Brazilian Soybean Production: Emergy Analysis With an Expanded Scope

Enrique Ortega
Otávio Cavalett
Robert Bonifácio
Marcos Watanabe
State University of Campinas, Brazil

This article offers the results of emergy analysis used to evaluate four different soybean production systems in Brazil that were divided into two main categories: biological models (organic and ecological farms) and industrial models (green-revolution chemical farms and herbicide with no-tillage farms). The biological models show better environmental, economical, and social performance indicators; however, at the national level, discussion of transgenic soybean seed release considers only industrial models without any mention of biological models. Classic emergy analysis shows biological options are the better alternatives but does not explain why decisions taken by farmers and government in Brazil were in opposition to these options. New research is proposed to identify and quantify the external forces that strongly interfere in the definition of public policy for soybean production. New parameters are proposed to enrich emergy methodology: Renewability of each input was considered in emergy calculations and negative externalities were included as additional services.

Keywords: *sustainability; soybean; agriculture ecosystems; externalities; emergy analysis*

Industrial agriculture has been the main support of the Brazilian economy during the past 30 years. This kind of agriculture is responsible of 42% of exports and 37% of jobs. Soybeans are the leading export; soybean production grew quickly from a harvest of 2 millions tons in the early 1970s to 53 million tons in 2003. Brazil is the world's second largest soybean producer, lagging behind the United States, which had a crop of 74 million tons in 2003 (Agrianual, 2004).

The growth of soybean production in Brazil was stimulated by the increase in demand for soybean meal used in industrial farming of pork meat, eggs, milk, and beef. With a favorable international market, because of cattle diseases in Europe transmitted by meals made with animal brains, the large-scale soybean producers (in Brazil) and soybean-consuming farmers (in Europe) increased their profits. The Brazilian farmers invested in lands, farm machinery, and more chemical inputs.

The environmental damages caused by one-crop large-scale farms in the Brazilian savanna (*cerrado*) are not commented on by Brazilian authorities; instead, they celebrate the expressive economic results of soybean exports, which allow for payment of the yearly interest on the international debt. The Brazilian government, as well as individual soybean farmers, makes important decisions concerning the use of ecosystems based only on short-term economic profit analysis.

To establish long-term sustainable agriculture public policy, it is necessary to use open-systems methods to evaluate all the social and ecological benefits and costs. The neoclassical economy vision of the production-consumption cycle is unable to represent either all the inputs and outputs or the flows of natural resources needed for production (Wackernagel & Rees, 1995). Therefore, the neoclassical economy methodology cannot be used to calculate sustainability parameters (Ulgiati, 1998). In this study, the

---

AUTHORS' NOTE: We are grateful to Gabriela Vernaza for her kind support in review of this article.

Bulletin of Science, Technology & Society, Vol. 25, No. 4, August 2005, 323-334
DOI: 10.1177/0270467605278367

emergy method of accounting developed by Odum (1983, 1996) was selected as it offers means of quantifying the direct and indirect environmental work involved in generating a product. The emergy analysis is a procedure used for planning, managing, and assessing human ecosystems.

Because emergy accounting mainly has been used to study fossil fuel, energy-intensive agriculture systems in Europe and the United States, the methodology procedures had to be improved to deal with the complex ecological agriculture systems, based on family labor, of the southern hemisphere (Ortega & Polidoro, 2002). This article discusses the new emergy parameters developed and used to enrich emergy methodology.

Agriculture is jeopardized by the decrease in the price of farm products and the increase in price of chemical inputs and commercialization costs everywhere (see Figure 1). The aim of this study was to discuss the direct and indirect costs and environmental impact of soybean production systems and to justify the opening of a new topic of research dedicated to the measurement of political forces that act, with great strength, in Brazilian agriculture.

Method

Soybean Production Systems in Brazil

The agricultural systems studied are classified in two main categories: biological (organic and ecological) and industrial (agrochemical and no-tillage with herbicides). Biological models included the family-managed ecological farms of the south and the organic enterprises in the central region. As industrial models, farms that adopted green-revolution standards (south) and agricultural enterprises that are adopting no-tillage (with or without use of transgenic seeds) in the south and central region were considered.

The ecological farm has a small or medium area (10 to 50 ha); it is managed by a family group who lives on the farm—usually obeying environmental laws and preserving and using properly the natural resources they have. These farms are not fully oriented to the market; they produce for self-consumption and exchange many things with their neighbors without the use of money. The main part of their products is consumed within the region. The ratio of people per hectare is high even if it is not considered formal employment.

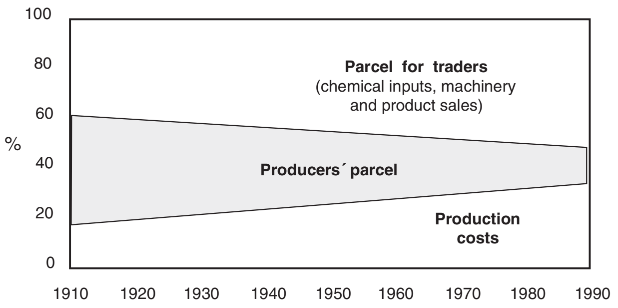

Figure 1. Decreasing Parcel Received by Producers
Note: Adapted from Gliessman (2000).

The size of industrial farms can be medium (50 ha), large (300 ha), or very large (3000 ha or more). They are operated by an urban enterprise and decisions are taken outside of the farm area, even outside of the region or the country. They intensively use industrial chemicals and machinery, employ few workers, and substantially affect the environment. Examples of industrial agriculture's environmental impact include decrease of soil fertility, erosion of nutrients, water pollution, biodiversity loss, lower plant resistance to predators, health problems attributable to contamination, and so forth (Altieri, 2000; Nilsson, 2004). Another important characteristic of industrial agriculture is the great quantity of fossil energy used in production. This is a capital question because of the inevitable reduction in availability of fossil fuels forecasted for the near future.

When the industrial farm converts to organic management, it substitutes organic for chemical inputs but maintains many other characteristics. Therefore, it does not create jobs; and its material and energy self-sufficiency remain low and, thus, nonsustainable.

To economically survive the coming years, biological agriculture systems must compete with industrial systems. This might be possible if inputs and outputs are priced and taxed appropriately; therefore, the accounting should consider the real values of inputs and include subsidies and externalities. The elaboration of public polices in agriculture must consider not only that industrial farming systems diminish their productivity because of physical and biological degradation of soil but also that richness transfer is established by increasing costs of chemical inputs and decreasing prices for agricultural products (Altieri, 2000).

In the case of transgenic soybean production, until 2005, there were limitations imposed by both state and federal governments as well as external markets. Fed-

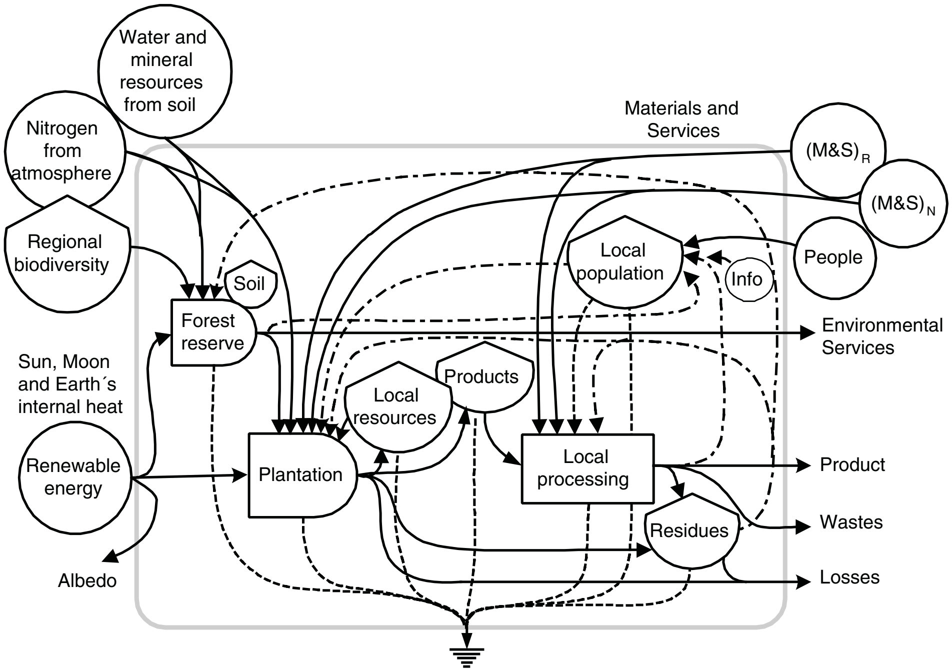

Figure 2. Emergy Flows Diagram of a Typical System of Soybean Production

eral regulations avoided its production and commerce; however, transgenic seeds were planted in the southern region—the seeds were smuggled from Argentina and, thus, Brazilian farmers did not pay any royalties for their use.

Emergy Analysis

Emergy methodology converts all forms of energy, materials, and human services into equivalents of one form of energy (solar emergy). The units of solar emergy are solar *emjoules* (sej). The emergy methodology has been described fully by Odum (1996) as well as in several other articles (Brown & Ulgiati, 2004; Higgins, 2003; Lefroy & Rydberg, 2003; Panzieri, Marchettini, & Hallam, 2000; Ulgiati, Brown, & Bastianoni, 1994).

In the industrial agriculture economy, the price considers inputs and human work aggregated but does not consider the external energy used in the formation of the biosphere's resources or the costs of negative externalities (paid by local society).

This research studies how emergy analysis could improve indicators of performance of agricultural ecosystems to include externalities and consider new specific biological inputs. For emergy calculations, the partial renewability of each of the materials and services was considered, as proposed by Ortega, Anami, and Diniz (2002) and as suggested by several other researchers (Bastianoni, Marchettini, Panzieri, & Tiezzi, 2001; Ortega & Polidoro, 2002; Panzieri, Marchettini, & Bastianoni, 2002). This approach is considered an evolution in emergy methodology, representing a step forward in describing with greater fidelity the sustainability of complex systems.

As an example of capturing such complexity, an emergy flows diagram for a typical soybean production system is presented in Figure 2. Table 1 shows the classification of emergy flows used that allows considering the partial renewability of materials and services. In Table 2, the emergy indicators were slightly modified to evaluate more properly the performance of the system by considering the renewability of each of the resources used.

Results and Discussion

Emergy Analysis of Soybean Production Systems

Data for items used in different categories of soybean production were obtained from other articles (Ortega et al., 2002; Ortega, Miller, Anami, & Beskow, 2001), agriculture manuals, and contacts with farmers. Table 3 shows all inputs (materials, services, and contributions from nature) used in soybean production on a per hectare basis during the period of 1 year and a

Table 1. Classification of Emergy Flows

Inputs and Service	Description
I: Nature contribution	R + N
R: Renewable resources from nature	Rain, materials and services from preserved areas, and nutrients from soil minerals and air
N: Nonrenewable resources from nature	Soil, biodiversity, and people exclusion
F: Feedback from economy	$F = M + S$
M: Materials	$M = M_R + M_N$
M_R: Renewable materials and energy	Renewable materials from natural origin
M_N: Nonrenewable materials and energy	Minerals, chemicals, steel, fuel, etc.
S: Services	$S = S_R + S_N + S_A$
S_R: Labor services (renewable)	Familiar labor (local and external): $S_R = S_{RL} + S_{RE}$
S_N: Other services (basically nonrenewable)	Taxes, money costs, insurance, etc.
S_A: Additional services (nonrenewable)	Externalities: effluents, medical and job costs, etc.
Y: Total emergy	$Y = I + F$

Table 2. Emergy Indicators Used for the Emergy Analysis

Indicators	Expression	Signification
Traditional emergy indicators		
Tr	Y/E	Empower/energy products
%R	$100x(R + M_R + S_R)/Y$	Renewable inputs/empower
EYR	$Y/(M_N + S_N + S_A)$	Empower/feedback
EIR	$(M_N + S_N + S_A)/(R + M_R + S_R + N)$	Paid inputs/free inputs
ELR	$(N + M_N + S_N + S_A)/(R + M_R + S_R)$	Nonrenewable/renewable
EER	$Y/[(\$)x(sej/\$)]$	Emergy delivered by the system to the economy divided by the emergy received by the sells
New social and externality emergy indicators		
LSR	S_R/S	Labor/services
LER	S_R/Y	Labor/empower
LWR	$S_{RL}/(S_R + S_N + S_A)$	Local labor/labor
ExER (externalities empower ratio)	S_A/Y	Externalities/empower

Note: Tr = solar transformity; %R = renewability; EYR = emergy yield ratio; EIR = emergy investment ratio; ELR = environmental loading ratio; EER = emergy exchange ratio; LSR = labor services ratio; LER = labor empower ratio; LWR = labor work ratio; ExER = externalities empower ratio.

factor of conversion used to transform these inputs into solar emergy (transformity in sej/unit). Data from soybean production farms were used to calculate solar emergy flows (see Table 4) in a slightly different manner; the values for the emergy flows of materials and services were multiplied by the renewability values (centesimal) of the respective input. Such renewability values were based on results from previous calculations, along with common sense derived from experience.

Table 4 shows values of renewable and nonrenewable emergy flows for the four types of soybean systems studied. The externalities were incorporated in this accounting as additional services (S_A). The values of externalities took into consideration both European research (Pretty et al., 2000) and Brazilian studies. Table 5 shows internal and external labor used in soybean production. Table 6 shows aggregated emergy flows. Emergy indicators calculated for the different categories of soybean production are shown in Table 7.

Emergy Analysis Using Traditional Indicators

Solar transformity measures how much emergy it takes to generate one unit of output, regardless of the renewability of resources used. It indicates the hierarchical position of a resource in the thermodynamic scale of the biosphere and can be regarded as a quality factor from the point of view of biosphere dynamics (Brown & Ulgiati, 2004). Transformity can be seen as

Table 3. Inputs (in unit/ha/year) and Respective Factor of sej/Unit of Soybean Production Systems

Item	Unit	Biological		Industrial		sej/unit	Reference
		Ecological	Organic	Chemical	Herbicide		
Renewable (R)							
Rain	Kg	1.50E + 06	1.50E + 06	1.50E + 06	1.50E + 06	1.50E + 07	1
Atmospheric nitrogen	Kg	180	180	180	180	6.38E + 12	1
Biologic control	US$	50	25.00	0	0	3.70E + 12	2
Nonrenewable (N)							
Soil loss	J	0	0	3.00E + 04	0	1.24E + 05	1
Materials (M)							
Local seeds	Kg	10	10	0	0	4.95E + 12	3
Certified seeds	Kg	70	70	70	85.00	4.04E + 12	3
Limestone	J	0	0	6.11E + 08	6.11E + 08	2.72E + 06	1
Phosphate fertilizer	Kg	0	0	150	250	6.55E + 12	1
Potash fertilizer	Kg	50	50	150	100	2.96E + 12	4
Manure	Kg	2660	2660	0	0	1.27E + 11	5
Inoc, 0ulum	Kg	1.00	1.00	1.70	1.70	2.49E + 13	1
Herbicides	Kg	0	0	4.30	5.30	2.49E + 13	1
Insecticides	Kg	0	0	1.80	1.80	2.49E + 13	1
Formicides	Kg	0	0	1.00	1.00	2.49E + 13	1
Fungicides	Kg	0	0	0.20	0.20	2.49E + 13	1
Petroleum fuels	J	1.43E + 09	1.91E + 09	3.82E + 09	1.91E + 09	1.11E + 05	1
Steel	Kg	1.00	2.70	2.70	2.70	1.13E + 13	1
Services (S)							
Unqualified manpower	years	1.66E – 02	1.14E – 02	3.65E – 04	5.71E – 05	6.32E + 16	1
Qualified manpower	years	2.28E – 04	3.65E – 04	8.22E – 03	4.57E – 03	6.32E + 16	1
Administrative labor	US$	4.00	4.30	4.30	4.30	3.70E + 12	2
Technical assistance	US$	10	10	2.00	2.90	3.70E + 12	2
Accounting services	US$	0.80	0.80	0.80	0.80	3.70E + 12	2
Costs of trips	US$	0.40	0.40	0.40	0.40	3.70E + 12	2
Governmental taxes	US$	9.50	9.50	13.60	13.60	3.70E + 12	2
Circulating capital costs	US$	2.95	2.95	2.95	2.95	3.70E + 12	2
Insurance	US$	1.00	1.00	0.60	1.00	3.70E + 12	2
Transportation	US$	6.80	6.80	6.80	6.80	3.70E + 12	2
Drying and storage	US$	14.30	14.30	14.30	14.30	3.70E + 12	2
Social security	US$	12.80	12.80	13.60	13.60	3.70E + 12	2
Additional services (S_A)							
Job lost	US$	0	20	40	40	3.70E + 12	2
Health treatment	US$	0	0	50	50	3.70E + 12	2
Effluent treatment	US$	0	0	50	50	3.70E + 12	2
Environmental restore	US$	0	20	20	20	3.70E + 12	2
Environmental services losses	US$	0	20	20	20	3.70E + 12	2
Products (Y)							
Soybean	Kg	2,240	2,240	2,400	2,400	—	
Wood	Kg	1,000	100	0	0	—	
Water	Kg	225,000	75,000	0	0	—	

Note: 1 = Brown and Ulgiati, 2004; 2 = Ortega, 1998; 3 = Estimated from Ortega, Anami, and Diniz, 2002; 4 = Panzieri, Marchettini, and Hallam, 2000; 5 = Bastianoni, Marchettini, Panzieri, and Tiezzi, 2001.

an inverse value of system efficiency. Therefore, the higher the transformity value, the lower the efficiency of the system. In this research, in decreasing order of efficiency, soybean production systems can be ranked as follows: ecological (1.47 × 10^5), herbicide (1.51 × 10^5), chemical (2.23 × 10^5), and organic (2.48 × 10^5). This shows that the ecological system is the most efficient in the use of emergy flows. These values were similar to those found in literature for cereals, usually between 2 × 10^5 and 7 × 10^5 sej/J (Brandt-Williams,

Table 4. Emergy Analysis of Soybean Production Systems (Emergy Flows × 10^{13} sej/ha/year)

		Renewable Emergy Flows				Nonrenewable Emergy Flows			
		Biological		Industrial		Biological		Industrial	
Item	Renewability Fraction	Ecological	Organic	Chemical	Herbiide	Ecological	Organic	Chemical	Herbicide
Renewable (R)									
Rain	1.00	2.25	2.25	2.25	2.25	0	0	0	0
Atmospheric nitrogen	1.00	114.84	114.84	114.84	114.84	0	0	0	0
Biolobic control	1.00	18.50	9.25	0	0	0	0	0	0
Nonrenewable (N)									
Soil loss	0	0	0	0	0	0	0	336.43	0
Materials (M)									
Local seeds	0.90	4.46	4.70	0	0	0.50	0.25	0	0
Certified seeds	0.70	19.80	19.80	19.80	24.04	8.48	8.48	8.48	10.30
Limestone	0.01	0	0	1.66	1.66	0	0	164.53	164.53
Phosphate fertilizer	0.01	0	0	0.98	1.64	0	0	97.27	162.11
Potash fertilizer	0.01	0.05	0.05	0.14	0.09	4.69	4.69	14.07	9.38
Manure	0.70	551.15	535.40	0	0	236.21	251.96	0	0
Inoculum	0.70	1.74	2.24	3.81	3.81	0.75	0.25	0.42	0.42
Herbicides	0.01	0	0	0.11	0.13	0	0	10.60	13.07
Insecticides	0.01	0	0	0.04	0.04	0	0	4.44	4.44
Formicides	0.01	0	0	0.02	0.02	0	0	2.47	2.47
Fungicides	0.01	0	0	0	0	0	0	0.49	0.49
Petroleum fuels	0.01	0.16	0.21	0.42	0.21	15.59	20.79	41.57	20.79
Steel	0.05	0.06	0.15	0.15	0.15	1.07	2.90	2.90	2.90
Services (S)									
Unqualified manpower	0.80	83.69	57.72	1.85	0.29	20.92	14.43	0.46	0.07
Qualified manpower	0.60	0.87	1.39	31.17	17.32	0.58	0.92	20.78	11.54
Administrative labor	0.60	0.89	0.95	0.95	0.95	0.59	0.64	0.64	0.64
Technical assistance	0.60	2.22	2.22	0.44	0.64	1.48	1.48	0.30	0.43
Accounting services	0.60	0.18	0.18	0.18	0.18	0.12	0.12	0.12	0.12
Costs of trips	0.05	0.01	0.01	0.01	0.01	0.14	0.14	0.14	0.14
Governmental taxes	0.60	2.11	2.11	3.02	3.02	1.41	1.41	2.01	2.01
Circulating capital costs	0.10	0.11	0.11	0.11	0.11	0.98	0.98	0.98	0.98
Insurance	0.60	0.22	0.22	0.13	0.22	0.15	0.15	0.09	0.15
Transportation	0.10	0.25	0.25	0.25	0.25	2.26	2.26	2.26	2.26
Drying and storage	0.40	2.12	2.12	2.12	2.12	3.17	3.17	3.17	3.17
Social security	0.60	2.84	2.84	3.02	3.02	1.89	1.89	2.01	2.01
Additional services (S_A)									
Job lost	0	0	0	0	0	0	7.40	14.80	14.80
Health treatments	0	0	0	0	0	0	0	18.50	18.50
Effluent treatment	0	0	0	0	0	0	0	18.50	18.50
Environmental restoration	0	0	0	0	0	0	7.40	7.40	7.40
Environmental services loss	0	0	0	0	0	0	7.40	7.40	7.40

2002; Brown & Ulgiati, 2004; Ortega et al., 2002; Panzieri et al., 2000).

The emergy yield ratio (EYR) is important because it indicates the efficiency of the farm in using purchased inputs. Primary energy sources (oil, coal, gas) show an EYR greater than 5. Secondary energy sources and primary materials such as cement and steel show an EYR in the range of 2 to 5, indicating moderate contribution to the economy (Brown & Ulgiati, 2004). The EYR for agricultural raw materials varies from 1.2 to 2.0 (Bastianoni et al., 2001; Ortega et al., 2002, Panzieri et al., 2000). The EYR values obtained for biological soybean systems (3.69 for ecological; 3.24 for organic) were better than those obtained for industrial systems (2.17 for chemical; 1.37 for herbicide). They show a good ability of biological systems to obtain local resources as a response to invested outside resources.

The emergy investment ratio measures the demand of monetary investment per unit of product. Industrial systems consume more fossil energy in direct and indirect form. A lower value means better use of renewable

Table 5. Manpower Used in Agricultural Systems Studied

	Biological		Industrial	
	Ecological	Organic	Chemical	Herbicide
Internal manpower	Unqualified labor, qualified labor (machine operators), administrative labor	Qualified labor (machine operators), administrative labor		
External manpower	Accounting labor, technical assistance	Unqualified labor, accounting labor, technical assistance	Unqualified labor, qualified labor, administrative labor, accounting labor, technical assistance	Unqualified labor, qualified manpower, administrative labor, accounting labor, technical assistance

Table 6. Aggregated Emergy Flows for Soybean Production Systems

	Biological		Industrial	
Emergy Flows	Ecological	Organic	Chemical	Herbicide
Renewable resources (R)	1.36E + 15	1.26E + 15	1.17E + 15	1.17E + 15
Nonrenewable resources (N)	0.00E + 00	0.00E + 00	3.36E + 15	0.00E + 00
Nature contribution (I)	1.36E + 15	1.26E + 15	2.34E + 15	2.34E + 15
Renewable materials (M_R)	5.77E + 15	5.63E + 15	2.71E + 14	3.18E + 14
Nonrenewable materials (M_N)	2.67E + 15	2.89E + 15	3.47E + 15	3.91E + 15
Total materials (M)	8.45E + 15	8.52E + 15	3.74E + 15	4.23E + 15
Labor services (S_R)	9.55E + 14	7.01E + 14	4.32E + 14	2.81E + 14
Nonrenewable services (S_N)	3.37E + 14	2.76E + 14	3.30E + 14	2.35E + 14
Additional services (A_S)	0.00E + 00	2.22E + 14	6.66E + 14	6.66E + 14
Total services (S)	1.29E + 15	1.20E + 15	1.43E + 15	1.18E + 15
Feedback from economy (F)	3.01E + 15	3.39E + 15	4.47E + 15	4.81E + 15
Total emergy (Y)	1.11E + 16	1.10E + 16	9.71E + 15	6.58E + 15

Table 7. Net Set of Emergy Indicators for Soybean Production Systems

	Biological		Industrial	
Emergy indicators	Ecological	Organic	Chemical	Herbicide
Traditional emergy indicators				
Tr	147,660	248,210	223,613	151,587
EYR	3.69	3.24	2.17	1.37
EIR	0.37	0.45	0.85	2.72
%R	72.9	69.1	19.3	26.9
EER	6.69	6.62	5.47	3.71
ELR	0.37	0.45	4.18	2.72
New social and externality emergy indicators				
LSR	0.74	0.58	0.30	0.24
LER	0.09	0.06	0.04	0.04
LWR	0.28	0.01	0.00	0.00
ExER	0.00	0.02	0.07	0.10

Note: Tr = solar transformity; EYR = emergy yield ratio; EIR = emergy investment ratio; %R = renewability; EER = emergy exchange ratio; ELR = environmental loading ratio; LSR = labor services ratio; LER = labor empower ratio; LWR = labor work ratio; ExER = externalities empower ratio resources, where the renewable energy can be replenished to continually feed the system. The biological systems have better emergy investment ratio values (0.37 for ecological; 0.45 for organic) than do industrial systems (0.85 for chemical; 2.72 for herbicide). Therefore, the biological options have lower production costs than the industrial options. Global trends indicate that nonrenewable energy will be less available and more costly in the future. It appears that agricultural production systems based on nonrenewable resources will not be able to compete with systems characterized by lower economic investment and bigger nature contribution. New farm designs combined with regional planning and fair trade rules must conduct adaptation strategies for systems that presently demand high rates of nonrenewable inputs (Odum, 1996).

In the long run, systems with higher renewability will prevail due in part to their ability to survive the stresses from which they are currently suffering. Renewability values reported for cereals in other studies vary from 19% to 72% (Ortega et al., 2002; Panzieri et al., 2000). This study shows that renewability is better in biological options (73% for ecological; 69% for organic) than in industrial options (19% for chemical; 27% for herbicide).

The emergy exchange ratio provides a measure of who loses in economic trade. Results show that farmers of biological systems are losing more emergy in exchange with the external market. The emergy exchange ratio values were found to be 6.69 for ecological, 6.62 for organic, 5.47 for chemical, and 3.71 for herbicide. Biological systems spend approximately 6.6 times more emergy to produce their products than what they receive in sales. This shows that prices of farming products are undervalued. Usually, agricultural systems transfer emergy to urban systems. This is evidence that prices of biological products should be higher. Agriculture products are low priced, whereas the price of purchased inputs increases every year. This results in a reduction of profits for a great parcel of farmers.

The environmental loading ratio obtained for biological systems (0.37 for ecological; 0.45 for organic) were better than for industrial systems (4.18 for chemical; 2.72 for herbicide). This ratio is a measure of ecosystem stress because of the process: The higher the value, the greater the pressure of the economic system on the local environment (Panzieri et al., 2002). The environmental loading ratio value indicates that biological options cause lower pressure on the environment, and they were even lower than values reported by literature: from 1.2 to 5.6 (Bastianoni et al., 2001; Lefroy & Rydberg, 2003; Ortega et al., 2002; Panzieri et al., 2000).

Emergy Analysis Using Indicators That Incorporate Local Labor and Externalities

New emergy indicators—labor services ratio, labor empower ratio, and labor work ratio (LWR)—were used to evaluate farm performance related to social justice. They show the intensity and characteristics of labor used in farming. The labor services ratio is the ratio of manpower labor to total services used; obtained values were 0.74 for ecological, 0.58 for organic, 0.30 for chemical, and 0.24 for herbicide systems. These results indicate the lower use of labor by the industrial systems and at same time, the lower use of other services by the biological systems. This was expected because industrial systems are characterized by heavy use of machinery and chemicals that replace human labor.

The labor empower ratio is the ratio of labor to the total empower; these ratios were 0.04 for industrial systems, 0.09 for ecological, and 0.06 for organic systems, indicating that the use of labor is rather small for all alternatives. Nevertheless, biological values are 3 times greater than industrial values.

The LWR is the ratio of local labor to total labor and is an important indicator when evaluating social justice. It measures the self-independence of a farm: The lower the LWR, the greater the dependence of the farm on external labor force. It is an indicator that the farm is actually family managed. The LWR values observed for industrial systems indicate low use of local or internal labor (0.01), whereas ecological systems use a lot (0.28).

In this study, a new indicator that measures the ratio between externalities and total empower is used. The industrial farming systems show more externalities (0.07 for chemical; 0.10 for herbicide) than biological systems (0 for ecological; 0.02 for organic). The consideration of these additional services as real costs could promote better social and environmental behavior of farming systems.

The calculation of costs of negative externalities still deserves more research. We use a very conservative value of externalities in the calculation of additional service emergy flows (US$180.00/ha/year) that corresponds to 60% of the value obtained by Pretty et al. (2000). Table 8 shows a calculation of externali-

Table 8. Values of Externalities for Brazilian Agriculture

Effect Measured	Value (US$/ha/year)	Source
Soil erosion	83.00	Santos, Nogueira, Pires, Obara, & Pires (2000)
Nutrients lost to erosion	13.60	Pretty et al. (2000)
Carbon dioxide emission	7.84	Brazil—Ministry of Science and Technology (2004)
Methane emission	20.52	Brazil—Ministry of Science and Technology (2004)
Nitrous oxide emission	32.00	Brazil—Ministry of Science and Technology (2004)
Effluent treatment	39.70	Pretty et al. (2000)
Savanna destruction[a]	98.50	—
Intoxication, invalidity, and deaths by pesticide use	0.20	Pretty et al. (2000)
Rural exodus (jobless expenses)	50.00	Ortega (2002)
Total	345.36	

a. *Calculation of unitary value of savanna destruction using emergy analysis:* The value of one hectare of deforested savanna can be estimated considering the time needed to recover its biodiversity, soil quality, and water aquifer. It could take at least 80 years if there are seed depositories in the region. If the land is allowed to rest, it will occur in succession until the climax is achieved and the system richness is recovered; then, in accordance with emergy analysis, the main energy introduced will be the water of rain. In a detailed analysis, the minerals solubilized by micro-biota to furnish nutrients to plants could also be considered.

Data:
Precipitation: $0.8\ m^3/m^2$/year
Area conversion factor: $10^4\ m^2$/ha
Water density: $1000\ kg/m^3$
Gibbs free energy of water: 5000 joules/kg
Water transformity: 18 200 sej/J
Dollar equivalence in emergy (in 2004): $3.7 \times 10^{+12}$ sej/dollar
Time to recover stocks: 80 years

Emergy stock = Energy of water × transformity × time × dollar equivalence
$[(0.8\ m^3/m^2/ha/year) \times (10^4\ m^2/ha) \times (10^3\ kg/m^3) \times (5000\ J/kg)] \times 18200$ sej/J
$7.28 \times 10^{+15}$ (sej/ha/year) × 80 years/$3.7 \times 10^{+12}$ (sej/US$)
15740 (US$/ha)

US$/ha/year = Emergy of stock (water accumulated and transformed)/Time
15740 (US$/ha)/80 years
196.76 (US$/ha/year)

In the savanna (*cerrado*), Brazilian law regarding agricultural projects establishes that 50% of farmland should be dedicated to native forest preservation; however, soybean farmers do not obey this law. Instead, they use almost 100% of the land for soybean production. Although there is public concern about this problem and farmers are fined by the government, there is nonetheless an environmental debt relative to forest destruction of 50% of farm area, a value of US$98.38/ha/year.

ties for soybean production in Brazil that gave US$345.00 per hectare per year, almost the same value obtained by Pretty et al. (US$330.00/ha/year).

Expanding the Scope of Analysis of Soybean Production Systems

There is an important public discussion about the release of transgenic soybean seeds in Brazil. However, the discussion limits its scope to a comparison of industrial options and does not take into consideration biological production (with better environmental and social qualities). Farming systems that adopt transgenic seeds become dependent on external systems because they can no longer produce seeds; instead, they will need to buy seeds every year from foreign enterprises that will control their price. This means loss of autonomy. In addition, small farmers will have to incur debts to buy costly equipment and inputs to produce with transgenic technology; they will compete with bigger farms in an unfavorable situation. After some years, many of them will sell their lands and leave the business.

In emergy analysis of agricultural systems, the political and technological forces are identified only as another external force (info) related with information and usually not quantified. Because of its importance, in this article, we make an effort to introduce the

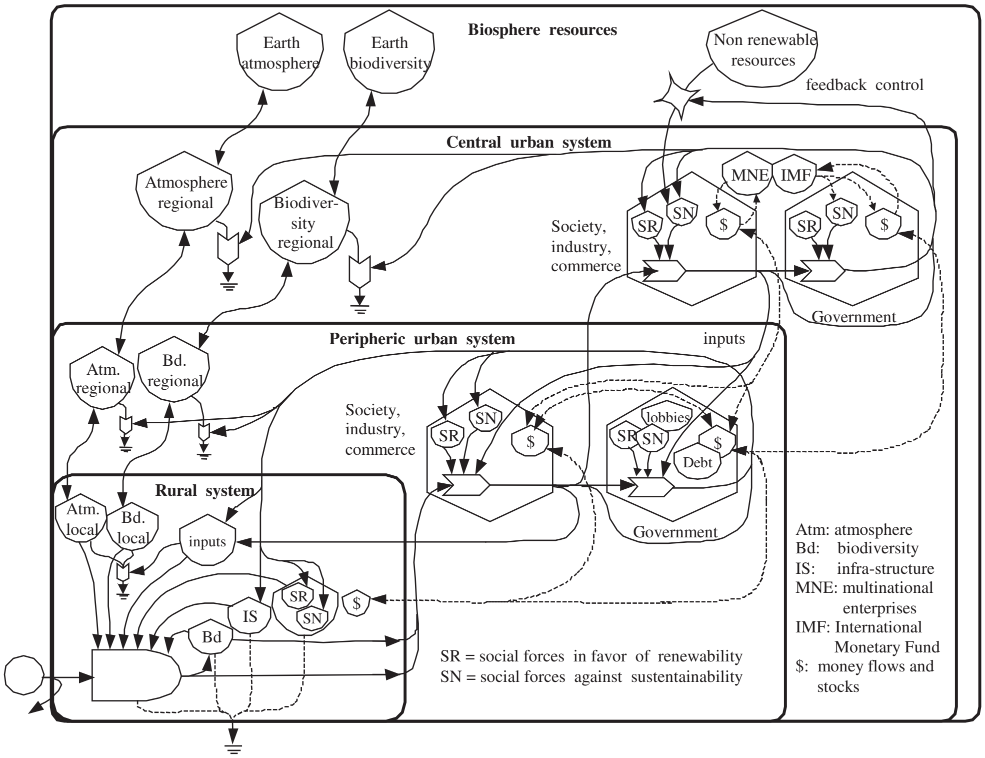

Figure 3. Emergy Flows Diagram of Global System of Soybean

complex net of influences that affect soybean-cropping systems as a first step toward a study devoted to identifying and measuring as emergy flows all the factors that define public policy and private decisions in soybean production.

A system diagram was prepared (see Figure 3) that shows the forces that act beyond the borders of the farming system. It depicts the structure of soybean production for export, with the main external forces and some of its most characteristic internal elements. It also contains the peripheral urban system, where agricultural system is inserted, and obeys country laws of production, commercialization, research, and financing. This frame is closer to the agricultural system and delivers a considerable force on it. Social agents and the government are the main actors. In the local society, there are social groups with opposing scientific and political proposals: Some are in favor of more renewability, whereas others favor more competitive economic arrangements and are clearly against sustainable proposals.

In the federal government, there are strong links established between the payment of external debt and the use of transgenic technology. The payment of international debt imposes as its highest priority the exports of agricultural products (as raw materials) to obtain a surplus. Thus, the mechanisms of investment in agriculture privilege the big farms of one crop for export that use industrial inputs. An opposite pressure is observed in some sectors of society to limit expansion of industrial agriculture in forested areas in the central and northern areas (the cerrado and the Amazon basin). Moreover, ecological concerns are increasing because large-scale farmers will not improve the environmental and social performance of soybean farms by themselves.

The peripheral urban system has many links with the central urban system. The government and social groups of the central urban system are represented in the diagram (see Figure 3). The central system is composed of developed countries. The peripheral rural system (Third World) is dependent on the impositions and interests of the central system (First World). Many times, countries of the peripheral system have debts with countries of the central system. The central system has the power to interfere in periphery governments, for example, the pressures on public policy by multinational enterprises and the International Monetary Fund.

The central urban system prefers to be a cheap raw-material buyer instead of producing its own food and fiber. This creates an incentive for maintenance of the current agricultural structure based on the industrial model of production in Brazil as well as in Europe.

Parts of biosphere resources are or could be renewable (biodiversity and atmosphere) and others are nonrenewable (fossil fuels). Nowadays, the nonrenewable resources support the global industrial system, and at the same time, their consumption contributes to the destruction of the remaining renewable resources. This complex relation between components is shown in the diagram (see Figure 3).

Through this broad vision, it is possible to identify several political forces: (a) the industrial agriculture congressional group that is a relevant force in the configuration of Brazilian laws related to soybean production, (b) transnational industries that have the economic power to affect policy and investments of local governments, and (c) the International Monetary Fund imposition that forces Brazil to pay its external debt (or at least the yearly interest), resulting in the country's huge need for economic resources that maintains the current structure of land tenure and the chemical agriculture model. To pay the debt, the government needs a high volume of exports and low social investments; the sector of agricultural business for export is able to contribute to this.

Because of all of these factors, even the ecological group of the federal government has knowledge of the social and environmental advantages of biological agriculture; however, it is overwhelmed by the economic group of the same government that imposes the transgenic modality of industrial agriculture. The observed result is that the external forces generate strong pressures to modify the Brazilian rural structure to increase the use of industrial chemical inputs even though it is neither the more economical solution nor the better ecological and social alternative.

Conclusion

Emergy methodology allows for the characterization of the four different types of soybean production system under study and shows how much better the biological options can be than the industrial options. The incorporation of the renewability factor to improve calculations of system indicators is convenient and valid, considering the use of renewable inputs purchased in the local or regional economy.

The biological systems are most efficient in the use of energy flows and demand less monetary investments for each unit of emergy produced. On the other hand, industrial systems consume more fossil energy in direct and indirect form. Biological systems are more renewable than industrial ones. The results indicate that biological options cause lower pressure on the environment and have a better ability to exploit and make available local resources by investing outside resources. This means that the biological system delivers more emergy per economic input. Results show that farmers of biological systems are losing more emergy in the exchange of their products with the external market.

The separation of labor into local and external allows the identification of family-managed systems using LWR. Biological systems are more labor intensive and use more local labor in the process, resulting in wide-ranging benefits to the region.

The inclusion of externalities as additional services makes possible a better social appraisal of production alternatives for agricultural products. Considering family-managed ecological production as a reference, it is possible to suggest fair prices for soybeans obtained from different processes. Considering the negative externalities, it is possible to suggest lower prices for products originating from nonecological production systems.

The main characteristic of biological models is the widespread use of available natural resources in ecosystems where the farm is inserted instead of purchased inputs. This brings a reduction in costs. In addition, an increase in the number of jobs per unit of area is observed, and biological systems preserve soil and forest reserves. This system benefits the producer directly and society indirectly.

The best performance observed in emergy analysis is obtained by increasing the use of renewable, natural resources and by reducing the use of materials and services as well as soil losses by erosion and externalities. The best option is an agricultural system based on small farms of ecological or organic cultures. This allows the farmer an acceptable quality of life, good use of natural resources, moderate use of economic resources, and recycling of materials. Small ecological farms can produce for regional and external markets with productivity equivalent to industrial systems (Odum, 2001).

The emergy methodology provides the identification of the macro structure that drives soybean production in Brazil. It is necessary to have a broad vision to allow the identification and to visualize the external forces that act in the agricultural systems. This vision provides evidence that there are significant forces defining the industrial system that are not considered in traditional emergy analysis. Between these forces can be cited several lobbies: the agricultural congressional group, the International Monetary Fund, international banks, great agricultural inputs companies, and finally, the favorable external market.

References

Agrianual. (2004). *Anuário da agricultura Brasileira* [Yearbook of Brazilian agriculture]. São Paulo, Brazil: Author.

Altieri, M. A. (2000). *Agroecologia: A dinâmica produtiva da agricultura sustentável* [Agroecology: The productive dynamics of sustainable agriculture] (2nd ed.). Porto Alegre, Brazil: Editora Universidade.

Bastianoni, S., Marchettini, N., Panzieri, M., & Tiezzi, E. (2001). Sustainability assessment of a farm in the Chianti area (Italy). *Journal of Cleaner Production*, *9*, 365-373.

Brandt-Williams, S. L. (2002). *Emergy evaluation of Florida agriculture* (Folio No. 4). Gainesville: University of Florida.

Brazil—Ministry of Science and Technology. (2004). *Inventário de Emissões e Remoções Antrópicas de Gases de Efeito Estufa não Controlados pelo Protocolo de Montreal, Painel Intergovernamental sobre Mudança do Clima IPCC 1990-1994* [Inventory of man-made emissions and removals of greenhouse gases—International Panel of Climate Change]. Retrieved December 8, 2004, from http://www.mct.gov.br/clima/comunic/ppt/apresent_ministro_COP10p.ppt

Brown, M. T., & Ulgiati, S. (2004). Emergy analysis and environmental accounting. *Encyclopedia of Energy*, *2*, 329-354.

Gliessman, S. R. (2000). *Agroecologia: Processos ecológicos em agricultura sustentável* [Agroecology: Ecologic process in sustainable agriculture]. Porto Alegre, Brazil: Editora Universidade.

Higgins, J. S. (2003). Emergy analysis of the Oak Openings region. *Ecological Engineering*, *21*, 75-109.

Lefroy, E., & Rydberg, T. (2003). Emergy evaluation of three cropping systems in southwestern Australia. *Ecological Modelling*, *161*, 195-211.

Nilsson, H. (2004). What are the possible influences affecting the future environmental agricultural policy in the European Union? An investigation into the main factors. *Journal of Cleaner Production*, *12*, 461-468.

Odum, H. T. (1983). *Systems ecology: An introduction*. New York: John Wiley.

Odum, H. T. (1996). *Environmental accounting: EMERGY and decision making*. New York: John Wiley.

Odum, H. T. (2001). *The prosperous way down*. Boulder: University Press of Colorado.

Ortega, E. (2000). *A soja no Brasil: Modelos de Produção, custos, lucros, externalidades, sustentabilidade e políticas públicas* [Soybean in Brazil: Production models, costs, profits, externalities and public policy]. Campinas, Brazil: State University of Campinas. Retrieved December 8, 2004, from http://www.unicamp.br/fea/ortega/soja/soybean-ortega.pdf

Ortega, E. (1998). *Tabela de transformidades* [Transformity table]. Retrieved July 13, 2004, from http://www.unicamp.br/fea/ortega/curso/transformid.htm

Ortega, E., Anami, M., & Diniz, G. (2002, September). Certification of food products using emergy analysis. *Proceedings of III International Workshop Advances in Energy Studies*, 227-237.

Ortega, E., Miller, M., Anami, M., & Beskow, P. R. (2001, September). From emergy analysis to public policy: Soybean in Brazil. *Proceedings of the Second Biennial Emergy Research Conference*. Gainesville: University of Florida.

Ortega, E., & Polidoro, H. (2002). Fatores a considerar na Análise emergética de projetos agroecológicos [Factors to consider in emergy analysis of agroecological systems]. In E. Ortega (Ed.), *Engenharia ecológica e agricultura sustentável*. São Paulo, Brazil. Retrieved December 8, 2004, from http://www.unicamp.br/fea/ortega/soja/soybean-ortega.pdf

Panzzieri, M., Marchettini, N., & Bastianoni, S. (2002). A thermodynamic methodology to assess how different cultivation methods affect sustainability of agricultural systems. *Journal of Sustainable Development and World Ecology*, *9*, 1-8.

Panzzieri, M., Marchettini, N., & Hallam, T. G. (2000). Importance of the Bradhyrizobium japonicum symbiosis for the sustainability of a soybean cultivation. *Ecological Modelling*, *135*, 301-310.

Pretty, J. N., Brett, C., Gee, D., Hine, R. E., Mason, C. F., Morison, J. I. L., et al. (2000). An assessment of the total external costs of UK agriculture. *Agricultural Systems*, *65*, 113-136. Retrieved August 25, 2003, from http://www.elsevier.com/locate/agsy

Santos, J. E., Nogueira, F., Pires, J. S. R., Obara, A. T., & Pires, A. M. Z. C. R. (2000, February). Funções Ambientais e Valores dos Ecossistemas Naturais—Estudo de Caso: Estação Ecológica de Jataí, Luiz Antônio, SP, 2000 [The values of environmental services of natural ecosystems. A study case: Jatai Ecological Reserve]. In *Valoração Econômica da Biodiversidade—Estudos de caso no Brasil*. Brazil: Ministério do Meio Ambiente, Secretaria de Biodiversidade e Florestas.

Ulgiati, S. (1998, May). Final document. *Proceedings of the Biennial International Workshop Advances in Energy Studies*, 629-636.

Ulgiati, S., Brown, M. T., & Bastianoni, S. (1994). Emergy analysis, environmental loading and sustainability: An emergy analysis of Italy. *Ecological Modelling*, *73*, 215-268.

Wackernagel, M., & Rees, W. (1995). *Our ecological footprint: Reducing human impact on the Earth*. Gabriola Island, British Columbia, Canada: New Society.

Enrique Ortega, Ph.D., is a chemical engineer and a professor at the State University of Campinas, Brazil. His research focuses on systems ecology and ecological engineering.

Otávio Cavalett is a food engineer and a Ph.D. candidate at the State University of Campinas, Brazil. His research focuses on the life cycle analysis of the soybean using emergy.

Robert Bonifácio is a sociology student at the State University of Campinas, Brazil.

Marcos Watanabe is a food engineering student at the State University of Campinas, Brazil. His research focuses on the costs of externalities in agriculture.