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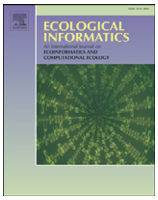

Time to re-think the GMO revolution in agriculture

G.C. Rótolo [a,*], C. Francis [b,c], R.M. Craviotto [a], S. Viglia [d], A. Pereyra [e], S. Ulgiati [d]

[a] *National Institute of Agricultural Technology (INTA), Oliveros Agricultural Experimental Station, Oliveros, Argentina*
[b] *University of NE-Lincoln, Department of Agronomy & Horticulture, Lincoln, USA*
[c] *Norwegian University of Life Sciences, Department of Plant Science, Aas, Norway*
[d] *Parthenope University of Naples, Department of Science for the Environmental, Naples, Italy*
[e] *Criadero de Semillas ACA CL, Pergamino, Argentina*

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ABSTRACT

Seeds of major crop cultivars provide a vital genetic and cultural link from one human generation to the next. Information embodied in seed is essential to continuity of food production, adaptation to changing climate, and evolution of human society. Introduction of transgenic (GMO) technologies simplifies management, appears profitable for seed companies and farmers, and promotes efficient industrialization of agriculture, although there is ongoing debate about potential of GMO varieties to increase genetic yield potential. Although short-term profits are one measure of success, there are other methods to evaluate long-term sustainability that are not accounted for in the market place. Emergy analysis accounts for biophysical, economic, environmental and information costs in seed production. It was used to calculate resource demand of GMO seed development and production for sale to farmers and to explore the direct and indirect environmental costs for storing new information. This includes initial transformation through testing to commercial seed production, and emphasizes environmental accounting. Maize (*Zea mays* L.) and soybean (*Glycine max* L.) seed production in Argentina are used to evaluate the GMO breeding strategy. We used our calculations for conventional hybrids and varieties as well as emergy evaluation of crop production from literature as references. Analysis of the GMO process was divided into a) identification and isolation of a desired gene and transfer into another genome; b) transfer of the chosen trait into a selected commercial line of maize or variety of soybean; and c) trials for adaptation and seed multiplication to obtain commercial products for sale to farmers. Comparable emergy used for conventional hybrids and varieties comes from steps b) and c). Results from step c) showed a low reliance of the GMO process on renewable resources (8%–12%); a lower or similar efficiency in converting input resources into the desired output compared to non-GMO crop production from other studies and our estimates from conventional seed production; and a high contribution from services (indirect labor, around 70% of total emergy). The resource investments for using, extracting and transforming available information of present GMO strategies are not commensurate with achieved results, and may increase due to unanticipated ecosystem reactions over the long term due to a continuous rebound effect.

1. Introduction

Crop seeds are the foundation of life as sources and carriers of information that are gathered, tested, copied, stored and dispersed again at planting time back into the environment (Odum, 1996; MEA, 2005a, 2005b). Selection over time of agricultural seeds has made unique contributions to food and feed production, trade and knowledge exchange (Perriere and Kastler, 2011). Agricultural knowledge embodied in seed includes comprehensive and organized information that reflects human traditions, adaptation to climate, and food preferences (Odum and Odum, 2001).

Indigenous humans and then farmers have for centuries selected and stored part of their harvest as seeds for the next year. Though documentation is scarce (FAO, 2001a), small farmers' seed production, selection and storage are the predominant sources of seed for the next season in many developing countries (Neate and Guei, 2010; Guidi, 2011), as high as 90%in Africa (Wekundah, 2012) and 75% in Latin America and the Caribbean (FAO, 2001b).

The close relationship between farmers and their local environment has provided the knowledge required to cope with climate change and enhanced potential to store information for developing complex and adaptive farming system. Seeds store this information and contribute to successful design of resilient agroecological habitats (Adger, 2000; Gunderson, 2000; Bisang, 2003; Chapin et al., 2009). Agricultural information embracing the interaction of nature and society has co-evolved over time and been captured in seed (Odum, 1996; Gunderson, 2000).

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* Corresponding author at: INTA EEA Oliveros, Ruta 11, Km. 353, 2206 Oliveros, Argentina. Tel.: +54 3476 498010, +54 3476 498011, +54 3476 498027.
E-mail addresses: gloriarotolo@yahoo.com.ar, rotolo.gloria@inta.gob.ar (G.C. Rótolo).

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Humans imbedded in this co-evolution process may not be totally aware of such mutual inter-relations and their importance for our survival (Odum, 1996; Steffen et al., 2007).

Resource management to preserve and promote information cycling (Odum, 1996) as well as to foster societal adaptation and resilience to environmental changes are central to human wellbeing (Adger, 2000; Longley, 2001; Chapin et al., 2009). Seeds are crucial carriers of information that reflect the management of their genetic manipulation and selection, storage and dissemination. Their use is coupled with transfer of knowledge of cropping practices and systems through generations of farmers, with continuous interplay of tradition and innovation. Today this historical pattern of information transfer is impacted by changing human demographics and research priorities. Rapid population growth and accelerated food demand has converted agriculture from producing for local sales to a global market-oriented food system. Maximizing yields and minimizing labor costs are main driving forces that over-ride traditional knowledge accumulation and transfer through seeds.

Agriculture in general and the seed industry in particular are imbedded in the rush toward concentrated ownership of production technologies (Meijerink and Danse, 2009; PEA[2], 2012) and homogenized cropping systems (Rabinovich and Torres, 2004; Manuel-Navarret et al., 2005). High investments in transgenic variety development techniques, producing seed generally identified as GMOs, presently dominate commercial plant breeding; these procedures are increasingly used to complement standard crossing techniques (Cubero, 2003). Seed varieties developed using transgenic technologies require patent protection to recoup research and development costs. We need to know to what extent this process accelerates loss of biodiversity and whether in the long term this technology skews benefits and also increases negative impacts on the environment.

After the green revolution in the 1960s, multinational corporations have taken over major crop commodity seed development, production and distribution, an activity formerly dominated by public sector plant breeding. Seed corporations have quickly increased their market share (Le Buanec, 2008; Dalle Mulle and Ruppanner, 2010). They can afford the costly process of obtaining GMO seeds that requires high technology and complex management at multiple scales, and could be compared to other high technology processes such as the internet (De Filippis, 1999). Three decades ago, 13% of the global seed market was controlled by 10 corporations; 80% was dominated by small companies and farmer-operated systems (Dalle Mulle and Ruppanner, 2010). Today, five seed companies control 35% of the global market (Le Buanec, 2008) and 33% of their product is transgenic (ETC, 2008; Meijerink and Danse, 2009; ISAAA, 2012). In the Americas, the area planted with GMO crops represents 87% of the world area, with USA, Brazil, Argentina and Canada as the main producers. In Argentina, transgenic cultivars represent an important share of most major commodity crops in percent of area planted: soybean (*Glycine max* L., 100%), cotton (*Gossypium* sp. L., 97%) and maize (*Zea mays* L., 85%) (James, 2011).

We recognize that improved technology and organizational structures are essential to meet growing food demand and the 2050 target of the World Food Summit for producing 70% more food (FAO, 2009); we are also convinced that these goals must be achieved by respecting essential ecosystem services and reducing impact on the environment. Industry promotion maintains that boosting grain production will only be accomplished through transgenic technologies (Hallauer, 2011; James, 2011; Senesi et al., 2011; ArgenBio, 2012). Although their advertising insists that essential production goals are attainable only with GMOs, results from science suggest that promotion may be far too ambitious since yields of major commodity crops appear to be approaching biological limits on productivity (Lobell et al., 2009).

Society's challenge is to meet rising demands for food, feed, fuel oil, land use, and water without permanently depleting natural resources, while at the same time improving equity of access to food and preserving quality of life (MEA, 2005a; Tester and Langridge, 2010; ISF, 2011). Information management and storage as well as contributions to resilient food production systems are among the expectations from improved crop varieties. In Europe, an environmental risk assessment for GMO crops is required before regulatory approval, according to the Cartagena protocol; some authors have clarified the main provisions (Hilbeck et al., 2011), scope and relevance of damage (Sanvido et al., 2012), and baselines for comparison of risk (Conner et al., 2003). Although Argentina did not sign the Cartagena Protocol (CBD, 2014), it is still legally necessary to guarantee agroecosystem safety, food safety for human and animal consumption, production and trade impact of large scale GMO release before wide commercial use. The first part of the evaluation includes biological analysis and field testing trials as part of the GMO development process before commercial scale production, and each step is clearly regulated by Resolution No. 701/11 (CONABIA, 2014).

At present, the information available about environmental accounting including material and energy use as well as information cycling for seed improvement is scarce. Most authors have estimated seed energy value and seed energy costs using data for conventional seeds (Pimentel et al., 1973; Heichel, 1976; Dos Santos, 2000; Bennett et al., 2006; Cohen et al., 2006; Rótolo et al., 2007; Alluvione et al., 2011). Patzek (2004) analyzed the energy and mass balances of maize and bioethanol production and specifically assigned an energy value to maize hybrid seeds, concluding they are seven times more energy intensive than the energy in the same mass of maize grains.

In this paper we focus on environmental accounting in the seed development process, specifically GMO cultivars, from initial research to commercial seed production for maize hybrids and soybean varieties in Argentina. We conducted an environmental emergy-based accounting that uses solar energy units to account for biophysical, economic, environmental and information costs (Odum, 1996; Franzese et al., 2009; Brown and Ulgiati, 2010; Li et al., 2010). This includes commercial energy inputs plus minerals, direct and indirect labor, renewable input sources, technology, and most importantly the time needed for resource regeneration, which is accounted for in the intensity factor of each component of the system. Sustainability according to the usual three pillars of economic, social, and environmental dimensions is addressed, plus embodied time and information included both in the intensity factors and in the indirect labor that are crucial to evaluation of any high tech process such as GMOs. This way of approaching the information cycling is new and little explored. Abel (2013) has utilized this method to analyze the information cycling related to cultural information.

Our objectives are to quantify direct and indirect environmental costs of storing new information in GMO commodity seeds as compared to conventional hybrids and varieties, identify the most resource/emergy-demanding steps in the process, and contribute to a more informed management and to a basis for rational research decisions in improving major food crops.

2. Concepts related to self-organizing systems and emergy analysis

Information cycling in a self-organizing system contributes to adaptation capacity or resilience in a coupled nature–society system such as food production. This concept is central to the analysis and evaluation of information storage in commodity seed crops. Materials, energy and information circulate at the interface of nature and society (Ruth, 1995; Odum, 1996; Brown and Ulgiati, 1999; Gunderson, 2000), while transformations occur that make the system resilient through adaptive flows and new structures (Odum, 1996; Chapin et al., 2009). Components of the system self-organize hierarchically and reinforce each other (Lotka, 1922; Odum, 1988, 1996; Perry, 1995; Olsson, 2003; Ulgiati and Brown, 2009) to maximize output or survival and allow each system to develop over time in competition with others by trial and error mechanisms (Lotka, 1922; Odum and Odum, 2001). Odum and Odum (2001) re-stated Lotka's maximum power principle (Lotka, 1922): “In the self-organizational process, systems develop those