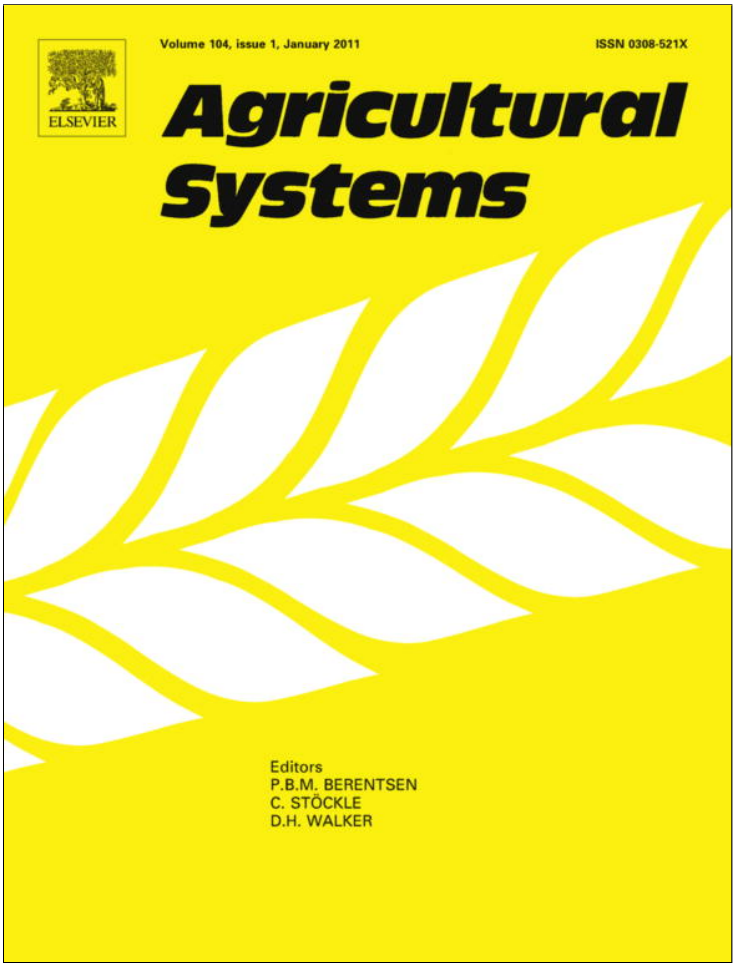

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Emergy assessment of a coffee farm in Brazilian Cerrado considering in a broad form the environmental services, negative externalities and fair price

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ABSTRACT

A new way of thinking about conservation is represented by the preservation of native areas and the payment for their environmental services. In the present study emergy synthesis was applied to assess the environmental performance of a coffee farm located in Coromandel, Minas Gerais, in the Brazilian Cerrado. The farm produces green coffee for exportation, and holds an area with native vegetation of 80 ha, larger than that required by Brazilian legislation. The assessment of the native area within the farm was carried out in order to determine its environmental sustainability. The emergy ternary diagram was employed to interpret the results, which show that a farm with 54 ha of productive area must be matched with 200 ha of native vegetation for medium term sustainability. The Cerrado's farm production is primarily for export, and an evaluation of the environment and economic changes with respect to importing countries was performed. Emergy synthesis is proposed to calculate the price of environmental services balancing trades in the international market. A discussion of the problem of assigning payments for environmental services is presented.

1. Introduction

Coffee is an important global commodity and forms a significant fraction of the export economy of many countries. It is globally traded and at times has ranked second in monetary value only to oil among traded commodities (ICO, 2010). Its production forms the backbone of more than 50 developing countries, with a contribution to the total foreign currency earnings reaching as much as 80% in the case of some countries (ICO, 2010). Coffee is a buyer-driven commodity, and trade between producing and consuming countries consists mostly of green coffee and, to a small extent, bulk instant coffee. Imported bulk instant coffee is usually blended and re-packed in consuming countries. The roasted coffee trade is almost always between consuming countries.

The Cerrado region is known for its rich biodiversity, but it is also a place of crop plantations. Large monocultures are currently covering the regions of southern Minas Gerais and the Cerrado, which implies a massive use of pesticides and chemical fertilizers. From only 200,000 ha of arable land in 1955, the Cerrado had well over 40 million ha in cultivation by the year 2005. In weight, this region provides 54% of all soybeans harvested in Brazil, 28% of the country's corn, and 59% of its coffee (IBGE, 2008). Currently, most high quality Brazilian coffee comes from sites within the Cerrado that have a micro-climate suitable for its cultivation, but coffee farms represent only a fraction of the agricultural landscape of the Cerrado. Nonetheless, coffee growing is an agent of habitat conversion in this unique ecosystem, offering fewer opportunities to preserve biodiversity than coffee growing in other regions.

Recently, coffee marketing has increasingly become concerned with environmental and social issues (Tallontire, 2002; Damodaran, 2002). The Brazilian so called legal reserve is a tool established by the Brazilian Forestry Code (Federal Law No. 4771, 1965) to ensure the permanence of the Cerrado limiting the land use of rural properties. The legal reserve law was established to ensure the conservation of Brazilian biomes, the conservation and restoration of ecological processes, biodiversity and the protection of wildlife and native flora by restraining the land use of rural properties. In the legal reserves, the vegetation cannot be removed, but it may be used to obtain social and economic benefits under a management system which respects the original ecosystem (Law No. 4771, 1965, Law No. 7803, 1989, Ordinance No. 113, 1995, Provisional Measure No. 2166–67 of 2001, and CONAMA Resolution No. 302 and 303, 2002). It currently establishes a minimum percentage between 20% and 35% of the land as a legal reserve for farms located in the Cerrado.

Recently, several methods proposing payments for environmental services (Claassen et al., 2008; Dobbs and Pretty, 2008; Pagiola, 2008; Wunder et al., 2008; Ferraro, 2001) and for valuating the natural capital and ecosystems' services (Costanza et al., 1997) have attracted increasing interest as a mechanism to translate external, non-market values of the environment into real financial incentives to provide a way to balance international trades.

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The responsibility for the payment for environmental services (PES) is still a topic addressed by few researchers, with the exception of a Special Issue published by Ecological Economics (Wunder et al., 2008). Wunder et al. (2008) defined payments for environmental services as voluntary transactions where a well-defined environmental service is 'bought' from a service provider, if and only if, the service provider secures service provision. In practice, PES programs differ in the type and scale of environmental services demand, the payment source, the type of activity paid for, the performance measure used, as well as the payment mode and amount.

There are PES systems designed to protect native vegetation or water quality in which payments are made by users (Wunder and Albán, 2008; Pagiola, 2008; Asquith et al., 2008). In this case, PES are user-financed, as buyers are the users of the environmental services, but there are also PES established to offset the carbon emissions of big European companies (Wunder and Albán, 2008). This kind of initiative is financed by a third-party, which could be the government (Kumar and Managi, 2009) or a non-governmental organization (NGO). In this case, buyers are third-parties on behalf of users of a given environmental service. Facilitated by a local NGO, 46 farmers are paid to protect a watershed containing the threatened cloud-forest habitat of migratory birds, in Bolivia's Los Negros valley. In the same region, downstream irrigators who benefit from stabilized dry-season water flows, which result if upstream cloud forests are successfully protected, have been reluctant to pay, but the Los Negros municipal government has contributed on their behalf (Asquith et al., 2008). There are also studies advocating that remuneration for environmental services has not sufficiently supported the goals of spending money more effectively on the environment and of motivating farmers (Haaren and Bathke, 2008), and that only a small share of the budgets for agriculture in the developed countries, is available for buying environmental goods and services beyond the level of good farming practice. All these studies are based on the "willingness to pay" approach, with the exception of the proposal of Pagiola et al. (2007), in which a Regional Integrated Silvopastoral Ecosystem Management project was encouraged by the adoption of the practice of paying farmers for the expected increase in biodiversity conservation and carbon sequestration services that these silvopastoral practices would provide. The project developed an 'environmental services index' (ESI) and pays participants for net increases in ESI points.

Also based on the "willingness to pay" mechanism, a relatively new approach to conservation is represented by forest carbon, which measures forests in terms of the carbon they sequester in their biomass and soil. A trading system known as 'reducing emissions from deforestation and forest degradation' (REDD) is among the most prolific to date (Turner et al., 2009; Seaton, 2009; Streck, 2010; Skutsch and McCall, 2010; Corbera et al., 2010). At present, REDD pilot projects are rapidly developing in communities around the tropics, often using government funds or in some cases carbon credits that have been issued on voluntary carbon markets (Corbera et al., 2010). As helpful as these individual projects might be for improving people's livelihoods and preserving local biodiversity, however, it's not clear that they measurably reduce global-warming emissions.

A third alternative method for valuating ecosystem services might be the adoption of the emergy accounting method (Odum, 1996), which is not usually met in economics but rather in ecological engineering (Menegaki, 2008). Emergy accounting is a surrogate market evaluation in determining the net value of environmental services to society and it is used to express the value of environmental and economic work on an equal basis. In this case, a production process can be divided in several steps and, for each step, a single consumer and producer are defined. According to Odum (1996) as part of environmental management and development, one ecosystem can be exchanged for another, provided that there is an accurate quantitative basis for establishing the equivalence between ecosystems. However, regulations pertaining to compensation are hindered by the lack of a clear means of quantitatively determining appropriate compensatory areas, and therefore it is difficult for legislators to determine a proper area for preservation. Emergy accounting is widely practiced in assessing ecosystems' services in an attempt to fill the gap for evaluating non-marketed ecosystems such as legal reserves (Chen et al., 2009; Liu et al., 2009; Lu et al., 2007; Tilley and Brown, 2006; Odum, 1995a,b) and agriculture sustainability (Lagerberg and Brown, 1999; Qin et al., 2000; Almeida et al., 2007; Agostinho et al., 2008; de Barros et al., 2009; Cavalett and Ortega, 2009; Bonilla et al., 2010). An interesting discussion on worth of natural capital and environmental services indicates that emergy is the most reliable scientific measure of environmental support, because it is capable of evaluating both the quantity and quality of this support, thereby providing a basis for managing the economic/environmental interface (Ulgiati et al., 2011).

This study focuses on the Cerrado, which produces most of the high quality coffee exported from Brazil. The Brazilian coffee farm studied is located in a region of coffee production in the Southern part of the state of Minas Gerais. In this study, coffee production and export in the Brazilian savannah were evaluated using emergy synthesis to:

(a) evaluate the benefits achieved by the conservation of a native vegetation area,
(b) evaluate of emergy that the farm obtains from sales of green coffee on the international market, and
(c) discuss the responsibility for payments for environmental services.

2. Methods

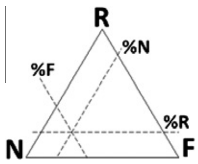
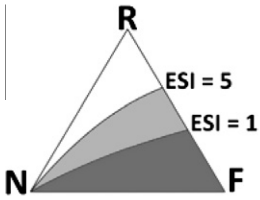
Emergy is a measure of real wealth or of the work that a product or service can do when it is used within a system. It is defined as the sum of the available energy of one type previously required directly and indirectly through the input pathways to make a product or service. The unit of emergy is solar emergy joules (seJ). Resources of nature, agricultural material and economic inputs of the farm studied were converted into emergy flows. The emergy flows represent three categories of resources: R as renewable resources, N as non-renewable resources and the inputs from the economy, F. R and N flows are provided by the environment and are economically free. The economic inputs, F, are provided by the market and related to fluxes that are accounted for in the economy. Transformity is the relationship between emergy and energy, given in seJ/J, and refers to the emergy needed to obtain one joule of a product or service, directly or indirectly. Questions about the baseline have not yet been resolved, and until they are it is necessary to choose one and make sure all transformities are expressed relative to it (Campbell, 2004; Brown and Ulgiati, 2010). Values of the transformities are mostly taken from the literature, and are relative to the 15.83×10^{24} seJ/year baseline (Odum and Odum, 2000). A brief description of the emergy indices is shown in Table 1.

To calculate the emergy exchange ratio (EER) of coffee sold and money paid, flows are converted to emergy units. This is the ratio of emergy exchange in a trade or purchase (Odum, 1996). When a good is sold and money is received in exchange, the EER gives a measure of the relative trade advantage of one partner over the other. In order to assess the advantages or disadvantages in terms of the price paid for coffee, the EER was calculated. The USA, Germany, Italy, Japan and Belgium represent about 60% of total exports of the Cerrado's coffee (MDIC, 2008). For the total exports, the weighted average of these countries' EMRs (Emergy Money Ratios), considering the percentages of coffee exported to each of

Table 1
Emergy based indices.

Symbol	Description	Equation
EYR	The emergy yield ratio (EYR) is the ratio of the emergy of the output (Y = R + N + F), divided by the emergy of those inputs (F) to the process that are fed back from outside the system	EYR = Y/F
ELR	This index of environmental loading is the ratio of non-renewable emergy (N + F) to renewable emergy	ELR = (N + F)/R
ESI	The environmental sustainability index aggregates the measure of yield and environmental loading. The objective function for sustainability is to obtain the highest yield ratio at the lowest environmental loading	ESI = EYR/ELR
EMR	The ratio of all emergy supporting the economy of a country ($Y_{country}$) to its gross domestic product (GDP). Provides an average measure of the purchasing power for a nation when compared with ratios from other nations	EMR = $Y_{country}$/GDP
EER	The ratio of emergy exchange in a trade or purchase, gives the extent of the relative trade advantage of one partner over another	EER = Y/$paid EMR
Em$	The Emprice is an expression of the emergy one receives in the product for each dollar paid for the product. It was introduced by Odum (1996) to estimate the monetary value of the emergy content of a good or service. The units of emprice are Em$	Em$ = Y/$EMR_{country}$

Table 2
The emergy ternary diagram and analytical properties used in this text. Further information can be found in Giannetti et al. (2006) and Almeida et al. (2007).

Properties	Description	Illustration
Resource flow lines	Ternary combinations are represented by points within the triangle, the relative proportions of the elements being given by the lengths of the perpendiculars from the given point to the side of the triangle opposite the appropriate element. These lines are parallel to the triangle sides and are very useful to compare the use of resources by products or processes	
Sustainability lines	The graphic tool allows us to draw lines indicating constant values of the sustainability index. The sustainability lines depart from the N apex in direction leading to the RF side allowing the division of the triangle into sustainability areas, which are very useful to identify and compare the sustainability of products and processes. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for the long term; the middle part (gray) marks the region (1 < ESI < 5) where systems are sustainable for the medium term, and the lower part of the diagram (dark gray) shows a region (ESI < 1) where systems are not sustainable	

them, was calculated as 3.05×10^{12} seJ/US$ (Appendix A). Emergy evaluation also offers the possibility to integrate economical and ecological assessments by calculating the emprice (Em$). The use of Em$ instead of US$ is only a way to differentiate the methodology used to calculate monetary values. It was introduced by Odum (1996) to estimate the monetary value of the emergy content of a good or service (natural or not).

Emergy evaluation tables, prepared according to the procedures described by Odum (1996), were used to estimate the energy incorporated into each product as a way to evaluate the sustainability of the farm. The emergy evaluation was performed to monitor coffee production in from 1997 to 2006. In this text, the emergy table corresponding to the year of 2006 is presented. The other nine tables may be requested from the authors.

A fourth step that further facilitates the communication of the results and the decision making process is the development of ternary diagrams (Giannetti et al., 2006; Almeida et al., 2007), which visually represent some of the indices mentioned above and can assist in the comparison of different development paths (Gasparatos et al., 2008). The analytical properties of ternary diagrams used in this work are presented in Table 2. With the aid of diagrams, one can evaluate the performance of a given system and its interactions with the environment (Agostinho et al., 2008, 2010; Almeida et al., 2010; Bonilla et al., 2010; Cai et al., 2008).

3. Results and discussion

3.1. Description of Santo Inácio farm's production system in emergy terms

Coffee production data were obtained from Santo Inácio coffee farm at Coromandel, in the Cerrado region, which produces green coffee exclusively for export (Cerrado Coffee). The farm has a total area of 140 ha, of which 54 ha are planted with 160,000 coffee trees (*Coffea arabica* L.), and 80 ha correspond to the native vegetation, where there is a spring from which a stream flows along the boundary of the property. This conservation area is about seven times larger than that required by the Brazilian law. In the conventional production system the coffee bushes are grown in alleys. After gathering the fruits, the coffee cherries are dried and the outer covering of the fruit is removed (pre-processing). The final product is green coffee. The green coffee is packed in 60 kg bags and stored in a warehouse of Producer's Cooperative for exportation.

Fig. 1 presents an overview of the coffee production area using energy system symbols. The diagram shows the energy sources driving the processes and the chosen system boundaries.

The different energy sources were aggregated. Purchased energies such as fuel and electricity, chemicals, labor, and machinery are shown on the top of the diagram. On the left-hand side of the diagram environmental resources are shown.

The natural savannah that is preserved is shown in a separate box evidencing the environmental benefits accounted for in this study and the environmental support necessary to this area (Fig. 1). The dominant driving energies of the natural system are: rainfall, the emergy contribution from geologic processes to the formation of the land structure, and the river source. Driving energies and ecosystem storages interact in several processes that generate ecosystem services. Four services of this ecosystem were evaluated: (1) transpiration of water, (2) gross primary production (GPP), (3) water recharge (infiltration), and (4) the interaction between the land structure and the underground water resulting in a stream that borders the property. The river water is not used by the coffee plantation, due to the land structure, and the topography. Transpiration and GPP are coproducts, so counting both transpiration and GPP would be double counting. Thus, only the largest one was used for the total of ecosystem services.

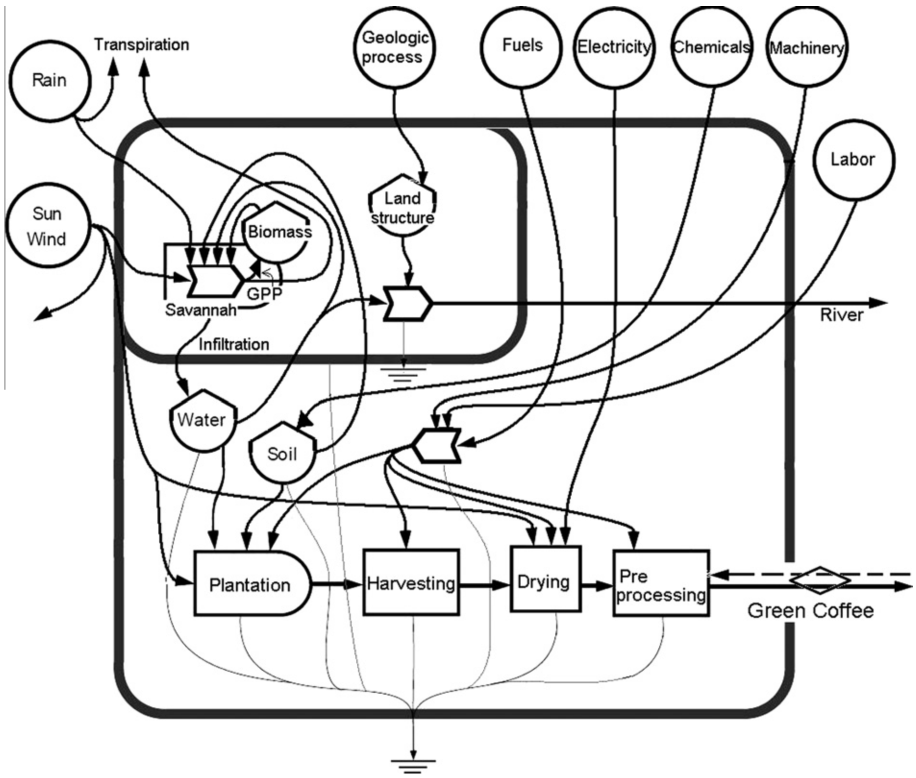


Fig. 1. System diagram of coffee production, processing and exportation at Santo Inácio farm. The emergy evaluation is performed for coffee production, coffee cherries harvesting, coffee cherries drying, and pre-processing.

Each processing step for traditional coffee production is evaluated and indicated in Table 3. In this table, the environmental benefits of the native area were not accounted in this table.

For the green coffee production system (Table 3) in 2006, the purchased services contributed with approximately 29% of the total emergy. Fuel represented 9% of total emergy. Direct labor accounted for 24% of total emergy, and chemicals fertilizers accounted for 28% of the emergy support required. Local renewable emergy accounted for 20% of the total emergy for producing green coffee. The emergy per unit calculated for the green coffee was 5.85×10^9 seJ/g.

3.2. Evaluation of the benefits achieved by the conservation of a native vegetation area

A summary of the evaluation of the preserved native area is presented in Table 4, while calculation procedures are shown in Appendix B. The main driving energies, environmental services, storages (natural capital) and the respective emprice of the environmental benefits supplied by the reserve maintained by the farm were evaluated. Values in Em$ were obtained according to the equation shown in Table 1, using Brazil's Emergy Money Ratio for the year 2000 (NEAD, 2009).

Environmental benefits accounted resulted in a total of 4.28×10^{15} seJ/ha year. The emergy of infiltration is high, and is the most valuable service of the native area (1.75×10^{17} seJ/year). The high value is consistent with the Cerrado soil composition, where Oxisols are recognized as soils that have, among other characteristics, low water retention, mainly due to the composition of the clay fraction and the presence of a granular-type structure. The GPP value was approximately the same of the infiltration value. This result shows that the assessment of only one aspect, such as carbon storage, can result in underestimating the value of environmental benefits of an area, depending on its intrinsic characteristics.

The value for transpiration considered corresponds to the average value estimated for *Campo denso* vegetation in the Cerrado (Oliveira et al., 2005). Because, transpiration and GPP are co-products, only GPP was accounted (Odum, 1996), but during the wet season the Emprice of this environmental service may eventually overcome those corresponding to the biomass production.

Annual driving emergy for the area was the sum of rain, the land structure and the river source that comes from underground water stored, and represents 3.89×10^{15} seJ/ha year. The annual operation costs for preserving the native area was calculated as Em$ 26598.29. This result shows the high dependence of the native area on soil and on rain availability. The same dependence on rain was observed in Table 3 for the coffee production process, in which rain contributes 19% to the total emergy. Thus, the fate both systems in this region, natural and anthropogenic, is highly conditioned to the possible effects of climate change.

Legal reserves and areas of permanent preservation aim to conserve and restore ecological processes, biodiversity and to protect wildlife and native flora. A minimum percentage of legal reserve between 20% and 35% of the total land area was established for farms located in the Cerrado by the current environmental legislation. This percentage was calculated by subjectively quantifying ecosystem value of the proposed impacted site, as well as accounting for the perceived ease of replacement and recovery time needed. With the aid of the ternary diagram, it is possible to evaluate the contribution of the natural preserved area to the coffee production sustainability (Fig. 2).

Results shown in Fig. 2 point out that Brazilian regulations fail to accurately quantify ecosystem value from a scientific perspective, since they are based solely on people's perceptions, not on the ecosystems' structural and functional components. It is clear that, as the percentage of native preserved area increases, the

Table 3
Emergy table for the coffee production in Santo Inácio farm, 2006.

Item	Description	Unit	Class[a]	Annual flow (unit/year ha)	Emergy per unit[b] (seJ/unit)	Emergy (seJ/year ha)	% (seJ/seJ)
Plantation							
1	Sun[c]	J	R	5.97×10^{13}	1	5.97×10^{13}	1
2	Wind, kinetic energy[c]	J	R	6.45×10^{6}	2.52×10^{3}	1.63×10^{10}	<1
3	Rain, chemical energy[c]	J	R	4.27×10^{10}	3.06×10^{4}	1.31×10^{15}	19
4	Rain, geopotential energy	J	R	8.21×10^{6}	1.76×10^{4}	1.44×10^{11}	<1
5	Organic fertilizer	J	29% R	2.72×10^{4}	2.96×10^{9}	8.05×10^{13}	1
6	Soil erosion	J	N	9.95×10^{7}	7.40×10^{4}	7.36×10^{12}	<1
7	Fuel and lubricants	J	F	1.67×10^{9}	1.11×10^{5}	1.85×10^{14}	3
8	Machinery and equipment	g	F	1.61×10^{4}	6.70×10^{9}	1.08×10^{14}	2
9	Labor[d]	J	F	1.85×10^{8}	4.30×10^{6}	7.96×10^{14}	11
10	Lime	g	F	7.41×10^{4}	1.68×10^{9}	1.24×10^{14}	2
11	Pesticides and fungicides	g	F	3.08×10^{3}	1.48×10^{10}	4.56×10^{13}	1
12	Nitrogen	g	F	1.65×10^{5}	6.62×10^{9}	1.09×10^{15}	16
13	Phosphate	g	F	7.14×10^{4}	9.35×10^{9}	6.68×10^{14}	10
14	Potassium	g	F	1.21×10^{5}	9.32×10^{8}	1.13×10^{14}	2
15	Organic fertilizer	g	71% F	6.35×10^{4}	2.96×10^{9}	1.88×10^{14}	3
	Total for plantation					5.94×10^{15}	67
Harvesting							
16	Fuel and lubricants	J	F	2.92×10^{9}	1.11×10^{5}	3.24×10^{14}	5
17	Machinery and equipment	g	F	1.80×10^{4}	6.70×10^{9}	1.21×10^{14}	2
18	Labor[d]	J	F	1.99×10^{8}	4.30×10^{6}	8.56×10^{14}	12
19	Lodging for temporary workers	g	F	2.68×10^{5}	2.42×10^{9}	6.49×10^{14}	9
	Total for harvesting					1.95×10^{15}	28
Drying							
20	Sun	J	R	1.29×10^{11}	1	1.29×10^{11}	
21	Wind, kinetic energy	J	R	1.12×10^{8}	3.06×10^{4}	3.43×10^{12}	<1
22	Evaporation	g	R	5.56×10^{5}	1.45×10^{5}	8.06×10^{10}	<1
23	Electricity	J	F	7.73×10^{7}	2.77×10^{5}	2.14×10^{13}	<1
24	Terrace drying surface	g	F	3.33×10^{4}	2.42×10^{9}	8.06×10^{13}	1
25	Silo for coffee storage	g	F	4.83×10^{4}	2.42×10^{9}	1.17×10^{14}	2
26	Machinery and equipment	g	F	7.67×10^{3}	6.70×10^{9}	5.14×10^{13}	1
27	Labor[c]	J	F	2.05×10^{7}	4.30×10^{6}	8.82×10^{13}	1
	Total for drying					3.62×10^{14}	5
Pre-processing							
28	Machinery and equipment	g	F	8.89×10^{2}	6.70×10^{9}	5.96×10^{12}	<1
29	Labor[d]	J	F	6.30×10^{6}	4.30×10^{6}	2.71×10^{13}	<1
30	Fuel	J	F	4.92×10^{8}	1.11×10^{5}	5.46×10^{13}	1
31	Jute bags	g	F	7.72×10^{1}	2.31×10^{10}	1.78×10^{12}	<1
32	Electricity	g	F	5.73×10^{7}	2.77×10^{5}	1.59×10^{13}	<1
	Total for pre-processing					1.05×10^{14}	1
	Total production	kg	Y	1.20×10^{3}	5.85×10^{12}	7.02×10^{15}	100

[a] R: local/free renewable resource, N: local/free non-renewable resource, F: feedback from the economy or purchased resources.
[b] Emergies per unit for items 1–7, 23 and 30 were taken from Odum (1996); for items 8, 17, 26 and 28 from Bjorklund et al. (2001); for item 10 from Brown and Buranakarn (2003); for item 11 from Panzieri et al. (2000); for items 12–14, 19, 24 and 25 from Cuadra and Rydberg (2006); for item 22 from Buenfil (2001); and for item 31 from Brandt-Willians (2002).
[c] Not accounted to avoid double-counting.
[d] Brazil's total emergy in 2000 (2.77×10^{24} seJ/year)/(1.80×10^{8} inhab/day $\times$ 1.26×10^{7} J/inhab $\times$ 285 days).

environmental load of the system decreases about seven times and the environmental sustainability index increases 66 times (Fig. 2). An area of 20% of legal reserve is not sufficient to guarantee sustainability for the long term, as ESI in this condition is lower than one. For a legal reserve of 35%, the system would have an ESI = 1.07 and would be located in a region of medium term sustainability.

These results show that the Brazilian regulations, despite being considered severe by most farmers, are not enough to assure the Cerrado's sustainability for the long term. The actual condition of Santo Inácio farm, with 80 ha of preserved native area, is a warrant that it will perform satisfactorily for a medium length of time. However, to achieve long term sustainability, the preserved native area should correspond to 70% of the total area (126 ha). For 80% of preserved native area, the farm would be complying with the legislation for rural properties in the Amazon rainforest, and its area should be increased to 216 ha for 54 ha planted in coffee. Pereira and Ortega (2010) found a similar value for sugarcane production. Using the renewable empower density to study the region of São Paulo State these authors estimated that an area of 2.2 ha of forest vegetation was needed for every hectare of sugarcane cultivated to insure long term sustainability of the entire system.

3.3. Evaluation of environmental and economic exchanges

All the green coffee produced in the farm is exported. Sales are usually done between harvests, in the months of March and April, with the aim of optimizing the price of a bag. Coffee is sold in US dollars through the Producer's Cooperative. Accordingly to the Brazilian Ministry of Industry and Commerce, about 60% of total exports go to USA, Germany, Italy, Japan and Belgium (MDIC, 2008).

To evaluate the environmental and the economic exchanges of Santo Inácio farm, two situations were analyzed:

Table 4
Emergy evaluation of annual driving energies and environmental benefits (water exportation and biomass production) of the preserved native area (see Appendix B for data sources).

		Emergy (seJ/year)	Emprice (Em$/year)
Environmental support			
1	Rain	1.33×10^{17}	11367.52
2	Spring	3.52×10^{16}	3008.55
3	Land structure	1.43×10^{17}	12222.22
	Total	1.68×10^{17}	26598.29
Environmental benefits			
4	Transpiration[a]	1.18×10^{17}	10085,45
5	GPP	1.41×10^{17}	12051.28
6	Infiltration	1.75×10^{17}	14957.26
7	Stream	2.61×10^{16}	2230.77
	Total	3.42×10^{17}	29239.32

[a] Not accounted to avoid double-counting.

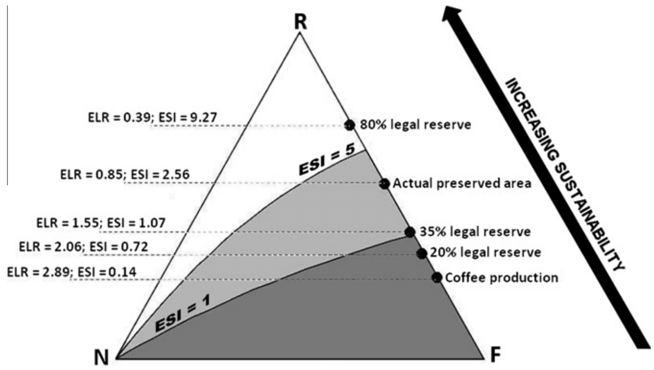


Fig. 2. Emergy ternary diagram representing the coffee production system and the addition of the preserved native area at Santo Inácio farm in 2006. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for long term; the middle part (gray) marks the region (1 < ESI < 5) where systems are sustainable for medium term, and the lower part of the diagram (dark gray) shows a region (ESI < 1) where systems are not sustainable [4]. On the right side of the diagram, values of ELR (environmental loading ratio) and ESI (environmental sustainability indice) can be observed for each situation.

a. "The business as usual" situation, in which coffee is produced and sold on the international market.
b. The situation in which the environmental benefits provided by the preserved native area are considered.

Fig. 3 shows the evaluation of the coffee trade for individual countries. The value of EER = 1, represents equity, where there is no benefit economically and environmentally favorable to the producer or the buyer. The EER for green coffee sold to Japan and USA is higher than one over the whole period. This means that trade with those countries should be more carefully evaluated, because those countries seem to have the largest advantage in emergy terms when trading with Brazil. The trade with Germany was advantageous to Brazil in 1998, 1999 and 2004 indicating that the combination of good market prices and productivity may lead to a fair trade with this country. The same occurs when the green coffee is sold to Italy, except that the average EER_{av} = 1.18 for the 10 years is lower than that of Germany (EER_{av} = 1.63). In this case, Brazil should prefer Italy for future trade. Belgium pays more emergy to Brazil than that received by the coffee bought.

This evaluation offers some possible options to balance the trade of green coffee in the international market. A first option would be to increase the price of exported coffee when trading to USA, Japan, Germany and Italy accordingly to the EER obtained. This would probably be the more direct way to balance the trade.

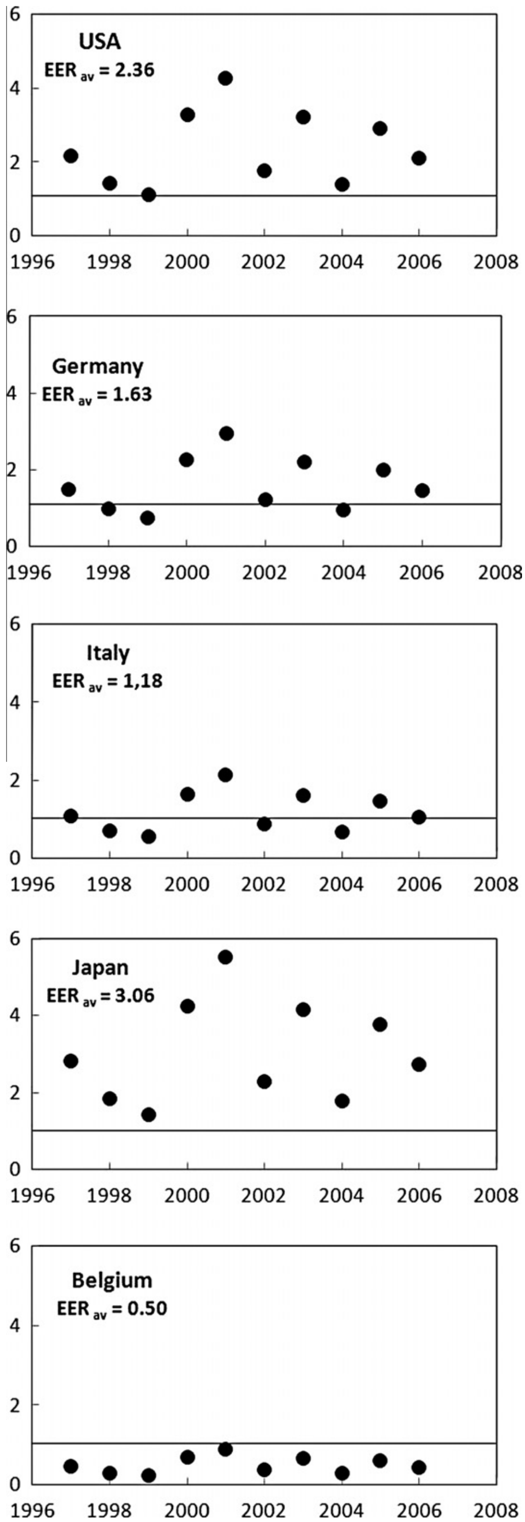


Fig. 3. Emergy exchange ratio (EER) of Santo Inácio farm exportations to USA, Germany, Italy, Japan and Belgium from 1997 to 2006.

However, this does not seem feasible as the coffee market is buyer-driven, and Brazil alone cannot determine the price for coffee. A second option would be the search for countries with similar emergy to money ratio to trade, or a combination of several countries (Fig. 3) with lower average EMR.

Fig. 4 shows the emergy exchange ratio (EER) for trading to the bloc formed by USA, Germany, Italy, Japan and Belgium with

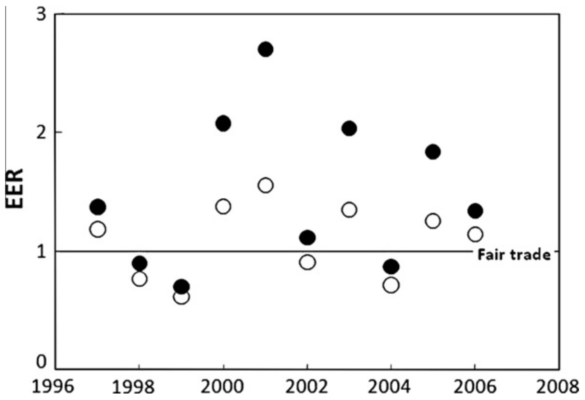


Fig. 4. Emergy exchange ratio (EER) of Santo Inácio farm exportations from 1997 to 2006 considering the actual 80 ha of native preserved area, where (●) represents the actual situation, and (○) represents the case in which environmental services are charged to buyers.

(white circles) and without considering payment for environmental services (black circles).

For the case in which the payment for the environmental services is not included, it can be observed that in the years of 1998, 1999 and 2004 points are below the line EER = 1 (Fig. 4, black circles). This was achieved by combining high productivity and good market prices. In the remaining years, the emergy exchange ratio reveals that purchasers generally benefit when buying green coffee from Santo Inácio farm. This means that the farm exports much more emergy in the green coffee sold than that contained in the money received for the coffee. In 2001, the value of EER = 2.69 indicates that in this year the farm exported nearly three times more emergy to buyers than what was paid for the coffee. Productivity was very low (7 bags/ha) and the market price was also low (US$ 80/bag) compared with the average market price for the 10 years studied (US$ 120/bag). Results show that it is possible to procure a fair price for the sale of green coffee establishing a relationship between productivity and market price (Giannetti et al., submitted for publication). The average EER for the period is 1.51.

For the case in which payment for environmental services is included, a direct option would be to cash in the environmental benefits supplied by the preserved native area (Fig. 4, white circles). The emprice calculated for those services is about 29,300 Em$/year (Table 4). Considering the environmental flows that the farmer takes from nature without payment (about 14,500 Em$/year), a value of approximately Em$ 15,000 remains to be charged to buyers, balancing the trade of green coffee in the international market. This option is equivalent to increasing the price of exported coffee, and this hypothetical sale including environmental services decreased the emergy benefit for purchasers, a situation that resulted in a fairer trade for Santo Inácio farm. In this case, the average EER for the period is 1.3.

3.4. The problem of assigning responsibility for the payments for environmental services (PES)

Payments for environmental services are attracting growing interest as a mechanism to translate non-market values of the environment into real financial incentives. The scientific discussion on mechanisms to perform those payments is still incipient. In many cases, payments for environmental services seem to be used randomly for market-based mechanisms of conservation, charging entrance fees to tourists or eco-certification. A review of the literature showed that there are several approaches currently used to deal with assigning responsibility, and in this section they will be discussed based on the results obtained for Santo Inácio farm.

A geographical-type approach suggests that direct or nearby users are responsible for the payments for environmental services. This approach is taken by Brazilian law which rules that natural areas are to be preserved in order to maintain threatened biomes, and farmers become responsible for the maintenance costs of conservation areas, to obey national regulations. But, in this condition, producers have to "pay" for the environmental services associated with something they will never benefit from, economically. At this point, a contradictory situation arises, because countries which only import green coffee produced in Brazil will benefit from a high standard of living coupled with a very low level of environmental responsibility. In the case of the "business as usual" condition, Santo Inácio farm exports 50% more emergy than that received from the money paid for the green coffee ($EER_{average}$ = 1.5). In the case in which the environmental support is assigned to the farmer, the $EER_{average}$ increases to 1.9, and almost twice the emergy is delivered to the purchaser than is available in the buying power of the payment.

Based on the beneficiary-pays rather than the producer-pays principle, PES were considered as commercial transactions where the environmental service is acquired from the coffee producer (Wunder et al., 2008) or as social transactions where the environmental service is provided by poor or marginalized landholders (Engel et al., 2008). In both cases, Santo Inácio farm should charge importing countries for the extra-emergy not included in current market prices. These considerations drive the discussion to an approach similar to the Ecological Footprint approach (Proops et al., 1999), based on consumers responsibility. Under this beneficiary-type approach, every economic activity has an impact on the planet due to the consumption of goods. A PES program, carried out on this basis, would as a result assign no responsibility to producing countries and a higher burden of obligation upon importing ones. This type of assignment would be fairer, because it would make final users pay for their higher standard of living, but without adequate incentives, policies or regulations, consumers are not usually observant of their environmental responsibilities, despite the fact that they should, in principle, choose producers, who practice environmental preservation and good farming practices. Under this viewpoint, producers are not necessarily encouraged to preserve and maintain environmental services, and it would lower the stimulus for producing countries to preserve native areas and to create better farming practices.

The option proposed in this text indicates the adoption of the emergy accounting method (Odum, 1996) that allows the production process to be divided in several steps and, for each step, a single consumer and producer are defined. Then, consumers and producers would be responsible for a portion of the PES. From this point of view, the emprice calculated for the environmental support and the environmental benefits of the preserved area (Table 4) should be used to establish who bears the responsibility for making payments for environmental services. Fig. 4 shows an attempt to distribute costs where only the conservation area benefits were divided between farmer and consumer. The $EER_{average}$ = 1.3 obtained shows that this distribution is still not enough to balance the trade between the parties. It should be noted that, even without considering the costs for maintaining the native area (business as usual, EER = 1.5) the farm had a 50% loss in the emergy exchange with the importers. However, using the proposed method for cost sharing, it is possible to calculate year by year, the best price to meet both the farmers, and importing countries, needs (Table 5). Note that calculations consider the actual 80 ha of native preserved area, and consequently, medium term sustainability as shown in Fig. 2.

As shown in Table 5, the coffee market is characterized by a chronic oversupply and extreme price volatility due to sudden changes in harvesting expectations (NYBOT, 2004; ITC, 2005;

Table 5
EER values, actual market prices and market prices recalculated to achieve EER = 1 as function of the productivity of each year.

Year	Productivity (bag/ha year)	EER	Actual market prices (US$/bag)	Calculated market prices for EER = 1 (US$/bag)
1997	17	1.37	203.45	153.83
1998	26	0.90	123.18	98.58
1999	41	0.70	103.2	41.63
2000	6	2.08	80	251.43
2001	7	2.70	81.18	355.53
2002	23	1.12	105.28	129.51
2003	3	2.04	135.64	414.18
2004	13	0.87	135.64	83.80
2005	4	1.84	117.72	314.08
2006	22	1.34	116.43	135.10

Ponte, 2002). Environmental support and benefits were considered constant for the period. It is interesting to note that when the farm productivity and market prices were low (2000, 2001, 2003, 2005) the trade was unfavorable to the farmer, but for balancing the trade, importing countries would have been penalized with a price much higher than that practiced in the market. In 1997, the farm produced 17 coffee bags/ha and coffee price in the international market was very high, stimulating investments in productivity. Coffee production increased to 26 bags/ha in 1998 and 41 bags/ha in 1999, but the higher productivity was achieved by the intensive use of chemical fertilizers. In this case, despite of the decrease in coffee prices in 1998 and 1999, trade was advantageous to the farmer, and for a fair trade, importing countries would have paid less for the green coffee. Fairer trade was achieved in 2002 and 2006, when prices to fulfill the condition EER = 1 were closer to those actually found in the international market. In these years, the farmer would have held the responsibility for maintaining the productivity, without intensifying the use of fertilizers, while importing countries would have contributed with reasonable values to the payment for the environmental services.

4. Conclusions

Coffee production and export in the Brazilian savannah (Cerrado) were evaluated using emergy synthesis to assess the environmental support required for sustainable green coffee, the exchange of emergy that the farm obtains from its sales of green coffee on the international market, and the benefits achieved by the conservation of a native area.

Adopting the emergy ternary diagram to assess the coffee production system provided a better understanding of the actual contribution of given inputs and the global sustainability of the coffee production process. According to the calculations performed using emergy synthesis, only a compensation ratio higher than 2:1 would be required to guarantee the sustainability of the coffee production for the long term, and this result could serve as reference for conservation policies. With such an evaluation, society and legislators could judge the costs, benefits, and trade-offs associated with agricultural impacts and mitigation. Furthermore, by using the relative values of ecosystem resources preserved more appropriate compensation ratios might be determined.

The approach presented to assign the responsibility for the payments for environmental services proposes a measure that is a trade-off between consumption and production accounting principles. Unlike most of the initiatives based on the "willingness to pay" approach, emergy synthesis is presented as a more effective tool, because it provides the means to calculate the price of these services with a strong scientific basis. This approach allows the sharing of responsibility among users and producers in an operative and fairer way.

Restoration and maintenance of natural areas are safe, inexpensive, and straightforward solutions in the effort to reduce greenhouse-gas emissions and adjust to unavoidable changes (Turner et al., 2009). But, in general, to achieve such an integrated approach that combines carbon inventory, land use control at the local level, and especially the proof regarding the decline of emissions, means fighting a multitude of compelling short-term political and economic interests. The use of a method that can be managed by producer–consumer accounting, may help to balance interests (environmental–economical–political) involved in decision making about how much to pay for environmental services.

Further studies are necessary to include and to account for other environmental services, such as the maintenance of the biodiversity and natural forests, the mitigation of greenhouse gas emissions; hydrological services, including provision of water for human consumption, irrigation, and energy production; and provision of scenic beauty for recreation and ecotourism. However, the approach proposed herein might be considered as a first step to fulfill the need for a fair accounting method to create an inventory of environmental services which also may help to assign responsibility for the payments.

Appendix A

Different countries have different emergy/US$ ratios, as already shown by Odum (1996), Rydberg and Jansen (2002), and Brown et al. (2003). Balanced trade is accomplished when emergy of imports and exports of trading partners is equal (Brown et al., 2003). However, emergy evaluations often show that such exchanges are not equal (Odum, 1996). Germany, which is a major buyer of the Brazilian coffee has as EMR of about 2.81×10^{12} seJ/US$, while that of Brazil is 1.17×10^{13} seJ/US$ (NEAD, 2009). Then, Brazil has a trade disadvantage of approximately four times trading with Germany. A weighted average EMR for importing countries was calculated for the years 1999–2004 on the basis of the contribution of each country to Brazilian gross domestic product (GDP) at each year. The EMR of the six countries was considered constant for the period of 1999–2004, and the values were taken from NEAD (2009). The weighted average of coffee exports comes from the sum of the weighted averages for the six countries divided by

Table A1
Emergy Money Ratio (EMR) and the gross domestic product (GDP) percentage relative to coffee exports from 1999 to 2004. The weighted EMR of the importing countries is calculated by dividing the total weighted EMR by the total % GDP of coffee exports.

	EMR ($10^{12} \times$ seJ/US$)	% GDP						Weighted EMR per country ($10^{12} \times$ seJ/US$)	% GDP per country
		1999	2000	2001	2002	2003	2004		1999–2004
USA	1.93	0.98	0.40	0.25	0.34	0.35	0.33	5.11	2.65
Germany	2.8	0.93	0.49	0.41	0.44	0.34	0.38	8.37	2.99
Italy	3.85	0.40	0.32	0.23	0.19	0.21	0.19	5.93	1.54
Japan	1.49	0.38	0.28	0.18	0.15	0.16	0.14	1.92	1.29
Belgium	9.17	0.22	0.14	0.11	0.10	0.07	0.09	6.69	0.73
Total								28.03	

the % GDP for the period 1999–2004, and equals 3.05×10^{12} seJ/US$ (Table A1).

Appendix B

Calculation procedure for the evaluation of the preserved native area presented in Table 4.

1. Rain, chemical potential energy:

Land area = 80 ha.
Average annual precipitation = 1100 mm/year.
Water flow = 1.1 m $\times$ 80 ha $\times$ 10^4 m^2/ha = 8.8 $\times$ 10^5 m^3/year.
Energy = 8.8 $\times$ 10^5 m^3/year $\times$ (Gibbs free energy, 4.94 $\times$ 10^3 J/kg) = 4.35 $\times$ 10^{12} J/year.
Transformity = 3.06 $\times$ 10^4 seJ/J (Buenfil, 2001).
Emergy = 1.33 $\times$ 10^{17} seJ/year.

2. Water driving the river source: as the source of the river is within the property, the value of flow rate was used for calculation:

River flow = 6.48 $\times$ 10^4 m^3/year.

Transformity = 5.43 $\times$ 10^{11} seJ/m^3 (Buenfil, 2001).
Emergy = 3.52 $\times$ 10^{16} seJ/year.

3. Land structure: As part of the main sedimentary cycle of the Earth, many types of sedimentary rocks are brought to the surface in different places. The adopted value of the sediment cycle was 2.4 cm per 1000 years and rock density of 2.6 g/cm (Odum, 1996, p. 46). Oxisols are soils with a high degree of weathering, with generally low chemical fertility, physical properties but with very favorable to plant growth and agricultural production. The Cerrados's Oxisols (from 600 to 800 g kg of clay) have high rates of water infiltration and aeration porosity, and low density of the soil in its natural state, due to their aggregation (Demattê et al., 1996; Azevedo and Bonumá, 2004). The flux of the sedimentary cycle is:

(2.4 $\times$ 10^{-3} cm/year) $\times$ (2.6 g/cm^3) $\times$ (80 ha) $\times$ (10^8 cm^2/ha) = 4.99 $\times$ 10^7 g/year Emergy = 4.99 $\times$ 10^7 g/year $\times$ 0.7 (clay; Demattê et al., 1996) $\times$ 3.36 $\times$ 10^9 seJ/g (Odum, 1996) + 4.99 $\times$ 10^7 g/year $\times$ 0.3 (sandstone; Demattê et al., 1996) $\times$ 1.68 $\times$ 10^9 seJ/g (Odum, 1996) = 1.51 $\times$ 10^{17} seJ/year.

4. Evapotranspiration: Evapotranspiration rates were estimated by a waterbalance equation:

$\mathrm{ET} = \Delta\mathrm{VWC} + P - D$

where ΔVWC is the change in volumetric water content in the soil profile between successive field measurements; P is precipitation; and D is drainage out of the measured profile over the same period (Oliveira et al., 2005). The area was characterized as Cerrado denso, which is a semi-closed canopy vegetation type with tree cover of ≅70%, and tree height from 5 to 9 m.

For *Campo denso* vegetation, evapotranspiration (Oliveira et al., 2005) in the Cerrado may vary from 0.8 mm/day (dry season) to 5.3 mm/day (wet season). The average value was taken for calculations:

Evapotranspiration = (3.05 L/m^2 day) $\times$ (10^{-3} L/m^3) $\times$ (80 ha) $\times$ (10^4 m^2/ha) $\times$ 365 day/year) = 8.91 $\times$ 10^5 m^3/year.
Energy = (8.91 $\times$ 10^5 m^3/year) $\times$ (Gibbs free energy, 4.94 J/mL) $\times$ (10^6 mL/m^3) = 4.40 $\times$ 10^{12} J/year.
Transformity = 2.69 $\times$ 10^4 seJ/J (Odum, 1996).
Emergy = 1.18 $\times$ 10^{17} seJ/year.

5. Gross primary product (GPP): Savannah like vegetation produces 0.7 kg/m^2 year of biomass (Prado-Jatar and Brown, 1997):

Energy = (0.7 $\times$ 10^3 g/m^2 year) $\times$ (3.6 kcal/g) $\times$ (4186 J/kcal) $\times$ (80 ha) $\times$ (10^4 m^2/ha) = 8.44 $\times$ 10^{12} J/year.
Transformity = 1.67 $\times$ 10^4 seJ/J (Ulgiati and Brown, 2009).
Emergy = 1.41 $\times$ 10^{17} seJ/year.

6. Infiltration: calculated by the energy difference between rainfall and evapotranspiration, as one of the limiting factors in the Cerrado is water deficiency, which occurs due to poor distribution of rainfall, intense evapotranspiration and soil characteristics that have a low capacity for water retention and high infiltration rate.

$V_{\mathrm{rain}} = V_{\mathrm{evapotransp}} + V_{\mathrm{infiltration}}$

Evapo-tanspitation: from January to August (dry season) 1.3 m/day (Oliveira et al., 2005) and from October to December (wet season) 3.8 mm/day.

$V_{\mathrm{evapotransp}}$ = [(1.3 mm/day) $\times$ (243 day) $\times$ (80 ha) $\times$ (10^4 m^2/ha)] + [(3.8 mm/day) $\times$ (122 day) $\times$ (80 ha) $\times$ (10^4 m^2/ha)].
$V_{\mathrm{evapotransp}}$ = 6.24 $\times$ 10^5 m^3/year.
$V_{\mathrm{infiltration}}$ = (8.8–6.24 $\times$ 10^5) m^3/year = 2.56 $\times$ 10^5 m^3/year.
Transformity = 6.85 $\times$ 10^{11} seJ/m^3 (Buenfil, 2001).
Emergy = 1.75 $\times$ 10^{17} seJ/year.

7. River flow = 6.48 $\times$ 10^{10} g/year.
Transformity = 8.15 $\times$ 10^{14} seJ/g.
Emergy = 2.61 $\times$ 10^{16} seJ/year.

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