25

Emergy Accounting of a Coffee Farm in the Brazilian Savannah

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ABSTRACT

Cerrado, a savannah region, is the second largest ecosystem in Brazil after the Amazon rainforest. Also, it is threatened with imminent destruction. 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 savannah. The emergy ternary diagram was employed to monitor coffee production from 1997 to 2006 and to present environmental indicators as a function of annual crop. As Cerrado´s farms production is primordially for export, the evaluation of the environment and economic changes with importing countries was performed. Brazilian law establishes that, in this region, for crop production twenty percent of native land must be maintained. The assessment of the native area within the farm was carried out in order to determine the environmental sustainability index of the farm, composed by a productive and a preservation area. Results show that the farm with 54 ha of productive area must count with two hundred hectares of native land for medium term sustainability.

INTRODUCTION

Historically, coffee production in Brazil has been marked by several cycles of territorial occupation and environmental imbalance caused by disordered replacement of natural ecosystems and soil degradation by broad farming areas. The share of coffee in total exports declined from 70% at the end of the 1920s to around 40% in the 1960s, to less than 10% in the 1980s and around 5% in the 1990s (Paiva, 2000). Coffee had many secondary effects on Brazilian economy history such as the campaign for slavery abolition, employment of free immigrant labor, foreign investment in infrastructure, capital accumulation of coffee growers, and the derived growth of industry (Baer, 2001). Since the second half of the nineteenth century Brazil is a leading exporter of coffee. Despite of representing only 5% of the country's total exports, Brazilian green coffee production reached 2,000,000 tons in 2007, and there was an increase of 23% in weight for 2008 (IBGE, 2008).

In the present days, most quality Brazilian coffee comes from the Southern Minas Gerais, Mogiana, Cerrado and Matas de Minas regions, more specifically, from micro-climates within those regions. Cerrado is a savannah-like area, dry and flat, in Minas Gerais state. The savannah region is known for its rich biodiversity, but it is also a place of coffee and soy plantations and other agricultural activities.

Regarding the use of resources, Sarcinelli and Ortega (2004) pointed out that better economic results could be achieved when small coffee producers made larger use of their renewable natural resources. Cuadra and Rydberg (2006) carried out an emergy evaluation on the systems of coffee production, processing and export in Nicaragua in order to evaluate the environmental contributions to the tradable products and, thus, to enrich the discussion about fair trade. These authors report that Nicaragua exports more emergy in the green coffee sold than it imports in the money received for the coffee.

Nowadays, compensatory mitigation is a usual practice; however, there is no clear understanding of the benefits or losses resulting from this practice. In Brazil, the legal reserve was

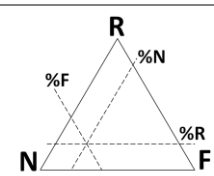
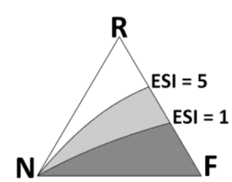
established (Federal Law No. 4771, 1965) to ensure the conservation of Cerrado restraining the land use by rural properties. Legal reserves and areas of permanent preservation aim to conserve and restore ecological processes, biodiversity and to protect wildlife and native flora. Current environmental legislation establishes a minimum percentage between 20% and 35% of legal reserve for farms located in Cerrado. Emergy accounting of non-marketed ecosystems such as legal reserves may fill a gap, and it is widely practiced in valuating ecosystems' services (Pereira and Ortega, 2010; Chen et al., 2009; Liu et al., 2009; Odum, 1995ab) and agriculture (Lagerberg and Brown, 1999; Qin et al., 2000; de Barros et al., 2009; Agostinho et al., 2008; Cavalett and Ortega, 2009, Bonilla et al., 2010).
This study focuses on Cerrado that produces most of the 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 in order to: (a) assess the environmental support to green coffee, (b) evaluate the exchange of emergy that farm obtains from sales of green coffee on the international market, and (c) evaluate the benefits achieved by the preservation of a native area.

METHODOLOGY

Emergy, a measure of real wealth, is defined as the sum of the available energy, i.e., the type previously required directly and indirectly through 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. Emergy evaluation tables, prepared according to the procedures described by Odum (1996), were used to estimate each production process of incorporated energy into its production as a way to evaluate the sustainability of the farm. Emergy evaluation was performed to monitor coffee production from 1997 to 2006. Results are shown in the ternary emergy diagrams, generated by a graphical tool (Giannetti et al., 2006; Almeida et al., 2007). Some functionalities of this tool used in this work are presented in Table 1, other functionalities can be found in (Giannetti et al., 2006; Almeida et al., 2007).

The emergy exchange ratio (EER) 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 price paid for coffee, the EER was calculated. USA, Germany, Italy, Japan and Belgium represent about 60% of total exports of Cerrado's coffee (MDIC, 2008). For the total exports, the weighted average of these countries' emergy money ratios (EMRs), considering the percentages of coffee exported to each of them, was calculated as 3.05×10^{12} seJ / US$ (Appendix 1).

Table 1. Functionalities of the emergy ternary diagram used in this text.

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 permits to draw lines indicating constant values of the sustainability index. The sustainability lines depart from the N apex in direction to the RF side allowing the division of the triangle in 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 long term; the middle part (grey) marks the region (1 < ESI < 5) where systems are sustainable for medium term, and the lower part of the diagram (dark grey) shows a region (ESI < 1) where systems are not sustainable.	

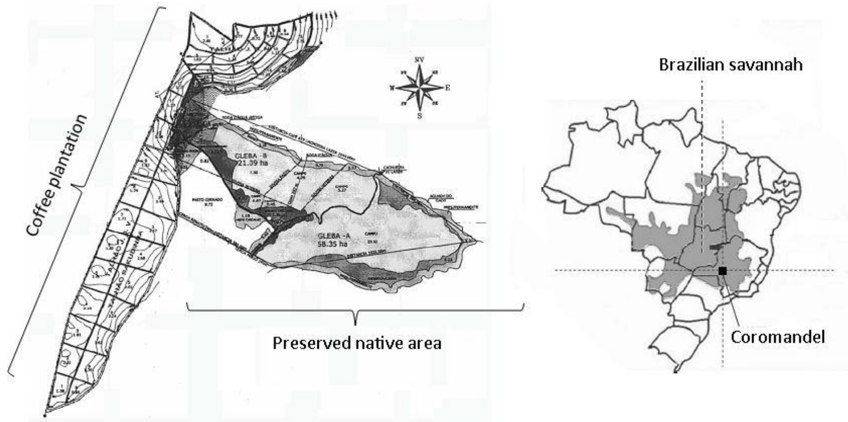


Figure 1. *Santo Inácio farm with the coffee plantation and the preserved native area, and Brazilian map with the location of Cerrado (gray area) and the municipality of Coromandel.*

Coffee production data were obtained from Santo Inácio coffee farm at Coromandel, in the Cerrado region (Figure 1), which produces green coffee exclusively for exportation (Cerrado Coffee). The coffee farm has a total area of 140 hectares, of which 54 hectares are planted with 160,000 coffee trees (*Coffea arabica L.*). The effects of land use on sustainability were evaluated by comparing the emergy indices along ten years. Figure 1 shows the Brazilian map with the location of Cerrado (Brazilian savannah), the municipality of Coromandel, and the farm area with the coffee plantation in the left and the preserved native area on the right.

Compensatory mitigation is already practiced at the farm and the preserved area is about six times larger than that required by the Brazilian law. Regulations pertaining to mitigation, as Brazilian laws, lack of objective means of quantitatively determining appropriate mitigation ratios. As a result, some questions arise: (1) how might the various resources and services of native areas be evaluated? (2) what services of native areas are the most valuable? (3) What is the appropriate size of compensatory areas? Santo Inácio farm uses an area of 54 ha for coffee production and preserves an area of 80 hectares of natural forest and native vegetation (Figure 1). The left side of Figure 1 shows the coffee plantation area, and on the right the area with native vegetation. In this area there is a springhead from which a river flows along the boundary of the property.

RESULTS AND DISCUSSION

Figure 2 presents an overview of the coffee production area using energy system symbols. The systems diagram shows the energy sources driving the processes and system boundaries. The different energy sources were aggregated. Environmental resources are shown on the left-hand side of the diagram. Purchased energies such as fuel and electricity, chemicals, labor, and machinery are shown on the top of the diagram. Each processing step was evaluated and indicated in Table 2.

The cultivation of coffee in Santo Inácio Farm started in 1970, with the first harvesting in 1973. In 1996, a renewal process of the plantation began, ending in 2005. The coffee production system evaluated was a conventional production system where coffee bushes are grown in alleys. After gathering the fruits, coffee cherries are dried and the outer covering of the fruit is removed (preprocessing). The final product is green coffee that is packed in 60 kg bags and stored in a Cooperative of Producers.

The environmental accounting was performed from 1997 to 2006, generating ten emergy tables, and enabling the evaluation of environmental and economic resources employed in the system over ten years. Table 2 shows the emergy table corresponding to the year of 2006. The other nine tables may be requested to the authors.

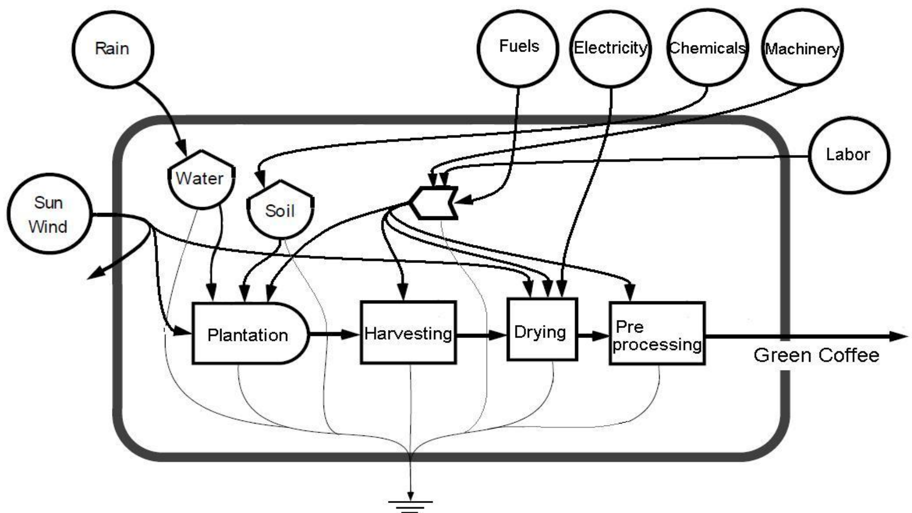


Figure 2. *System diagram of coffee production, processing and exportation at Santo Inácio farm. The emergy evaluation is performed for coffee production, coffee cherries harvesting, coffee cherries drying, and preprocessing.*

For green coffee production system (Table 2) in 2006, purchased services contributed with almost 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 green coffee production. Emergy per unit calculated for green coffee was 5.85 x 10^9 seJ/g.

The total amount of emergy at the plantation phase corresponds to 2/3 of the emergy required to put green coffee at farm's gate. During harvesting, there are only contributions provided by the economic system and direct labor force is responsible for 21% of the emergy required at this stage. Drying process uses nature's free resources (sun, kinetic energy of wind and evaporation), but their contributions to the total emergy are very low, less than 1% seJ/seJ. No direct renewable emergy flows were identified in preprocessing phase, and the non-renewable flows contribute with less than 1% of the total emergy demand for green coffee production.

Table 3 shows the more significant resources annually used at Santo Inácio farm from 1997 to 2006, and the quantity of coffee bags produced per hectare during the ten years studied. Renewable resources and resources from outside the system are shown as percentage terms of the total emergy for each year.

Chemical fertilizers and labor are the most important economic resources used during green coffee production. Diesel and lubricants contribute with 3% to 9% of the total emergy. The higher use of fertilizers in the years 1997, 1998 and 1999 increased the productivity in these years. The higher quantities of organic fertilizers employed in 1997 and 2002 increased the percentage of renewable resources use, increasing system's environmental sustainability.

Evaluation of emergy indices based on coffee productivity

A summary of the calculated indices for the different years of coffee production is presented in Figure 3. Figure 3A shows the EYR as a function of the farm's productivity. EYR decrease with the increase in productivity, indicating a decrease of the ability to exploit local resources. Figure 3B shows the increase of EIR values with increasing productivity. This behavior is expected because of higher productivity is achieved by the intensive use of resources provided by the economy, especially chemical fertilizers. ELR values also increase as production increases, indicating the higher pressure exerted by the system in the environment.

Table 2. Emergy table for the coffee production in Santo Inácio farm, 2006.

Item	Description	Unit	Class	Annual flow/ (unit/year ha)	Emergy per unit/ (seJ/unit)	Emergy/ (seJ/year ha)	%/ (seJ/seJ)
	Plantation						
1	Sun	J	R	5.97×10^{13}	1	5.97×10^{13}	1
2	Wind, kinetic energy	J	R	6.45×10^{6}	2.52×10^{3}	1.63×10^{10}	<1
3	Rain, chemical energy	J	R	4.27×10^{10}	3.06×10^{4}	$1,31 \times 10^{15}$	19
4	Rain, geo potential 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	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					$\mathbf{5.94 \times 10^{15}}$	**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	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					$\mathbf{1.95 \times 10^{15}}$	**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	Yard	g	F	3.33×10^{4}	2.42×10^{9}	8.06×10^{13}	1
25	Granary	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	J	F	2.05×10^{7}	4.30×10^{6}	8.82×10^{13}	1
	Total for drying					$\mathbf{3.62 \times 10^{14}}$	5
	Preprocessing						
28	Machinery and equipment	g	F	8.89×10^{2}	6.70×10^{9}	5.96 x 1012	<1
29	Labor	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					$\mathbf{1.05 \times 10^{14}}$	**1**
	Total production	kg		1.20×10^{3}	5.85×10^{12}	$\mathbf{7.02 \times 10^{15}}$	100

Table 3. Coffee production per hectares and the main contributions to the total emergy of Santo Inácio farm from 1997 to 2006.

Year	Coffee production /(bags/ ha)	% Resource use / (seJ/seJ)							
		Rain, chemical energy	Organic fertilizer	**Renewables subtotal**	Labor	Chemical fertilizer	Fuel	Others	**Economic subtotal**
1997	17	11	17	**28**	19	47	3	3	**72**
1998	25	17	2	**19**	28	41	3	9	**81**
1999	40	15	-	**16**	26	46	4	9	**85**
2000	6	22	-	**22**	39	24	6	9	**78**
2001	7	24	-	**24**	43	19	4	10	**76**
2002	23	19	6	**25**	33	26	5	9	**75**
2003	3	23	-	**23**	39	23	6	9	**77**
2004	13	22	1	**23**	39	23	4	11	**77**
2005	5	22	2	**24**	40	21	6	10	**76**
2006	22	19	1	**20**	24	28	9	19	**80**

Figure 4 shows clearly the relationship between production yield and environmental performance. Transformity may be interpreted as the inverse of efficiency, called here global productivity (GP). Thus, the point corresponding to 1997 lies in a region where ESI and GP are high. In the same way, the point for 2006 is located in a region where both GP and ESI are high. The analysis of Figure 4 shows that there is an optimum interval for coffee production at Santo Inácio farm (10 < coffee bags/ha < 25), where GP and environmental performance are maximized. If the quantity of coffee bags is lower than 10, the ESI is high, but GP is low. For the point corresponding to 1999, the efficiency is high, but the sustainability indice is low. Thus, if the production per hectare exceeds 25 coffee bags, the GP highly dependent on economic investment increases, disfavoring the environmental performance. In contrast, if production is lower than 10 bags per hectare, the environmental stress is low, but the efficiency related to the resource use is also low. According to this data, Santo Inácio farm would have to produce approximately 20 bags of green coffee per hectare to accomplish its best performance, regarding both the production efficiency and the environment.

Accompanying the environmental performance along time using the emergy ternary diagram may give additional information on the Brazilian coffee farm. Figure 5 shows the emergy ternary diagram containing production data from 1997 to 2006. All points are located within a region characteristic of agricultural systems shown by the dashed triangle (Guarnetti et al, 2007). In 1997, the farm produced 17 coffee bags. With increase of the economic investment, production increased to 26 bags in 1998 and 41 bags in 1999, but the environmental load (ELR) increased to the double (Fig.5). All other indices got worse as well, which is promptly observed in the diagram by the points shifting in direction to the F apex. Observing the point corresponding to the production of 2006, when 22 bags were produced, it is easy to note that there is a relationship between the production yield and the environmental performance.

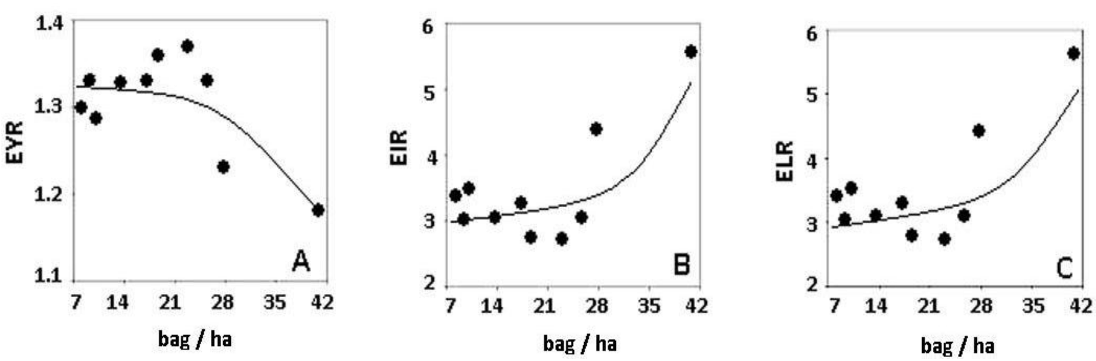


***Figure 3**. Emergy indices as function of Santo Inácio farm productivity. Production is accounted in bags of coffee of 60 kg.*

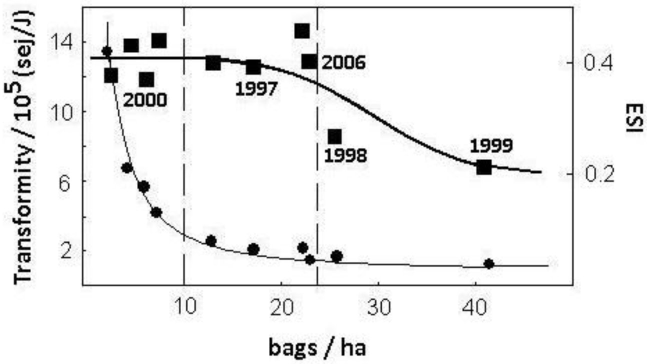


Figure 4. *Transformity (●) and ESI (■) as function of coffee bags produced in Santo Inácio coffee farm from 1997 to 2006.*

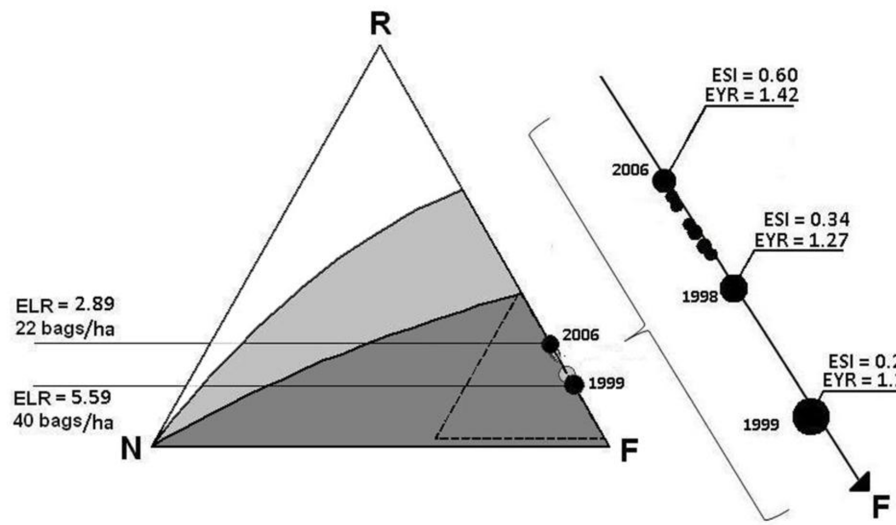


Figure 5. *Emergy ternary diagram for accompanying the coffee production systems in Brazil from 1997 to 2006. On the right, the augmentation of the RF axis is shown. The size of the circles is proportional to the productivity of each year. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for long term; the middle part (grey) marks the region (1 < ESI < 5) where systems are sustainable for medium term, and the lower part of the diagram (dark grey) shows a region (ESI < 1) where systems are not sustainable.*

A high ELR indicates the system's distance from the state of environmental equilibrium, and a high dependency from outside or a high degree of support from outside. This is observed for the year of 1999 when 85% of the total emergy was provided by resourced from outside the system (Table 3). But, it is also important to make clear that a high ELR does not necessarily indicate a stress or load that leads to environmental degradation. The farm becomes non-sustainable due to the inputs if they are not likely to last.

Evaluation of environmental and economic exchanges

All the green coffee produced in the farm is exported to other countries, and there are no sales to the local industry. Sales are usually done between harvesting periods in the months of March and April, with the aim of optimizing the bag's price. The coffee is sold in U.S. dollars for several countries through the Cooperative of Producers. Accordingly to the Brazilian Ministry of Industry and Commerce, about 60% of total exports go to USA, Germany, Italy, Japan and Belgium (MDIC, 2008).

Different countries have different emergy/US$ ratios, as already shown by Odum (1996), Rydberg and Jansen (2002), and Brown (2003). Balanced trade is accomplished when emergy of imports and exports of trading partners is equal (Brown, 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 x 10^{12} seJ/US$, while that of Brazil is 1.17 x 10^{13} seJ/US$ (Sahel, 2000). Then, Brazil has a trade disadvantage of approximately 4 times trading with Germany. A weighted average EMR for importing countries was calculated for the years 1999 to 2004 (Appendix 1).

Figure 6 shows the emergy exchange ratio (EER) for trading to the bloc formed by USA, Germany, Italy, Japan and Belgium. The value of EER = 1, represents the equity where there is no benefit economically and environmentally favorable to the producer or the buyer. In the years of 1998, 1999 and 2004 points are below the line EER = 1 and 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 for buyers than that was paid for the coffee. In this year the 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 ten years studied (US$ 120/bag). The results of 1998, 1999 and 2004 show that it is possible to procure a fair price for the green coffee sales establishing a relationship between the quantities sold and the market price.

Accounting the preserved native area

According to Odum (1996) as part of the environmental management and development, an ecosystem can be exchanged for another, requiring for this a quantitative basis for establishing the equivalence between ecosystems. However, regulations pertaining to compensation are puzzled by a lack of a clear means of quantitatively determining appropriate compensatory areas, and for legislators it is difficult to determine a proper area for preservation.

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 Cerrado limiting land use by rural properties. 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 between 20% and 35% of legal reserve was established for farms located in Cerrado by the current environmental legislation. In legal reserves 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).

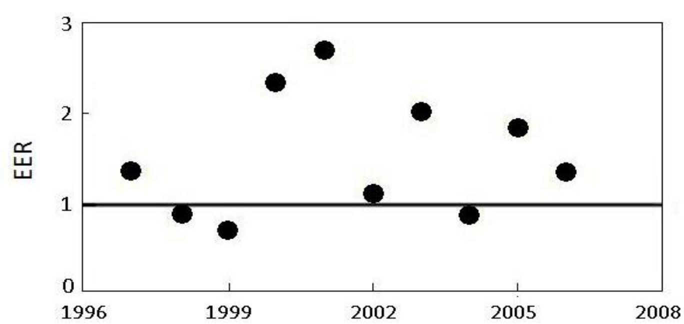


***Figure 6**. Emergy exchange ratio (EER) of Santo Inácio farm exportations from 1997 to 2006.*

Emergy accounting can determine the environmental values of the whole systems. With such an evaluation, society and legislators could judge costs, benefits, and trade-offs associated with agriculture impacts and mitigation. Furthermore, by using the relative values of ecosystems resources preserved more appropriate compensation ratios might be determined.

Figure 7 shows the system diagram of the native preserved area at Santo Inácio farm. The main driving energies, environmental services, and storages (natural capital) were evaluated. The dominant driving energies of the ecosystem are: rainfall, the emergy contribution from geologic processes to land structure formation, and 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 land structure and underground water resulting in the river that borders the property. A summary of the evaluation of preserved native area is presented in Table 4, while calculation procedure is shown in Appendix 2.

Annual driving emergy for the area was the sum of rain, geologic input and land structure, and represents 2.12 x 10^{15} seJ/ha year. The main driving emergy of the native area was rain, which contributed nearly 75 times for the emergy of geologic input for land structure. Environmental services contribute with 4.28 x 10^{15} seJ/ha year. The emergy of infiltration is high (1.75 x 10^{17} seJ/year), but the value is consistent with Cerrado soil composition. Cerrado's oxisols are recognized as soils that have, among other characteristics, low water retention, due mainly to the composition of a clay fraction and presence of granular-type structure. GPP value was approximately the same of infiltration value.

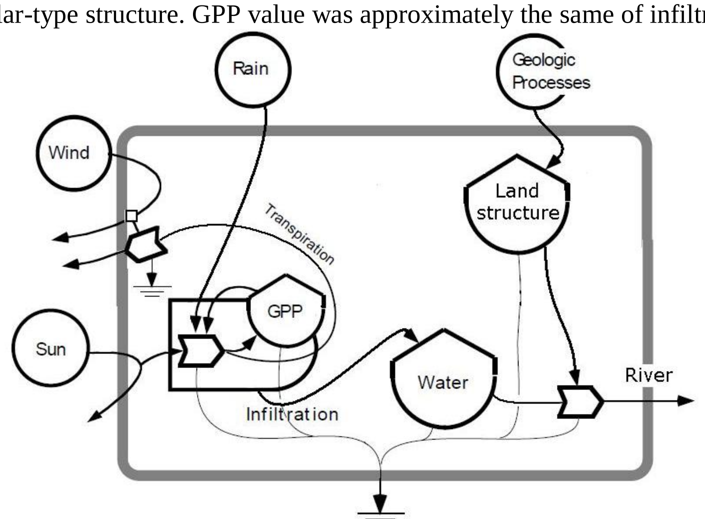


Figure 7. *System diagram of the preserved native area at Santo Inácio farm. The river source is represented by the interaction symbol. GPP = Gross Primary Production.*

Table 4. Evaluation of the preserved native area considering the use of environmental support and the environmental benefits (water exportation and biomass production).

		Emergy / (seJ/year)
	Environmental support	
1	Rain	1.33 10^{17}
2	River source	3.52 10^{16}
3	Land structure	1.76 10^{15}
	Environmental benefits	
4	Transpiration	2.71 10^{14}
5	GPP	1.41 10^{17}
6	Infiltration	1.75 10^{17}
7	River flow	2.61 10^{16}

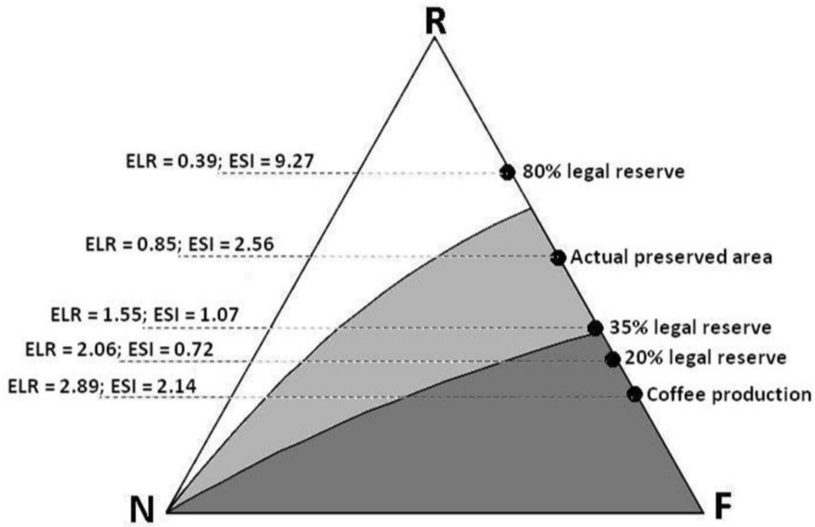


Figure 8. *Emergy ternary diagram representing the coffee production system and the addition of the preserved native area at Santo Inácio farm in 2006. The upper part of the diagram (white) shows the region (ESI > 5) where systems are sustainable for long term; the middle part (grey) marks the region (1 < ESI < 5) where systems are sustainable for medium term, and the lower part of the diagram (dark grey) shows a region (ESI < 1) where systems are not sustainable.*

Under current regulations, the percentage of 20% of legal reserve is required to Santo Inácio farm. 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.

By the observation of the emergy ternary diagram, it becomes clear that as the percentage of native preserved area increases, the environmental load of the system decreases and the environmental sustainability index increases (Fig. 8). If the farm had only an area of 20% of legal reserve, it would be not sufficient to guarantee its sustainability for a long term, as ESI of this system would be 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 Brazilian regulations, despite of being considered severe by most farmers, are not enough to assure Cerrado's sustainability for a long term. The actual condition of Santo Inácio farm, with 80 ha of preserved native area, may serve as a warrant that it will perform satisfactorily for a medium term period. However, to achieve long term sustainability, the preserved native area should be superior to approximately 70% of the total area. For 80% of preserved native areas, the farm would be complying with the legislation for rural properties in the Amazon rainforest, and its area should be increased to 216 hectares. The results obtained for coffee are consistent with that obtained by Pereira and Ortega (2010). These authors, using the renewable empower density for sugarcane production, estimated that only 30% of the area should be cultivated, while the other 70% should be maintained as native vegetation.

CONCLUSIONS

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

Regarding the resource use for coffee production, chemical fertilizers and labor are the most important economic resources used. Diesel and lubricants contribute with less than 10% of the total emergy. The higher use of fertilizers increases the productivity, jeopardizing sustainability. An optimum interval for coffee production at Santo Inácio farm (10 < coffee bags/ha < 25) was proposed in order to maximize resource use efficiency and environmental performance. The evaluation of environmental and economic exchanges shows that foreign purchasers generally benefit when buying green coffee from Santo Inácio farm, but that it is also possible to procure a fair price for green coffee sales establishing a relationship between quantities sold and market price. Environmental services provided by native preserved area contribute with to the whole system with 4.28 10^{15} seJ/ha year, and the main contributions are associated to infiltration and to biomass production (GPP).

Adopting the emergy ternary diagram to assess coffee production system provided a better understanding of the actual contribution of given inputs and the global sustainability of the production process. If the farm had only an area of 20% of legal reserve, as required by the present Brazilian laws, it would be not sufficient to assure its sustainability for long term, as its ESI would be lower than one. The actual condition of Santo Inácio farm, with 80 ha of preserved native area, guarantees medium term sustainability. However, to achieve long term sustainability, the preserved native area should be superior to approximately 70% of the total area.

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APPENDIX 1

The EMR of the six countries was considered constant for the period of 1999 to 2004, and the values were taken from http://sahel.ees.ufl.edu/. A weighted average was calculated on the basis of the contribution of each country to Brazilian GDP at each year. The weighted average of coffee exports comes from the sum of the weighted averages for the six countries divided by the % GDP for the period 1999 to 2004, and equals 3.05 x 10^{12} seJ/US$.

	EMR x 10^{12}/ (seJ/US$)	1999 % GDP	2000 % GDP	2001 % GDP	2002 % GDP	2003 % GDP	2004 % GDP	Weighted EMR per country x 10^{12}/ (seJ/US$)	1999-2004 %GDP per country
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**	**9.2**

APPENDIX 2

1. Rain, chemical potential energy: land area = 80 ha; average annual precipitation = 1100 mm/year.
Water flow = 1.1m x 80 ha x 10^4 m^2/ha = 8.8 10^5 m^3/year.
Energy = 8.8 10^5 m^3/year x (Gibbs free energy, 4.94 10^3 J/kg) = 4.35 x 10^{12} J /year
Transformity = 3.06 x 10^4 seJ/J (Buenfil, 2001).
Emergy = 1.33 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 x 10^4 m^3/year
Transformity = 5.43 10^{11} seJ / m^3 (Buenfil, 2001).
Emergy = 3.52 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 1,000 years and rock density of 2.6 g/cm^3 (Odum 1996, page 46).
Energy = (2.4 x 10^{-3} cm/year) x (2.6 g /cm^3) x (80 ha) x (10^8 cm^2/ha) x (Gibbs free energy, 611 J/g) = 3.05 10^{10} J/year
Transformity = 34,377 x 1,68 = 5.78 10^4 seJ/J (Odum, 1996).
Emergy = 1.76 10^{15} seJ/year

4. Transpiration: Savannah like vegetation absorbs 17 t of carbon per hectare per year (Chen et al, 2003).
$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$
←----- (transpiration)
Transpiration = (108 g/mol) / (72g/mol) x (17 t/ha year) x (80 ha) x (10^3 m^3/t) = 2.04 10^3 m^3/year
Energy = (2.04 10^3 m^3/year) x (Gibbs free energy, 4.94 J/ml) x (10^6 ml/m^3) = 1.00 10^{10} J/year
Transformity = 2.69 10^4 seJ/J (Odum, 1996).
Emergy = 2.71 10^{14} 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 10^3 g /m^2 year) x (3.6 kcal/g) x (4,186 J/kcal) x (80 ha) x (10^4 m2/ha) = 8.44 10^{12} J/year
Transformity = 1.67 10^4 seJ/J (Ulgiati and Brown,2009)
Emergy = 1.41 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.
$V_{rain} = V_{evapotransp} + V_{infiltration}$
Evapotranspiration: 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.
$V_{evapotransp}$ = [(1.3 mm/day) x (243 day) x (80 ha) x (10^4 m^2/ha)] + [(3.8 mm/day) x (122 day) x (80 ha) x (10^4 m^2/ha)]
$V_{evapotransp}$ = 6.24 10^5 m^3/year
$V_{infiltration}$ = (8.8 10^5 – 6.24 10^5) m^3/year = 2.56 10^5 m^3/year
Transformity = 6.85 10^{11} seJ/m^3 (Buenfil, 2001)
Emergy = 1.75 10^{17} seJ/year

7. River flow= 6.48 x 10^{10} g/year
Transformidade = 8,15 10^{14} seJ/g, Emergia = 2.61 10^{16} seJ/year