in income distribution lead us to think that it will become even more valuable in the future. Currently, the use of genetic engineering in the process of obtaining seeds for commercial grain lines requires high technology and complex systems management at different scales. It is necessary to update the information on the system behavior and the environmental impact of the resource used in the different stages of seed production as well as in the integrated system. The objective of this study was to account for the environmental cost of the transgenic event production and its transfer to commercial seed production. It will contribute to orient research and development alternatives in the seed obtaining process and upgrade the current agroecosystems analysis. An assessment that integrates not only natural but also socio-economic contexts and that evaluates the costs from fossil fuel energy consumption as well as from human and natural resources contribution was carried out.

INTRODUCTION

Since ancient times, grain seed for sowing has been a precious good because they are the foundation of world food and feed. Producing seeds is not the same as producing grains. Obtaining seeds for grain production requires different developments according to the selection method, both for varieties and for hybrids. The options for obtaining varieties and hybrids are either the use of conventional reproduction, genetic engineering or a combination of both. Plants that need cross-fertilization, like corn (*Zea mays* L.), are usually commercialized as hybrids, while self-fertilization plants, like soybean (*Glycine max* L.), are usually commercialized as varieties.

While farmers would traditionally save part of the grain production as seed for the next cycle (it is not usually the case for corn), after the green revolution, companies took the lead in seed production. Along with the demographic growth and the development of technology worldwide, seed corporations have evolved (Dalle Mulle and Ruppanner, 2010; Le Buanec, 2008). Today, the use of genetic engineering in the process of obtaining seeds for commercial grain lines requires high technology and complex systems management at different scales and this process has evolved quite fast. Figure 1 provides a picture of the current agricultural system worldwide, with different patterns for information management in seeds (fully natural, human-dominated, industrial seed management).

Three decades ago 13% of the global seed market was controlled by 10 corporations, while around 80% was in the hands of the rest of the market, such as small companies and farmer-saved systems (Dalle Mulle and Ruppanner, 2010). Nowadays, top 5 seed companies control 35% of the global market (Le Buanec, 2008), and 33% of the world seeds market is transgenic (ISAAA, 2010; ETC, 2008) with some differences when considered on a crop-by-crop basis; for example the top 5 corporations control 85% of the global corn market (Le Buanec, 2008).
Figure 1. The information cycle within the current commodity seed production system. Three parallel systems keep operating: (a) A fully natural pattern, day-by-day decreasing, operated by animals and natural forces. Information (DNA in seeds) is generated and copied through natural patterns. Wind and other environmental driving forces disperse seeds randomly. Consumers (still without special dominance by humans) feed on, select and disperse seeds without using advanced technological tools. Light pressure by consumers may generate some, likely negligible, disturbance on the ecosystem. (b) A human-dominated pattern (in large part of the world) where humans take a dominant role in seed selection, but do not use GM techniques. (c) A high-tech system where information is selected, extracted, transferred and copied via genetic techniques building on existing information developed by Nature.

Besides, biotech crops such as corn, cotton (Gossypium sp L.), soybean, sugar beet (Beta vulgaris), squash (Cucurbita sp), papaya (Carica papaya) and colza (Brassica napus), occupied 37% of the global production area (James, 2009; FAOSTAT, 2009). According to James (2011) USA, Brazil and Argentina lead the area occupied with transgenic crops utilizing 69 million ha, 30 million ha and 23.7 million ha respectively.

In the Americas, the area sowed with transgenic crops represents 83.4% of the world area, with the USA, Brazil, Argentina and Canada as the main producers (James, 2011). In Argentina, the area cropped with genetically modified (GM) corn in the last 14 years has increased 64%, at different rates (Trigo and Cap, 2006), while in the period 2007-2008, 73% of the maize cropped was transgenic and 7% of that rate was Glyphosate tolerant and 66% was Bt (Argenbio, 2007). In addition, Argentina is 3rd in the ranking of maize exports worldwide and the 6th in production (FAOSTAT, 2009).

Both circumstances, the technology development as well as the growing demand, lead to think that raising grain yield to the required volumes through genetic engineering will increase (Argebio 2012; James, 2011; Senesi et al, 2011; Hallauer, 2011).

Moreover, society is facing the challenge of meeting the rising demand for food and its equity access, without depleting natural resources (FAO, 2002; MEA, 2005; ISF, 2011); being seed production a fundamental echelon in this process.
Environmental accounting information available for seed production is scarce. When high tech seed is included in different energy basis analyses, authors usually estimate the seed energy unit value used in their reports (Dos Santos, 2000; Cohen et al. 2006; Bennett et al, 2006; Rótoło et al. 2007; Alluvione et al. 2011; among others). That estimate is frequently based on Pimentel et al (1973) and Heichel (1976) information.

The objective of this study was to account for the environmental impact and the system behavior of the resource use at different stages of the transgenic event production and its transfer to commercial seed production. The product obtained aimed to contribute a more accurate seed unit emergy value (UEV) for further agricultural analysis in which GMO corn seeds are used as an input in the emergy studies.

In this study we will analyze the process for obtaining transgenic corn seed.

MATERIALS AND METHODS

An Emergy study that includes not only natural but also socio-economic contexts and that evaluates the costs of fossil fuel energy consumption as well as the contribution of human and natural resources needs was carried out. Details about the emergy approach can be found in Franzese et al., 2009; Brown and Ulgiati, 2004; Odum, 1996.

It was assumed that each genetic crop modification can be used within the market along 5 years and after that a new one is released, i.e that the work done at the laboratory part and for the transfer of the transformed plant to a desired transformed commercial plant can last approximately 5 years; instead, the bulking process (last year of Part C) is repeated every year. Therefore: a) the Unit Emergy Value (UEV) obtained for the engineered seed inflowing to Part B of the process, as well as the raw values of Labor and Services that are associated to those seeds and entering to Part C were divided by 5 to account for such turnover time; b) the gasoil used for carrying on and supervising the trials in Part C was divided by 10, because the expert take care of around 10 projects at the same time.

Characterization of the Studied System

The study was divided into three Parts; A, B and C

Part A) Identification and isolation of the desired gene and its transfer into a vegetal genome without commercial value (Figure 2).

During Part A, 4 projects/year are usually executed with 2-3 molecular strategies/project and 25-30 events/molecular strategies. Finally, 2-3 events are selected. Each project takes approximately two years to arrive at an event. We assumed the selection to a single gene dominant trait. The final product obtained consists of approximately 40 transformed plants/project without commercial interest.

To easily understand it, this part was further divided into three phases:

Phase A1) Desired gene identification and isolation;
During this phase, the deoxyribonucleic acid (DNA) is extracted from the selected material (soil, plant or animal); it is amplified and then sequenced. Then, with bioinformatics and database support, gene function is predicted (identified). Genes or gene families whose characters are deemed relevant in a plant, are selected in this phase. At the end of this phase, a nucleotide sequence with potential interest for agro-biotechnology is obtained. The selected nucleotide sequence is cloned in a plasmid in order to be preserved and designed. This phase depends mostly on high tech appliances, reagents and human labor.

Phase A2) Molecular biology gene design;
The selected nucleotide sequence should be designed to express the desired function and placed within the genome of another individual, usually Escherichia coli (from now on E. coli). The products are genetic strategies ready to be inserted into a plant. This phase also depends mostly on high tech appliances, reagents and human labor.
Figure 2. Systems diagram showing the first steps of maize seed transformation process. Crop A is crop genotype with regeneration potential used as the basic seed line to which the desired gene will be transferred; crop T1 is Crop A + 1 event. Phase A1 is desired gene identification and isolation; phase A2 is molecular biology step with gene design; phase A3 is tissue culture and plant transformation. Crop T1 is then transferred to steps B for further back-crossing and yield comparative trials and then to step C for final multiplication.

Depending on the Company, Phases 1 and 2 could be either carried out by the same Company or it could buy the desired genetic strategies and insert them directly into a plant.

Phase A3) Tissue culture and plant transformation;
This phase receives E. coli with the designed gene. It is transferred to Agrobacterium and starts the proper transformation trials. During this phase the designed strategy is transferred to a corn plant that can stand tissue culture manipulations. These are usually non-commercial varieties. Phase 3 uses tissue culture techniques, reagents, drugs and appliances; a growing chamber is required for the first steps of the cultures and a greenhouse for the last ones. Along this phase some events are selected; therefore the selected events should return to Phase 2 in order to identify if the transformation exists in the adequate place without altering any other characteristic. If this is confirmed, the process of this event continues in Phase 3.

The regulation and patent inscription procedures corresponding to Part A, which started at the end of Phase 2, should be ended and paid for in this period.

Part B) Transfer of the transformed, non-commercial plant in to a desired and selected commercial Line (T1).

The transformed corn plants need to be crossed with a commercially desirable Elite Line (ELA,B,C). The result of the crossing is the T1; which is backcrossed (BC) with ELA,B,C, in order to stabilize the desirable characters of the commercial Line. This procedure is performed either in the field or in the greenhouse, according to the period of a year, until obtaining BC6, which could take approximately 4 years. Usually, the breeder works on one event in 3 EL, (i.e. 3EL/event), which represents the project
for this step. The product obtained is approximately 500 g of backcrossed seeds, which still needs to be tested and multiplied in order to obtain volume; procedure that will occur in Part C.

The Part B of the process is carried out both at the Breeding Center (open field and greenhouse) and in farm fields at an average distance of 50 km from the Center. The field area employed is about 135 m² and the greenhouse area is about 110 m² for the 4 year project.

The renewable and non-renewable local flows are assumed as being the same for the entire area.

Electricity is required for seed conservation in the Cold Chamber (assuming 3% of its capacity allocated to this Part B of the project), and for the water pump for irrigation at the Breeding Center.

Natural gas is used for the greenhouse 5 h/d for 3 months and the consumption was allocated to the area assigned to this project.

The greenhouse was made of polyethylene, wood and steel. The values of material and energy costs were allocated according to the area employed for one project.

Weeding was done by hand, sowing by a Field Trial Seeder, while other machinery, when necessary, belonged to the farmers.

During Part B, the breeder used molecular markers to check the presence of the event when selecting to pass to the following BC. For this study, Seed BTK test strips were utilized.

**Part C** Multiplication to obtain the commercial seeds.

This process is carried out, for practical reasons, at different locations such as: a) in the Breeding Center, an area of 2,500 m², b) in farm lands around the Breeding Center (40,000 m² and approximately 180 ha), at an average distance of 500 km from the Center (10 farms), and c) at 1,200 km from the Breeding Center (a location in Formosa Province) (11,000 m²).

In addition to obtaining the desired seed volumes, the purposes of this Part of the process are related to control phenotype pest resistance, adaptation to different environmental conditions and yield response.

These field trials carried out in farmlands are managed by the farmers and monitored by the breeder’s team. The farmers have to follow a management protocol delivered by the Breeder Center. The breeder’s team travels an average of 11,060 km/project.

The field trials carried out at the Breeding Center and its surroundings aimed both to test the environmental parameters behavior of the selected Lines and to increase volume. The ones carried out at a distance from the Center only aimed to obtain increased volumes.

The largest trial area is located in the Breeding Center and surroundings, which is a prairie ecosystem. We assumed that the renewable flows might be all similar in this area. Since the fields located farther from the Center occupied a smaller area (1.1 ha) and were only used for obtaining volume, we also assumed the same values for the renewable flows as in the main trial area.

However, the topsoil loss contribution from the main area and Formosa were accounted for in different ways, because in Formosa there is clearly a different type of soil.

Electricity accounts for seed conservation in the Cold Chamber (assuming 10% of its capacity allocated to this Part of the project), and for the water pump for irrigation at the Breeding Center.

The field trials (10 in total) carried out on farms are paid for by the breeder. The farmers use their own machinery except for sowing when the Field Trial Seeder needs to be employed.

Part C received the EL already transformed with the event (ELₑ) and followed different steps to obtain the best Line, which will be commercialized. This Part takes approximately another 4 years to complete a project.

Once the ELₑ is stabilized by self-pollination (ELₑT&E-EL transformed and stabilized-), it was made the first Top Cross (hybrid) with ELₑM&P which (M&P) are Elite Lines already established as commercially good and desirable. While maintaining and increasing the volume of ELₑT&E, it is necessary to maintain plots of ELₑM&P as well in order to produce the hybrid that will be commercialized.
Data Sources

The procedure for obtaining commercial transgenic corn seed and inputs information used for this paper was supplied by experts from Instituto de Agrobiotecnología - Rosario - Argentina and Asociación de Cooperativas Argentinas Coop. Ltda. (ACA); the environmental information by EEA INTA Oliveros (sun radiation and the calculated real evapotranspiration) and Servicio Meteorológico Nacional (rain, potential evapotranspiration and wind); pot soil from packaging information; land soil from literature; prices from Sigma and Brand catalogues as well as expert information and the Agromercado monthly journal. The unit emergy values were obtained from literature and adjusted to the baseline of year 2000 (Odum 2000).

RESULTS


Part A: Identification and isolation of the desired gene and its transfer into a vegetal genome without commercial value

This Part takes place mainly inside the laboratory and in the greenhouse as shown in Figure 2. Table 1 shows the main emergy flows corresponding to each Phase and Part of this Section.

The renewable (R) flow contribution is represented by a small portion of the biological individuals that live in the soil sample in Phase A1 and by the contribution of sun, rain and wind during the last steps in Phase A3. The major material (M) flow contribution corresponded to the biological material from the first phases, necessary to run the next ones, and electricity. The biological material represented 7% and 5% of the total emergy including L&S respectively to Phase A2 and A3; the values without including L&S were 50% and 40% correspondingly. Electricity, when accounting for L&S, contributed with 9%, 7% and 7% respectively in Phase 1, 2 and 3.

The higher percentage of labor (L) and services (S) found in Part A is mainly due to the use of high technology appliances and the regulation processes.

Part B: Transfer of the transformed, non-commercial plant into a desired and selected commercial Line (T1)

The case is carried out on a small portion of land. It needs about 250-300 m² to obtain BC₆. Table 1 shows that L&S included in the seeds that are necessarily used in Part B to continue with the transformation processes are the main contributors to the total emergy with 3% and 90% respectively. Instead, without accounting for L&S, natural gas, the non-commercial plants with the event (Lₑ) - which are the outputs of part A-, and electricity represent the higher flows of the total emergy with 49%, 41% and 9% respectively. Natural gas is used in greenhouse heating.

Part C: Multiplication to obtain the commercial seed

Many selected Elite Lines (EL₁,₂,₃) are crossed with the selected and transformed Elite Lines (EL₄), the ones that carry the desired event. The functional unit used is still “the project” since during this process many hybrids are tested, resulting in only one that will be commercialized. Therefore, at the end of 1 project, 1 Transformed Hybrid was obtained.

Table 1 shows that, accounting or not for L&S, the high M is mainly due to fertilizers (12%).

The high contribution of services, 68%, corresponds to the many field trials performed on farm lands at different locations around the nucleus zone, the services associated to the laboratory process is due to the high technology applied. Labor associated with the Part C of the process and the Laboratory part is 2%.

Given that each Part yields was an input to the next step, the final results of the emergy indicators were obtained from the analysis of Part C since it was fed with the contributions of the previous ones. Table 2 shows the emergy indicators and the final unit emergy value (UEV) obtained with reference to both units of mass and energy (“g” and “J”).

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Table 1. Emergy flows, products and Intensities along the transformation process for getting corn GMO from laboratory until obtaining the commercial seed.

<table>
<thead>
<tr>
<th>PART A</th>
<th>Unit</th>
<th>A1º Phase</th>
<th>A2º Phase</th>
<th>A3º Phase</th>
<th>% U</th>
<th>% Uwt</th>
<th>PART B</th>
<th>% U</th>
<th>% Uwt</th>
<th>PART C</th>
<th>% U</th>
<th>% Uwt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Renewable (R)</td>
<td>seJ/project</td>
<td>5.20E+03</td>
<td>0.00E+00</td>
<td>2.64E+12</td>
<td>0.00</td>
<td>0.00</td>
<td>3.47E+13</td>
<td>0.00</td>
<td>0.04</td>
<td>2.56E+17</td>
<td>10.96</td>
<td>36.50</td>
</tr>
<tr>
<td>Local Non Renewable (NR)</td>
<td>seJ/project</td>
<td>3.71E+09</td>
<td>7.01E+12</td>
<td>8.64E+14</td>
<td>0.00</td>
<td>0.31</td>
<td>1.50E+14</td>
<td>0.01</td>
<td>0.18</td>
<td>1.10E+17</td>
<td>4.69</td>
<td>15.62</td>
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<td>Material (M)</td>
<td>seJ/project</td>
<td>6.09E+16</td>
<td>1.22E+17</td>
<td>2.74E+17</td>
<td>11.48</td>
<td>99.69</td>
<td>8.21E+16</td>
<td>3.65</td>
<td>99.78</td>
<td>3.36E+17</td>
<td>14.38</td>
<td>47.89</td>
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<td>Labor (L)</td>
<td>seJ/project</td>
<td>1.97E+16</td>
<td>2.26E+16</td>
<td>3.46E+16</td>
<td>1.45</td>
<td>0.04</td>
<td>7.45E+15</td>
<td>0.33</td>
<td>2.46E+16</td>
<td>1.05</td>
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<tr>
<td>Labor (LA)(associate with Lab process)</td>
<td>seJ/project</td>
<td>-------</td>
<td>1.97E+16</td>
<td>4.23E+16</td>
<td>1.77</td>
<td>0.04</td>
<td>7.69E+16</td>
<td>3.42</td>
<td>1.54E+16</td>
<td>0.66</td>
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<tr>
<td>Labor (LN)(associate with Part B)</td>
<td>seJ/project</td>
<td>-------</td>
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<td>-------</td>
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<td>-------</td>
<td>1.49E+15</td>
<td>0.06</td>
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<td>Services (S)</td>
<td>seJ/project</td>
<td>6.08E+17</td>
<td>1.28E+17</td>
<td>1.30E+18</td>
<td>54.47</td>
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<tr>
<td>Services (SA)(associate with Lab process)</td>
<td>seJ/project</td>
<td>-------</td>
<td>6.08E+17</td>
<td>7.36E+17</td>
<td>30.79</td>
<td>2.04E+18</td>
<td>90.5</td>
<td>4.08E+17</td>
<td>17.45</td>
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<tr>
<td>Services (SB)(associate with Part B)</td>
<td>seJ/project</td>
<td>-------</td>
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<td>9.43E+15</td>
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<td>Total Emergy (U) with L&amp;S</td>
<td>seJ/project</td>
<td>6.88E+17</td>
<td>9.00E+17</td>
<td>2.39E+18</td>
<td>100.0</td>
<td>2.25E+18</td>
<td>100.0</td>
<td>2.34E+18</td>
<td>100.0</td>
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<tr>
<td>Total Emergy (U) without L&amp;S</td>
<td>seJ/project</td>
<td>6.09E+16</td>
<td>1.22E+17</td>
<td>2.75E+17</td>
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<td>8.23E+16</td>
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<td>7.02E+17</td>
<td>100.0</td>
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</table>

**Product (Y)**

- g ADN mass/pj: 1.00E-06
- g E.coli with desired gene/pj: 2.97E-04
- gseedsDM/pj: 2.47E+02
- J/pj: 4.67E+06
- USS/pj: 9.39E+06

**Unit emergy value without L&S**

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<tr>
<th>Unit</th>
<th>seJ/g</th>
<th>6.09E+22</th>
<th>4.11E+19</th>
<th>-------</th>
<th>-------</th>
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</tr>
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<tbody>
<tr>
<td>seJ/gDM</td>
<td>-------</td>
<td>-------</td>
<td>1.11E+15</td>
<td>3.30E+13</td>
<td>7.20E+08</td>
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<tr>
<td>seJ/J</td>
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<td>-------</td>
<td>5.90E+10</td>
<td>1.75E+09</td>
<td>3.82E+04</td>
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<tr>
<td>seJ/USS</td>
<td>-------</td>
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<td>-------</td>
<td>-------</td>
<td>2.19E+11</td>
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**Unit emergy value with L&S**

<table>
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<tr>
<th>Unit</th>
<th>seJ/g</th>
<th>6.88E+23</th>
<th>3.30E+20</th>
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<tr>
<td>seJ/gDM</td>
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<td>9.56E+15</td>
<td>9.04E+14</td>
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<tr>
<td>seJ/J</td>
<td>-------</td>
<td>-------</td>
<td>5.12E+11</td>
<td>4.80E+10</td>
<td>1.27E+05</td>
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<tr>
<td>seJ/USS</td>
<td>-------</td>
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<td>-------</td>
<td>-------</td>
<td>7.28E+11</td>
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DISCUSSION

According to the objective of this paper, it should be emphasized that the discussion is centered along the process for obtaining the transformed seed and not on the environmental impacts that might occur when they are used to obtain grain.

The results of this study were contrasted with studies where the unit emergy values (UEV) of seeds were calculated as industrial agriculture utilizing no GMO seeds. Analyzing the resulting indicators, some challenges and controversies require a discussion regarding the issues of:

- Seed production and Ecosystem Services.
- High-tech crop seed production and conventional/industrial seed production
- Making a contribution to the GMO seed’s production chain in order to improve/lower its environmental impact.

Crop Seeds Production and the (Agro) Ecosystem Services

An ecosystem is a dynamic complex of (micro) organism communities and their non-living environment interacting as a functional unit, being humans an integral part of its metabolism (MEA 2005). When it is highly modified towards agricultural production is referred to as agroecosystems. (Agro-)Ecosystems provide benefits (functions and services) that make human life both possible and worth living (Daily 1997; MA 2005), shaping their communities, and at the same time, those functions and services are impacted and shaped by human communities in a feedback process (Rótolo and Francis, 2008). There are many classifications of the benefits that ecosystems provide to human beings (MEA, 2005; DeGroot, 2002; Daily, 1997; Farber et al, 2006), however, they are usually grouped as provisioning, regulating, cultural, and supporting services. In this paper, we adopted the classification established by Farber et al. (2006).

Biodiversity is structural for ecosystem functioning and underpin all ecosystem process (MEA, 2005), offering and demanding numerous ecosystem services, both indirectly and directly (MEA 2005 chapter 11). Biodiversity and its offspring production are in increasing demand as a source of commercial material (MEA, 2005).

Seed production can be considered as both supporting and provisioning services (Farber et al., 2006). The mechanisms of seed dispersal and pollination that are necessary for natural and conventional seed production are supporting services, which are part of the ecological functions and structures that are essential to the delivery of ecosystem services. In a natural context seed production is a providing service because seeds are usually a source of genetic resources (i.e. genes and genetic information used for preserving the specie, plant breeding and biotechnology) and the way for obtaining edible plants and grains.

High-tech crop seed production is usually found in the literature as an input, (MEA, 2005) as “industrial seeds” (MEA, 2005). Accordingly, our results showed that the renewable resources contribution in obtaining commercial transformed seeds accounted for 11% of the total emergy used, and showed a value of 0.15 for the ESI (Emergy Sustainability Index) (Table 2-study), while material input, labor and services accounted for 15%, 2% and 69% of the whole process respectively (Table 1).

Today, our society is organized and structured in a way that we no longer rely on natural process nor traditional or conventional procedures for seed crop production. Moreover, biotechnology and specifically modern agro-biotechnology has been part of the technological and scientific advance of our civilization for a long time (FAO (2004, ch 2; CBI; IAASTD, 2009; Hallauer, 2011) and we cannot a-priori discard it; we need to wisely manage its contributions in benefit of both humans and nature (IAASTD, 2009; IAASTD, 2009- pp3).

On the one hand, (high)-tech crop seed production (independently from the technology applied, tissue culture, molecular markers, gen transformations, etc), needs a contribution from the natural context along the process. Besides, these high-tech seeds are necessary inputs to produce grain, which is a service provided by agroecosystems though they are not providing genetic resources with stable
Table 2. Emergy Indicators and Unit Emergy Values (UEV) of transformed maize seed production obtained in this study is shown together with other analysis for maize grain production.

<table>
<thead>
<tr>
<th></th>
<th>Study accounted with L&amp;S</th>
<th>Values accounted without L&amp;S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>EYR</td>
<td>1.19</td>
<td>1.62</td>
</tr>
<tr>
<td>ELR</td>
<td>8.12</td>
<td>3.28</td>
</tr>
<tr>
<td>ESI</td>
<td>0.15</td>
<td>0.49</td>
</tr>
<tr>
<td>%Ren</td>
<td>10.96</td>
<td>23.00</td>
</tr>
<tr>
<td>(E+9 seJ/gDM)</td>
<td>2.40</td>
<td>0.44</td>
</tr>
<tr>
<td>(E+5 seJ/J)</td>
<td>1.27</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Note: Study: results show the analysis for obtaining transformed seeds. (1) Rótolo et al (2007): values refer to a low input corn system to feed, as supplement, grazing cattle. (2) After Ulgiati 2001. (1-2) Emergy Indicators correspond to the corn grain production system.

desirable characters any longer. Other ecosystem services (such as soil retention, nutrient cycling, sun radiation, wind flow, etc.) are demanded along the process, not only for producing high-tech seeds that represent 11% of total emergy contribution, but also for producing the parental plant lines. These parental lines also, cultivated within a conventional (no GMO) breeding system, have ecosystem service requirements during their production process. Actually, these demands of emergy requirements from environmental contributions cannot be avoided.

Therefore, high-tech crop seed production processes, indeed demand supporting and regulating ecosystem services in order to participate in the provision of agroecosystem services (grain production). More extensive discussion should be centered on high-tech seeds as part of the current and evolving paradigm of crop production and the current and dynamic crop land ecosystem stewardship.

High-Tech Crop Seed Production and Conventional Seed Production

The coexistence of various seeds production methods is common, and moreover, breeders and farmers used them to breeding and producing crops according to different standards and preferences (ISF, 2004).

In this section we discuss the results obtained from a process that uses GM seed production in relation with a conventional process where the farms use part of their grain as seeds (Table 2). Most farmers today still use the conventional process of selecting and saving seeds from year to year in many crops and in hybrids also (using the F2 from maize). ISF (2004) stated that in 2003 conventional agriculture represented 94% of all arable land worldwide, while agriculture that used GMO represented 4.4%. However, in conventional agriculture (eventually) and in industrial no GM agriculture, it is necessary to renew seeds after re-sowing for several generations.

Based on the limited available information about UEV of GM seed calculation, it is feasible to use those values as a close frame for discussion. Values from this study showed that the transformed seed production involved high complexity. Actually, considering L&S, it is necessary from 5.5 to 4 times more emergy contribution from the process to produce 1 g of transformed seed than the conventional systems (Table 2).

Focusing on the high input conventional process (Table 2) and assuming that the breeder will need more time, as it is explained by referent breeders and shown in the Nebraska-Lincoln University website, we can assume that the gap in UEV could vary. It would be necessary, consequently, to carry out a complete analysis of conventional crop seed breeding.
Contribution to lower the environmental impact along the GMO seeds production chain

This section aims to detect some of the components in the entire process for obtaining high-tech seeds over which it is possible to intervene in order to increase its environmental sustainability by lowering the environmental load in the long term. Starting from Part C, this load is both directly due to the local non-renewable contribution (top soil lost and water used) and indirectly due to the imported non-renewable flows and indirect labor (services) contribution along the process. Therefore, diminishing the environmental load will relatively increase the participation of local renewable resources.

It seems difficult to directly increase the low local renewable resources contribution to the final product. However, its high environmental load (ELR) is mainly due to services (68%), and fertilizers (12%). This ELR could be partially lowered by means of alternative approaches that lead the process indirectly to favor the appropriation of local renewable resources. To reduce the energy load associated to labor and services of the elite line transformed (ELT) is necessary to intervene in the Part (Part B).

The higher contributors to the final emergy value of Part B are natural gas, labor and services (4.6%), Lc seeds (1.5%) and L&S associated at the Laboratory process (3.4% and 90% respectively). L&S for Part B exclusively, account for 0.66% and 3.4% respectively. The value in services corresponds mainly to the cost of insecticides and natural gas. Since this part of the process is mostly carried out inside greenhouses, a way to partially contribute to lowering the use of insecticides could include the use of integrated pest management (Greer and Diver, 1999). Besides, services contribution can also be slightly reduced by replacing greenhouse material and heat mechanisms with others that can capture and maintain sun radiation more efficiently, reducing the need of fuel (Greer and Diver, 2000; Science Daily, 2012). In turn, to reduce the emergy load contributed by the associated flows to obtain Lc, it is necessary to intervene in Part A.

The top contributors to the final emergy value of Part A are electricity, the microorganism with the desired and modified gene, labor and services+regulations and the services associate to gene extraction and construction. The biological input utilized sequentially in the subsystems of Part A (Phase A1, A2 and A3), which is output of the previous phase, has a high contribution within the material as well as the labor and services flows.

Consequently, it is quite difficult to lower the emergy contribution of Part A because the higher input comes from the biological components and from the labor and services associated (regulation and the cost of important appliances).

Discussion about the use of public goods as natural resources for commercial interest is out of the purpose of this paper, but should not be disregarded in a broader policy statement.

Therefore, the high unit emergy value for the output of Part A, impacts on the other two parts. Since Part B and C are carried out mostly outside the laboratory and require more agronomical components, they seem to provide more alternatives to lower the environmental load.

Therefore, the possibilities of increasing environmental sustainability of the “industrial seed system” and decreasing the environmental load are more feasible in the last part of the process (Parts B and C) than in Part A.

CONCLUSION

Agriculture uses natural resources such as landscapes, plants, animals, soils, minerals, water and atmospheric N and C needed for the production of public services (clean air, clean water supply, genetic resources, etc), and goods (food, feed, fiber, fuel, habitat) (IAASTD, 2009 page 6). Therefore, agricultural activities require changing the natural ecosystem to an agricultural system that is orientated toward human use (IAASTD, 2009,). The population size and the way our society is currently organized needs a wise use of technology to produce the feed, fiber and food that enables survival without jeopardizing natural resources and the environment.
This study makes a contribution to the UEV of GM corn seed to be used in future emergy analyses of agricultural systems that use transgenic corn seeds as input, however, we encourage other colleagues to perform similar studies in order to have a broader scope and make this value more accurate. On the other hand, this study provides information from the partial values obtained along the study revealing the components that have more relevance in the industrial process, and thus showing where to intervene in order to partially lower the environmental load. The total process showed not to be environmentally sustainable.

In traditional systems, seeds are part of the (agro)ecosystem services since they provide genetic material resources (it is a providing ecosystem service), while in high-tech industrial seeds that also have genetic material resources, the maintenance of desirable functions by reproduction depends mainly on human guide (it is mainly a “society providing service”).

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