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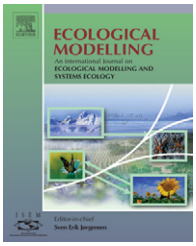

# The use of emergy assessment and the Geographical Information System in the diagnosis of small family farms in Brazil

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ABSTRACT

In this work, emergy analysis was used in association with the Geographical Information System (GIS) in order to improve the evaluation of family-managed farms that adopt either the ecological or the chemical production models. Three small farms, located in Amparo County, in São Paulo state, Brazil, were studied. One of them, Duas Cachoeiras farm, uses agroecological concepts for its agricultural production. The two others (Santa Helena farm and Três Lagos farm) use the conventional chemical model. In an attempt to improve the precision of the data used in emergy analysis, the Universal Soil Loss Equation (USLE) was incorporated to the GIS tool to calculate the topsoil loss in the farms. The GIS tool also allowed the calculation of the amount of rain water that infiltrates the ground and can recharge the aquifer. This percolated water is a system output and was incorporated in the emergy accounting. Another modification in comparison to previous emergy analyses was that the renewability factor of each input was considered in the emergy accounting. Results showed that the agroecological farm is more sustainable and can be used as a model for small farms in their transition to ecological agriculture. The GIS–emergy tools were used to compare the environmental performance of the four main productive areas of Duas Cachoeiras farm (annual cultures, orchard, forest, and pasture). These results demonstrate the emergy performance of each kind of land use and may be used in watershed planning.

## 1. Introduction

A wrong, widespread idea is that in order to solve the famine problem, it is necessary to increase agricultural production and that this increase can only be achieved through the use of more industry-made chemicals (using fossil fuels). We may believe that there is, in fact, enough food, and that the problem comes not from production but from distribution; better still, it is a problem of the production and consumption model. So the problem is not technological but political.

The chemical agriculture establishes a vicious cycle: chemicals destroy the topsoil quality (structure, organic matter content, pH, micro-biota, rain drop protection); therefore, the ground absorbs less water and becomes nutrient-deficient and vulnerable to erosion. The soil loses ecological functions and decreases in quantity and quality.

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In a future perspective where no fossil fuels are available, food production will have to be supported by renewable resources. This situation brings uncertainties about the limits for human existence on the planet (MEA, 2005; Wackernagel et al., 1999; WCED, 1987; Meadows et al., 1972).

It is necessary to adopt agroecological procedures and to prepare new assessment tools to diagnose farms in a fast and efficient way. This analysis should consider the resources from human economy as well as all contributions from nature to produce the output and absorb environmental impacts. The emergy methodology was proposed by Odum (1996) for system analysis, accounting, and diagnosis. The methodology was improved during the last decade. Emergy measures of natural and economic resources are expressed in a common basis: solar equivalent Joules (seJ). Emergy analysis is based on Biology Energetics (Lotka, 1922), General Systems Theory (Von Bertalanffy, 1968) and Systems Ecology (Odum, 1983). Several ecosystems and economic systems emergy evaluations were made all over the world (Brown and Ulgiati, 2004; Higgins, 2003; Brown and Buranakarn, 2003; Yang et al., 2003; Lefroy and Rydberg, 2003; Qin et al., 2000; Panzieri et al., 2002, 2000; Ulgiati and Brown, 1998), as well as theoretical studies and discussions (Herendeen, 2004; Hau and Bakshi, 2004; Brown et al., 2004; Bastianoni and Marchettini, 2000). However, there are few emergy studies that evaluate agricultural production (Ortega et al., 2002; Martin et al., 2006; Castellini et al., 2006), especially of small family farms, which have singular characteristics.

The objective of this research is to demonstrate that emergy analysis can show farm performance more clearly with the support of Geographical Information Systems, and to suggest better management practices for the improvement of farming systems.

## 2. Methodology

### 2.1. Description of the farming systems

Two agricultural production models were compared: (a) the chemical or conventional model, which has the increase of economic profit as its unique objective, and (b) the agroecological model, that envisions sustainable development. Three agricultural farms located in Amparo County, São Paulo state, Brazil (Fig. 1) were evaluated: Duas Cachoeiras farm (29.7 ha), Santa Helena farm (15.6 ha) and Três Lagos farm (25.3 ha). The three farms have the same climate conditions (solar radiation, wind speed and direction, amount of rain, relative humidity), the same soil characteristics, the same land relief, approximately the same area, and all are family managed. The main difference between the farms is the production model (conventional or agroecological) adopted.

Duas Cachoeiras farm adopted Agroecology in 1985. During the last two decades, it has implemented soil decontamination and natural fertility recovery, reforestation and local biodiversity recovery, chemical input free food production, internal residue cycling (nutrients), enhanced use of local resources, and introduction of extension work, ecological tourism and education. The other two farms use the chemical model. Santa Helena produces vegetables, fruits, and coffee. Três Lagos produces milk and meat.

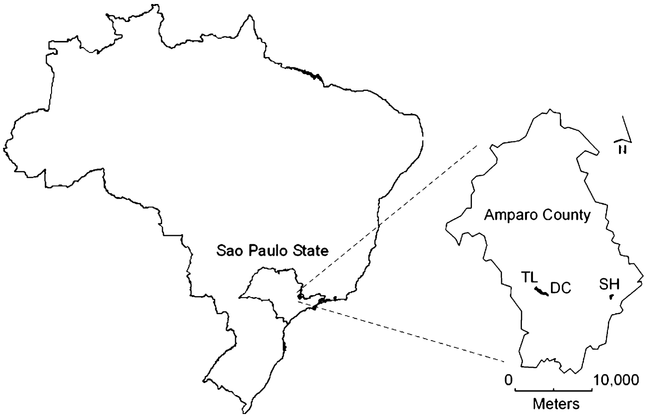

**Fig. 1 – Study area. Brazil Country, Sao Paulo State, Amparo County. TL: Três Lagos farm; DC: Duas Cachoeiras farm; SH: Santa Helena farm.**

### 2.2. Emergy methodology

The emergy analysis is based on the works of Odum (1996), Ulgiati and Brown (1998), and Brown and Ulgiati (2004). The first step in the application of the emergy methodology is to construct system diagrams to identify all components and their relationships. Fig. 2 shows an aggregated flow diagram that uses a symbolic language to represent the flows and interactions. Table 1 shows the description of the emergy flows.

The second step is to build the emergy table, placing the numerical value and the units of each flow mentioned in the diagram. The table allows the conversion of all the resources in terms of solar emergy Joules using transformities (Odum, 1996). The third step is to obtain the emergy indicators (Table 2) in order to evaluate the system environmental performance.

This work incorporates some changes in emergy methodology in order to get closer to reality. These changes are the following:

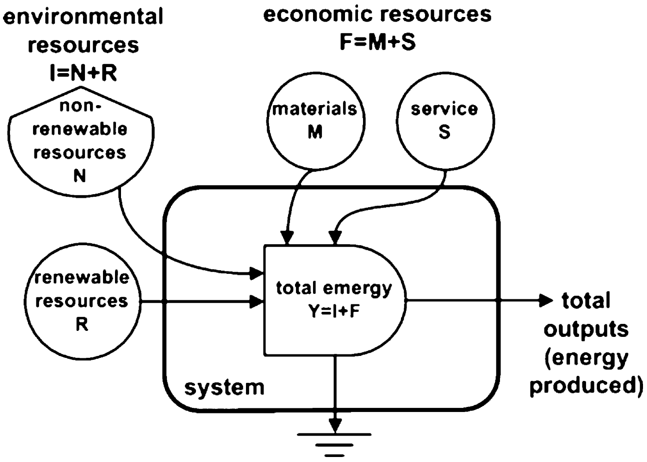

**Fig. 2 – Emergy system diagram of a generic production system.**

**Table 1 – Classification of emergy flows used in environmental accounting**

| Inputs and services | Description |
|---|---|
| Nature contributions (*I*) | $R+N$ |
| Renewable natural resources (*R*) | Rain, materials, and services from preserved areas, nutrients from soil minerals and air |
| Non-renewable natural resources (*N*) | Soil, biodiversity, people exclusion |
| Feedback from economy (*F*) | $F=M+S$ |
| Materials (*M*) | $M=M_R+M_N$ |
| Renewable materials and energy ($M_R$) | Renewable materials of natural origin |
| Non-renewable materials and energy ($M_N$) | Minerals, chemicals, steel, fuel, etc. |
| Services (*S*) | $S=S_R+S_N$ |
| Renewable services ($S_R$) | Manpower supported by renewable sources |
| Non-renewable services ($S_N$) | Other (external) services, taxes, insurance, etc. |
| Total emergy (*Y*) | $Y=I+F$ |

Ortega et al., 2002.

(1) The renewability factor of each item have been considered, according to Ulgiati et al. (1994), Ortega et al. (2005, 2002), Ortega and Polidoro (2002), Ulgiati et al. (2005) and Cavalett et al. (2006). The emergy indexes were slightly changed to evaluate sustainability more properly, by considering renewability of each of the economic resource used. The incorporation of the renewability factor is particularly valid when the system uses materials and services, purchased at the local or regional economy, that are not totally considered as nonrenewable resource (such as labor, electricity power, manure and services). Thus, the incorporation of the renewability factor should be added to emergy methodology when applied to assess sustainability (Ortega et al., 2005, 2002).

(2) The soil loss was calculated through the Universal Soil Loss Equation (USLE) in accordance with Wischmeier and Smith (1978) and the aid of the Geographical Information System (GIS). Soil loss equation enumerates the main factors that influence the rain erosion. The equation (USLE) is expressed as follows: $A=R\times K\times L\times S\times C\times P$, where $A$ = soil loss given by area unit [t/(ha year)]; $R$ = rain factor; expression of rain erosion [MJ mm/(ha h year)]; $K$ = soil erodibility factor [t h/(MJ mm)]; $L$ = slope length factor [non-dimensional]; $S$ = slope steepness factor [non-dimensional]; $C$ = cover-management factor [non-dimensional]; $P$ = support practice factor [non-dimensional]. Aerial photographs were obtained from the archives of Amparo City Hall (scale 1:30,000), covering the three research units. Initially, they were geographically located through ERDAS Imagine software (version 8.7) and exported to GIS software (ArcGIS 9.0) for constructing thematic maps (land use and soil type). The factors required by soil loss equation were obtained through several works (Resende and Almeida, 1985; Bertoni and Lombardi Neto, 1999; Guerra et al., 1999; Gabriels et al., 2003; Lu et al., 2004; Shi et al., 2004) and linked to these maps. An Arc Macro Language (AML) routine was used to determine the topographical factor in Arc Info Workstation 9.0, according to Lu et al. (2004). The AML routine was developed by Hickey (2000) and Van Remortel et al. (2001), and is available at the Internet address: http://www.cwu.edu/~rhickey/slope/slope.html. The flowchart used to calculate soil loss can be seen in Fig. 3. Through this procedure, the amount of soil loss calculated is closer to the reality of the specific location;

(3) For the agroecological system analyzed in this work, the ground macronutrients (nitrogen, potash, phosphorus and limestone) removed in the harvest (see Table 3) have been considered as renewable resources from nature, since the process used in the farm makes the acquisition of macronutrients from external sources unnecessary (Agostinho, 2005). The green manure (fertilization using

**Table 2 – Emergy indicators**

| Indicator | Expression | Meaning |
|---|---|---|
| Solar transformity (Tr) | Y/E | The ratio of the emergy of the output divided by the energy of the products. |
| Renewability (%R) | $100x(R+M_R+S_R)/Y$ | The ratio of the renewable inputs divided by the total emergy of the system. |
| Emergy yield ratio (EYR) | $Y/(M_N+S_N)$ | The ratio of total emergy used divided by the emergy of nonrenewable inputs from the economy. |
| Emergy investment ratio (EIR) | $(M_N+S_N)/(R+M_R+S_R+N)$ | The ratio of emergy of nonrenewable economic inputs divided by the emergy of nature investment (nature input plus renewable inputs from economy). |
| Emergy exchange ratio (EER) | Y/[($) × (seJ/$)] | The ratio of emergy delivered by the producer to the economy divided by the emergy received from the buyer. |
| Environmental loading ratio (ELR) | $(N+M_N+S_N)/(R+M_R+S_R)$ | The ratio of nonrenewable emergy and renewable inputs. |
| Emergy sustainability index (ESI) | EYR/ELR | Indicates the sustainability of the system. |

Source: Ortega et al., 2002; based on Odum, 1996.

**Table 3 – Calculation of nutrients removed from the ground**

| Product | Protein[a] (g) | P[a] (g) ($\times 10^{-3}$) | K[a] (g) ($\times 10^{-3}$) | N[b] (g) | Ca[a] (g) ($\times 10^{-3}$) | Others[a] (g) ($\times 10^{-3}$) |
|---|---|---|---|---|---|---|
| Maize | 9 | 210 | 287 | 1.44 | 7 | 167 |
| Sunflower | 23 | 705 | 689 | 3.68 | 116 | 373 |
| Beans | 4 | 37 | 187 | 0.64 | 17 | 28 |
| Pumpkin | 1 | 44 | 340 | 0.16 | 21 | 14 |
| Cassava | 1 | 27 | 271 | 0.16 | 16 | 35 |
| Sweet potato | 2 | 28 | 204 | 0.32 | 22 | 24 |
| Rice | 15 | 433 | 427 | 2.40 | 21 | 194 |
| Soybean | 13 | 194 | 620 | 2.08 | 197 | 86 |
| Vegetable | 1 | 23 | 257 | 0.16 | 32 | 18 |
| Fruit | 1 | 11 | 156 | 0.16 | 10 | 11 |

| Product | Productivity (kg/ha year) | P (kg/ha year) | K (kg/ha year) | N (kg/ha year) | Ca (kg/ha year) | Others (kg/ha year) |
|---|---|---|---|---|---|---|
| Maize | 3,000 | 6.3 | 8.6 | 43.2 | 0.2 | 5.0 |
| Sunflower | 1,000 | 7.0 | 6.9 | 36.8 | 1.1 | 3.7 |
| Beans | 900 | 0.3 | 1.6 | 5.7 | 0.1 | 0.2 |
| Pumpkin | 3,500 | 1.5 | 11.9 | 5.6 | 0.7 | 0.5 |
| Cassava | 10,000 | 2.7 | 27.1 | 16.0 | 1.6 | 3.5 |
| Sweet potato | 10,000 | 2.8 | 20.4 | 32.0 | 2.2 | 2.4 |
| Rice | 2,500 | 10.8 | 10.6 | 60.0 | 0.5 | 4.8 |
| Soybean | 2,400 | 4.6 | 14.8 | 49.9 | 4.7 | 2.0 |
| Vegetable | 30,000 | 6.9 | 77.1 | 48.0 | 9.6 | 5.4 |
| Fruit | 10,000 | 1.1 | 15.6 | 16.0 | 1.0 | 1.1 |
| Total |  | 44.0 | 194.6 | 313.2 | 21.7 | 28.6 |

Duas Cachoeiras farm, year 2003.

[a] Source: Table of Chemical Composition of Foods. U.S. Department of Agriculture, Agricultural Research Service. Nutrient Database for Standard Reference, release 14. Amount of nutrients in 100 g of sample. Available at http://www.unifesp.br/dis/servicos/nutri, accessed on 18th June 2004. P, phosphate; K, Potash; N, Nitrogen; Ca, Limestone;

[b] The amount of nitrogen corresponds approximately 16% of protein amount.

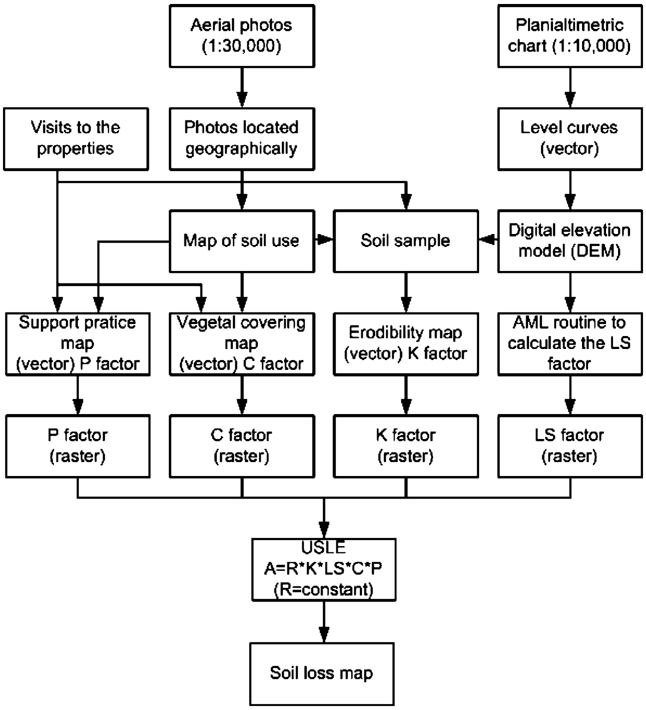

**Fig. 3 – Flowchart used in soil loss calculation.**

leguminous plants), the incorporation of animal manure, compost and organic matter surplus after harvest to the ground ensure that the amount of ground minerals removed in the crop could be replaced in a renewable way. Since 1985, Duas Cachoeiras farm uses no chemical inputs in food production, displaying a ground mineral extraction equal to or lower than natural restoration;

(4) The fact that the farms have native vegetation areas, which besides serving as a natural defense against plagues, causes some rain water to infiltrate the ground. This increases the amount of water in underground watersheds (Agostinho, 2005). The land use, soil type, soil handling and landscape slope are the most important factors that affect the water pathways after the rain initiates. There are mathematical models able to estimate the water infiltration in the ground, runoff and interception by vegetal covering, but all of them demand many raw data. The calculation of water infiltration into the ground considering vegetable covering was not the main aim of this paper, thus there were used previous works by other researchers (Adekalu et al., 2007; Souza and Alves, 2003; Centurion et al., 2001; Lima, 1996). The following percentages were considered: 30% for forest areas and silviculture; 20% for Napier grass, maize, orchard, chayote, meadows and annual culture; 5% for grassland and cultures with low biomass accumulation. Through the GIS land use map of the three properties (Figs. 4–6) with the values of plant covering areas expressed in hectares and the respective rain infiltration ratio (%), it was possible to estimate the water

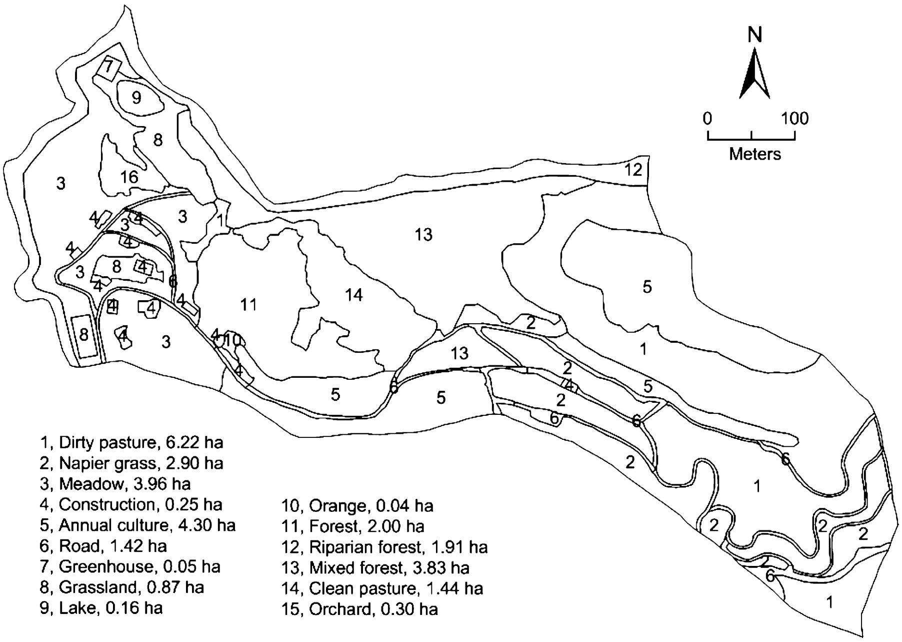

**Fig. 4 – Land use of Duas Cachoeiras farm.**

infiltrated into the ground (see Tables 4–6). The infiltrated water was considered in the emergy analysis as another output. A great part of this high quality resource leaves the farms and become available to the down-stream watershed users;

(5) One characteristic of small family farms in Brazil is the diversity of their production and the presence of native vegetation areas in a greater proportion than of the chemical farming enterprises (agribusiness), because the small farms obey environmental laws and need the environmental services of preserved forested areas. In preserved natural areas, the accumulation of biomass does not leave the system immediately, it is a novelty to consider this characteristic in the emergy evaluation. The farm biomass accumulation was estimated through net primary productivity (Aber and Melillo, 2001) data and land use maps obtained from GIS (see Tables 7–9). The native vegetation biomass was considered as a flow of renewable natural resources because the farm depends on the environmental services and products produced in those areas.

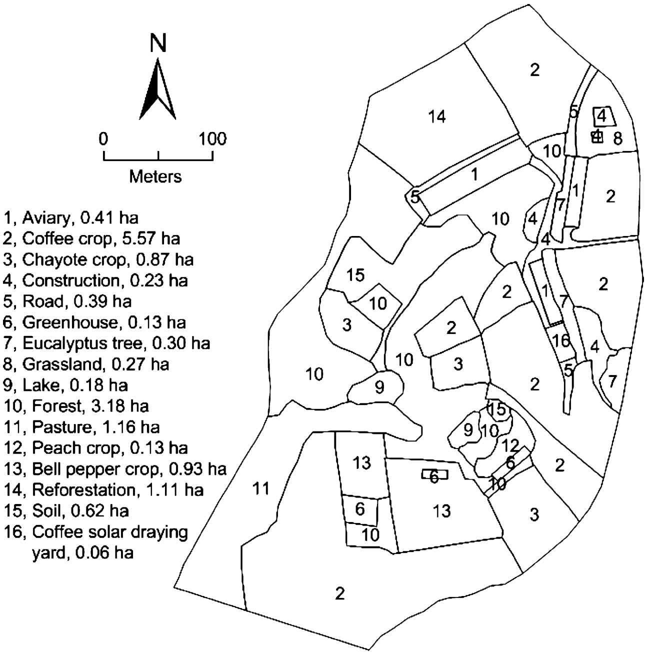

**Fig. 5 – Land use of Santa Helena farm.**

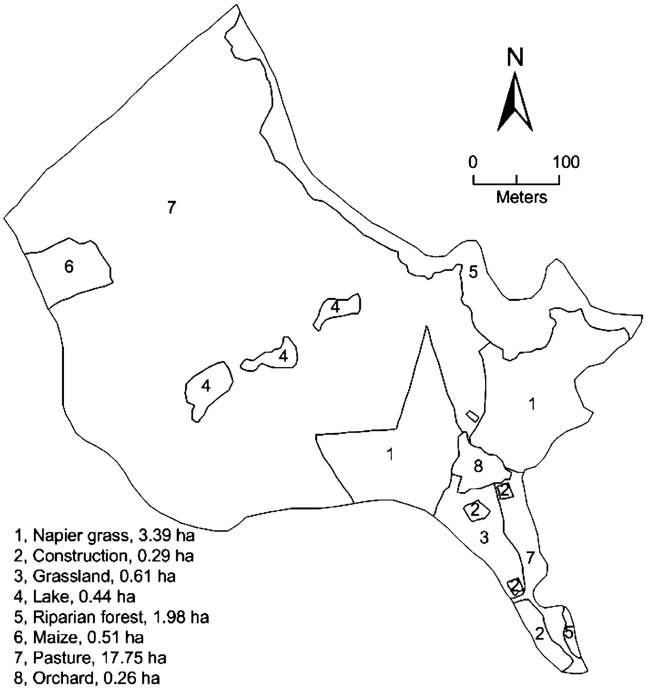

**Fig. 6 – Land use of Três Lagos farm.**

**Table 4 – Total percolated water in Duas Cachoeiras farm, year 2003**

| Vegetation covering | Area (ha) | Total water in area[a] (million of l/year) | Percolation[b] (%) | Total water percolated (million of l/year) |
|---|---|---|---|---|
| Forest | 2.00 | 25.10 | 30 | 7.53 |
| Mixed forest | 3.83 | 47.90 | 30 | 14.37 |
| Riparian forest | 1.91 | 23.90 | 30 | 7.17 |
| Orchard | 0.30 | 3.75 | 20 | 0.75 |
| Orange crop | 0.04 | 0.50 | 5 | 0.02 |
| Meadow | 3.96 | 49.50 | 20 | 9.90 |
| Napier grass | 2.90 | 36.30 | 20 | 7.26 |
| Annual culture | 4.30 | 53.80 | 20 | 10.76 |
| Clean pasture | 1.44 | 18.00 | 2 | 0.36 |
| Dirty pasture | 6.22 | 77.90 | 20 | 15.58 |
| Grassland | 0.87 | 10.90 | 5 | 0.55 |
| Lake | 0.16 | 2.00 | 0 | 0.00 |
| Total percolated water | | | | 74.25 |

[a] 1250 mm of water/year.
[b] Percentage estimate about: Adekalu et al., 2007; Souza and Alves, 2003; Centurion et al., 2001; Lima, 1996.

**Table 5 – Total percolated water in Santa Helena farm, year 2003**

| Vegetation covering | Area (ha) | Total water in area[a] (million of l/year) | Percolation[b] (%) | Total water percolated (million of l/year) |
|---|---|---|---|---|
| Forest | 3.18 | 39.75 | 30 | 11.92 |
| Reforestation | 1.11 | 13.87 | 30 | 4.16 |
| *Eucalyptus* tree | 0.30 | 3.75 | 30 | 1.12 |
| Peach crop | 0.13 | 1.62 | 5 | 0.08 |
| Coffee | 5.57 | 69.62 | 10 | 6.96 |
| Dirty pasture | 1.16 | 14.5 | 20 | 2.90 |
| Green house | 0.93 | 11.62 | 0 | 0.00 |
| Chayote crop | 0.87 | 10.87 | 20 | 2.17 |
| Grassland | 0.27 | 3.37 | 5 | 0.17 |
| Lake | 0.18 | 2.25 | 0 | 0.00 |
| Total percolated water | | | | 29.50 |

[a] 1250 mm of water/year.
[b] Percentage estimate about: Adekalu et al., 2007; Souza and Alves, 2003; Centurion et al., 2001; Lima, 1996.

(6) Finally, the emergy ternary diagram proposed by Giannetti et al. (2006) was used to graphically represent the emergy sustainability index (ESI) to help the visualization of emergy flows (*R*, *N* and *F*) of the studied systems. This representation granted more clarity to the interpretation of results.

## 3. Results and discussion

The emergy indices calculated in this paper (see Table 2) were: transformity (Tr), renewability (%*R*), emergy yield ratio (EYR), emergy investment ratio (EIR), emergy exchange ratio (EER) and environmental loading ratio (ELR). The

**Table 6 – Total percolated water in Três Lagos farm, year 2003**

| Vegetation covering | Area (ha) | Total water in area[a] (million of l/year) | Percolation[b] (%) | Total water percolated (million of l/year) |
|---|---|---|---|---|
| Forest | 1.98 | 24.75 | 30 | 7.42 |
| Napier grass | 3.39 | 42.37 | 20 | 8.47 |
| Maize | 0.51 | 6.37 | 20 | 1.27 |
| Clean pasture | 17.75 | 221.87 | 2 | 4.44 |
| Orchard | 0.26 | 3.25 | 20 | 0.65 |
| Grassland | 0.61 | 7.62 | 5 | 0.38 |
| Lake | 0.44 | 5.50 | 0 | 0.00 |
| Total percolated water | | | | 22.64 |

[a] 1250 mm of water/year.
[b] Percentage estimate about: Adekalu et al., 2007; Souza and Alves, 2003; Centurion et al., 2001; Lima, 1996.

Table 7 – Total biomass flow in Duas Cachoeiras farm, year 2003

| Vegetal covering | Area (ha) | Net primary productivity[a] (gC/m²/year) | Reference for (gC/m²/year) | Total biomass storaged[b] (kg/year) |
|---|---|---|---|---|
| Forest | 2.00 | 800 | Aber and Melillo, 2001 | 32,000 |
| Mixed forest | 3.83 | 800 | Aber and Melillo, 2001 | 61,280 |
| Riparian forest | 1.91 | 800 | Aber and Melillo, 2001 | 30,560 |
| Orchard | 0.30 | 290 | Aber and Melillo, 2001 | 1,740 |
| Orange | 0.04 | 290 | Aber and Melillo, 2001 | 232 |
| Meadow | 3.96 | 315 | Aber and Melillo, 2001 | 24,948 |
| Napier grass | 2.90 | 400 | Estimated | 23,200 |
| Annual culture | 4.30 | 290 | Aber and Melillo, 2001 | 24,940 |
| Clean pasture | 1.44 | 225 | Aber and Melillo, 2001 | 6,480 |
| Dirty pasture | 6.22 | 300 | Estimated | 37,320 |
| Grassland | 0.87 | 225 | Aber and Melillo, 2001 | 3,915 |
| Lake | 0.16 | 225 | Aber and Melillo, 2001 | 720 |
| Total biomass flow | | | | 247,335 |

[a] 55% of total biomass = carbon (Ponce-Hernandez et al., 2004).
[b] Total biomass storaged = area × net primary productivity.

Table 8 – Total biomass flow in Santa Helena farm, year 2003

| Vegetal covering | Area (ha) | Net primary productivity[a] (gC/m²/year) | Reference for (gC/m²/year) | Total biomass storaged[b] (kg/year) |
|---|---|---|---|---|
| Forest | 3.18 | 800 | Aber and Melillo, 2001 | 50,880 |
| Reforestation | 1.11 | 800 | Aber and Melillo, 2001 | 17,760 |
| Eucalyptus tree | 0.30 | 800 | Aber and Melillo, 2001 | 4,800 |
| Peach crop | 0.13 | 290 | Aber and Melillo, 2001 | 754 |
| Coffee crop | 5.57 | 290 | Aber and Melillo, 2001 | 32,306 |
| Dirty pasture | 1.16 | 300 | Estimated | 6,960 |
| Bell pepper crop | 0.93 | 290 | Aber and Melillo, 2001 | 5,394 |
| Chayote crop | 0.87 | 290 | Aber and Melillo, 2001 | 5,046 |
| Grassland | 0.27 | 225 | Aber and Melillo, 2001 | 1,215 |
| Lake | 0.18 | 225 | Aber and Melillo, 2001 | 810 |
| Total biomass flow | | | | 125,925 |

[a] 55% of total biomass = carbon (Ponce-Hernandez et al., 2004).
[b] Total biomass storaged = area × net primary productivity.

emergy sustainability index (ESI) was used only in a ternary diagram. Moreover, some Best Management Practices were suggested as a means to improve their performance.

### 3.1. *Comparing agricultural production models*

The emergy evaluation of farms is presented in Tables 10–12, and the aggregate emergy flows are presented in Table 13. In

Table 9 – Total biomass flow in Três Lagos farm, year 2003

| Vegetal covering | Area (ha) | Net primary productivity[a] (gC/m²/year) | Reference for (gC/m²/year) | Total biomass storaged[b] (kg/year) |
|---|---|---|---|---|
| Forest | 1.98 | 800 | Aber and Melillo, 2001 | 31,680 |
| Napier grass | 3.39 | 400 | Estimated | 27,120 |
| Maize | 0.51 | 290 | Aber and Melillo, 2001 | 2,958 |
| Clean pasture | 17.75 | 225 | Aber and Melillo, 2001 | 79,875 |
| Orchard | 0.26 | 290 | Aber and Melillo, 2001 | 1,508 |
| Grassland | 0.61 | 225 | Aber and Melillo, 2001 | 2,745 |
| Lake | 0.44 | 225 | Aber and Melillo, 2001 | 1,980 |
| Total biomass flow | | | | 147,866 |

[a] 55% of total biomass = carbon (Ponce-Hernandez et al., 2004).
[b] Total biomass storaged = area × net primary productivity.

**Table 10 – Emergy evaluation of Duas Cachoeiras farm (DC) in the year 2003 (emergy flows in E + 13 seJ/ha/year)**

| Note | Item | Renewability fraction | Unit | Unit/ha/year | seJ/unit | Reference for seJ/unit | Renewable emergy flow | Non-renewable emergy flow | Total emergy flow |
|---|---|---|---|---|---|---|---|---|---|
| Renewable inputs (R) | | | | | | | | | |
| 1 | Sun | 1.00 | J | 1.52E + 11 | 1.00E + 00 | Definition | 0.02 | 0.00 | 0.02 |
| 2 | Rain | 1.00 | J | 6.25E + 10 | 3.10E + 04 | Odum et al. (2000) | 193.75 | 0.00 | 193.75 |
| 3 | Wind | 1.00 | J | 1.52E + 10 | 2.45E + 03 | Odum et al. (2000) | 3.72 | 0.00 | 3.72 |
| 4 | Water spring | 1.00 | J | 2.29E + 09 | 4.85E + 04 | Bastianoni and Marchettini (2000) | 11.11 | 0.00 | 11.11 |
| 5 | River water | 1.00 | J | 1.09E + 08 | 2.55E + 05 | Bastianoni and Marchettini (2000) | 2.78 | 0.00 | 2.78 |
| 6 | Nitrogen | 1.00 | kg | 3.13E + 02 | 6.38E + 12 | Brown and Ulgiati (2004) | 199.82 | 0.00 | 199.82 |
| 7 | Phosphate rock | 1.00 | kg | 4.40E + 01 | 3.90E + 09 | Brandt-Williams (2002) | 0.02 | 0.00 | 0.02 |
| 8 | Potash | 1.00 | kg | 1.95E + 02 | 1.74E + 12 | Brandt-Williams (2002) | 33.86 | 0.00 | 33.86 |
| 9 | Limestone | 1.00 | kg | 2.17E + 01 | 1.00E + 12 | Brandt-Williams (2002) | 2.17 | 0.00 | 2.17 |
| 10 | Biomass | 1.00 | J | 1.39E + 11 | 1.00E + 04 | Estimated, Brown and Bardi (2001) | 139.00 | 0.00 | 139.00 |
| Non-renewable inputs (N) | | | | | | | | | |
| 11 | Soil loss | 0.00 | J | 2.98E + 10 | 1.24E + 05 | Brandt-Williams (2002) | 0.00 | 369.52 | 369.52 |
| Materials (M) | | | | | | | | | |
| 12 | Depreciation | 0.05 | US$ | 1.23E + 02 | 3.30E + 12 | Coelho et al. (2003) | 2.03 | 38.56 | 40.59 |
| 13 | Fuel | 0.00 | J | 5.29E + 07 | 5.50E + 05 | Bastianoni et al. (2005) | 0.00 | 2.91 | 2.91 |
| 14 | Electricity | 0.70 | J | 3.88E + 08 | 2,77E + 05 | Brown and Ulgiati (2004) | 7.52 | 3.22 | 10.75 |
| 15 | Materials | 0.10 | US$ | 1.29E + 01 | 3.30E + 12 | Coelho et al. (2003) | 0.43 | 3.83 | 4.26 |
| Services (S) | | | | | | | | | |
| 16 | Simple labor | 0.60 | US$ | 7.00E + 01 | 3.30E + 12 | Coelho et al. (2003) | 13.86 | 9.24 | 23.10 |
| 17 | Family labor | 0.90 | US$ | 7.00E + 01 | 3.30E + 12 | Coelho et al. (2003) | 20.79 | 2.31 | 23.10 |
| 18 | Maintenance | 0.10 | US$ | 1.01E + 01 | 3.30E + 12 | Coelho et al. (2003) | 0.33 | 3.00 | 3.33 |
| 19 | Tax | 0.05 | US$ | 2.24E + 00 | 3.30E + 12 | Coelho et al. (2003) | 0.04 | 0.70 | 0.74 |
| 20 | Service | 0.05 | US$ | 1.35E + 00 | 3.30E + 12 | Coelho et al. (2003) | 0.02 | 0.42 | 0.45 |
| 21 | Phone | 0.05 | US$ | 1.62E + 01 | 3.30E + 12 | Coelho et al. (2003) | 0.27 | 5.08 | 5.35 |
| Total emergy (Y) | | | | | | | 492.53 | 438.80 | 1070.33 |
| Total outputs (O) | | J | 1.63E + 10 | | | | | | |
| Money from the sale of products | | US$ | 751.95 | | | | | | |

**Table 11 – Emergy evaluation of Santa Helena farm (SH) in the year 2003 (emergy flows in E + 13 seJ/ha/year)**

| Note | Item | Renewability fraction | Unit | Unit/ha/year | seJ/unit | Reference for seJ/unit | Renewable emergy flow | Non-renewable emergy flow | Total emergy flow |
|---|---|---|---|---|---|---|---|---|---|
| Renewable inputs (R) | | | | | | | | | |
| 1 | Sun | 1.00 | J | 1.52E + 11 | 1.00E + 00 | Definition | 0.02 | 0.00 | 0.02 |
| 2 | Rain | 1.00 | J | 6.25E + 10 | 3.10E + 04 | Odum et al. (2000) | 193.75 | 0.00 | 193.75 |
| 3 | Wind | 1.00 | J | 1.51E + 10 | 2.45E + 03 | Odum et al. (2000) | 3.70 | 0.00 | 3.70 |
| 4 | River water | 1.00 | J | 1.25E + 09 | 2.55E + 05 | Bastianoni and Marchettini (2000) | 31.88 | 0.00 | 31.88 |
| 5 | Biomass | 1.00 | J | 1.35E + 11 | 1.00E + 04 | Estimated, Brown and Bardi (2001) | 135.00 | 0.00 | 135.00 |
| Non-renewable inputs (N) | | | | | | | | | |
| 6 | Soil loss | 0.00 | J | 5.33E + 10 | 1.24E + 05 | Brandt-Williams (2002) | 0.00 | 660.92 | 660.92 |
| Materials (M) | | | | | | | | | |
| 7 | Depreciation | 0.05 | US$ | 4.77E + 02 | 3.30E + 12 | Coelho et al. (2003) | 7.87 | 149.54 | 157.41 |
| 8 | Fuel | 0.00 | J | 2.29E + 08 | 5.50E + 05 | Bastianoni et al. (2005) | 0.00 | 12.60 | 12.60 |
| 9 | Electricity | 0.70 | J | 1.73E + 09 | 2,77E + 05 | Brown and Ulgiati (2004) | 33.54 | 14.38 | 47.92 |
| 10 | Materials | 0.10 | US$ | 4.27E + 01 | 3.30E + 12 | Coelho et al. (2003) | 1.41 | 12.68 | 14.09 |
| 11 | Fungicide | 0.05 | kg | 3.33E + 01 | 2.49E + 13 | Brandt-Williams (2002) | 4.15 | 78.77 | 82.92 |
| 12 | Herbicide | 0.05 | kg | 5.00E-01 | 2.49E + 13 | Brandt-Williams (2002) | 0.06 | 1.18 | 1.25 |
| 13 | Calcium | 0.05 | kg | 2.40E-01 | 1.00E + 12 | Brandt-Williams (2002) | 0.00 | 0.02 | 0.02 |
| 14 | Nitr. Calcium | 0.05 | US$ | 1.58E + 00 | 3.30E + 12 | Coelho et al. (2003) | 0.03 | 0.50 | 0.52 |
| 15 | Nitr. Potass. | 0.05 | US$ | 2.14E + 00 | 3.30E + 12 | Coelho et al. (2003) | 0.04 | 0.67 | 0.71 |
| Services (S) | | | | | | | | | |
| 16 | Family labor | 0.90 | US$ | 2.67E + 02 | 3.30E + 12 | Coelho et al. (2003) | 79.30 | 8.81 | 88.11 |
| 17 | Tax | 0.05 | US$ | 2.46E + 00 | 3.30E + 12 | Coelho et al. (2003) | 0.04 | 0.77 | 0.81 |
| 18 | Service | 0.05 | US$ | 2.36E + 01 | 3.30E + 12 | Coelho et al. (2003) | 0.39 | 7.40 | 7.79 |
| 19 | Phone | 0.05 | US$ | 1.54E + 01 | 3.30E + 12 | Coelho et al. (2003) | 0.25 | 4.83 | 5.08 |
| Total emergy (Y) | | | | | | | 491.42 | 953.06 | 1444.48 |
| Total outputs (O) | | J | 1.65E + 10 | | | | | | |
| Money from the sale of products | | US$ | 1,536.10 | | | | | | |

**Table 12 – Emergy evaluation of Três Lagos farm (TL) in the year 2003 (emergy flows in E + 13 seJ/ha/year)**

| Note | Item | Renewability fraction | Unit | Unit/ha/year | seJ/unit | Reference for seJ/unit | Renewable emergy flow | Non-renewable emergy flow | Total emergy flow |
|---|---|---|---|---|---|---|---|---|---|
| Renewable inputs (R) | | | | | | | | | |
| 1 | Sun | 1.00 | J | 1.52E + 11 | 1.00E + 00 | Definition | 0.02 | 0.00 | 0.02 |
| 2 | Rain | 1.00 | J | 6.25E + 10 | 3.10E + 04 | Odum et al. (2000) | 193.75 | 0.00 | 193.75 |
| 3 | Wind | 1.00 | J | 1.51E + 10 | 2.45E + 03 | Odum et al. (2000) | 3.70 | 0.00 | 3.70 |
| 4 | Water spring | 1.00 | J | 9.98E + 08 | 4.85E + 04 | Bastianoni and Marchettini (2000) | 4.84 | 0.00 | 4.84 |
| 5 | Biomass | 1.00 | J | 9.79E + 10 | 1.00E + 04 | Estimated, Brown and Bardi (2001) | 97.90 | 0.00 | 97.90 |
| Non-renewable inputs (N) | | | | | | | | | |
| 6 | Soil loss | 0.00 | J | 1.07E + 11 | 1.24E + 05 | Brandt-Williams (2002) | 0.00 | 1326.80 | 1326.80 |
| Materials (M) | | | | | | | | | |
| 7 | Depreciation | 0.05 | US$ | 1.04E + 02 | 3.30E + 12 | Coelho et al. (2003) | 1.72 | 32.60 | 34.32 |
| 8 | Fuel | 0.00 | J | 1.34E + 08 | 5.50E + 05 | Bastianoni et al. (2005) | 0.00 | 7.37 | 7.37 |
| 9 | Electricity | 0.70 | J | 1.79E + 09 | 2,77E + 05 | Brown and Ulgiati (2004) | 34.71 | 14.87 | 49.58 |
| 10 | Materials | 0.10 | US$ | 3.95E + 01 | 3.30E + 12 | Coelho et al. (2003) | 1.30 | 11.73 | 13.04 |
| 11 | Vaccines | 0.00 | US$ | 1.58E + 01 | 3.30E + 12 | Coelho et al. (2003) | 0.00 | 5.21 | 5.21 |
| Services (S) | | | | | | | | | |
| 12 | Simple labor | 0.60 | US$ | 1.23E + 02 | 3.30E + 12 | Coelho et al. (2003) | 24.35 | 16.24 | 40.59 |
| 13 | Tax | 0.05 | US$ | 1.32E + 00 | 3.30E + 12 | Coelho et al. (2003) | 0.02 | 0.41 | 0.44 |
| 14 | Service | 0.05 | US$ | 6.59E + 00 | 3.30E + 12 | Coelho et al. (2003) | 0.11 | 2.07 | 2.17 |
| 15 | Phone | 0.05 | US$ | 1.32E + 01 | 3.30E + 12 | Coelho et al. (2003) | 0.22 | 4.14 | 4.36 |
| Total emergy (Y) | | | | | | | 362.63 | 1421.45 | 1784.08 |
| Total outputs (O) | | J | 6.82E + 09 | | | | | | |
| Money from the sale of products | | US$ | 386.56 | | | | | | |

**Table 13 – Aggregate emergy flows of the emergy evaluation—year 2003**

| Emergy flows (flows in E + 13 seJ/ha/year) | Duas Cachoeiras farm | Santa Helena farm | Três Lagos farm |
|---|---|---|---|
| Renewable resources (*R*) | 586.24 | 364.34 | 300.21 |
| Non-renewable resources (*N*) | 369.52 | 660.92 | 1326.80 |
| Nature contribution (*I*) | 955.76 | 890.26 | 1627.01 |
| Renewable materials ($M_R$) | 9.98 | 47.09 | 37.73 |
| Non-renewable materials ($M_N$) | 48.53 | 270.34 | 71.79 |
| Total materials (*M*) | 58.50 | 317.43 | 109.52 |
| Renewable services ($S_R$) | 35.31 | 79.98 | 24.70 |
| Non-renewable services ($S_N$) | 20.75 | 21.81 | 22.85 |
| Total services (*S*) | 56.06 | 101.79 | 47.56 |
| Feedback from economy (*F*) | 114.57 | 419.22 | 157.08 |
| Total emergy (*Y*) | 1070.33 | 1444.48 | 1784.08 |

the emergy evaluation tables, all the flows that enter the system have been converted into emergy through transformity values available in the literature, after their applicability was verified in the studied systems. The flows of materials and services that enter the system were multiplied by their corresponding renewability factors, in order to divide them in their renewable and non-renewable fractions. Total renewable (*R*), non-renewable (*N*), services (*S*) and materials (*M*) emergy flows were calculated by summing up the respective fractions of each input flow.

The renewability factor of purchased inputs used in this work was obtained from previous works about soybean and maize production in Brazil (Ortega et al., 2005, 2002) and about fish production (Cavalett et al., 2006).

Table 14 presents the emergy indicators for the three properties.

### 3.1.1. *Transformity*

Bastianoni and Marchettini (2000), studying systems that include co-production of goods, calculated their transformity ($\mathrm{Tr} = Y/\Sigma\mathrm{Ep}$) by dividing the total emergy entering the system (*Y*) by the sum of energies of all co-products ($\Sigma$Ep) instead of using the energy of the main product (Ep) as the denominator. According to these authors, this calculation provides a better indicator in cases where production is diversified. Since small agricultural properties in Brazil usually cultivate more than one product, the present work has adopted this approach.

The farm's transformities obtained are: 650,000 seJ/J (Duas Cachoeiras), 870,000 seJ/J (Santa Helena), and 2,620,000 seJ/J (Três Lagos). These results indicate that family-managed ecological small farms can be more efficient in the transformation of potential energy when compared to chemical family-managed farms.

### 3.1.2. *Renewability*

The renewability ratio ($\%R = R/Y$) is the percentage of renewable emergy used by the system. In the long term, production systems with a high percentage of renewable emergy are likely to be more sustainable and to prevail (they are more able to survive the economical stress) than those using a high amount of non-renewable emergy (Brown and Ulgiati, 2004; Lefroy and Rydberg, 2003).

The renewability of Duas Cachoeiras farm was 59%, while for Santa Helena farm and Três Lagos farm the values were 34% and 20%, respectively, indicating that agroecological properties are more sustainable than chemical ones.

Since non-renewable resources are the driving force of the majority of the current production systems, the foreseen oil depletion in the next decades will be a great problem that systems with a low renewability indicator will have to face. The adoption of agroecological practices (product diversification, nutrient recycling, planning of cultures to favor water percolation, conservation of topsoil, and biological control of plagues) reduces the purchasing of chemical inputs and contributes for more renewability. Agenda 21 recommendations or Best Management Practices can be used to promote the adjustment of chemical–agriculture farms in order to reduce negative social and environmental impacts.

### 3.1.3. *Emergy yield ratio*

The emergy yield ratio ($\mathrm{EYR} = Y/F$) is the ratio between total emergy and emergy value of purchased inputs. This ratio is a measure of the ability of a process to exploit and make local resources available by investing in outside resources. It provides a measure of the appropriation of local resources by a process, which can be read as a potential additional contribution to the main economy, gained through the investment of resources.

The EYR for Duas Cachoeiras was of 15.4, while for Santa Helena and Três Lagos the values were 4.9 and 18.8, respectively. These results indicate that Duas Cachoeiras and Três Lagos farms use more natural resources (renewable and non-renewable), showing less dependency on economic resources. However, although Três Lagos farm EYR value was high, 81% of its nature emergy input ($R + N$) is non-renewable (*N*), while for Duas Cachoeiras only 39% are non-renewable natural emergy input (*N*).

Intensive conventional agricultural systems have EYR values lower than two (Ortega et al., 2002; Panzieri et al., 2000; Odum, 1996; Ulgiati et al., 1994), indicating that all studied farms display a low dependency on non-renewable economic resources.

### 3.1.4. *Emergy investment ratio*

The emergy investment ratio ($\mathrm{EIR} = F/I$) evaluates if a process is a good user of the invested emergy while compared to other alternatives for the use of the same resources (Brown and Ulgiati, 2004). The EIR value for Duas Cachoeiras farm was 0.07, while for Santa Helena farm and Três Lagos farm they

**Table 14 – Emergy indicators calculated considering the renewability factor of material and services—year 2003**

| Emergy indicators | Duas Cachoeiras farm | Santa Helena farm | Três Lagos farm |
|---|---|---|---|
| Tr (seJ/J) | 650,000 | 870,000 | 2,620,000 |
| %R | 59.00 | 34.02 | 20.33 |
| EYR | 15.45 | 4.94 | 18.85 |
| EIR | 0.07 | 0.25 | 0.06 |
| EER | 4.31 | 2.85 | 13.99 |
| ELR | 0.69 | 1.94 | 3.92 |

were 0.25 and 0.06, respectively. The results indicate that both, Duas Cachoeiras and Três Lagos farms, use more environmental inputs than Santa Helena farm. Therefore, production costs are reduced, representing better market performance. Current global trends indicate that low cost energy will not be available in the future. Moreover, agriculture could face many difficulties due to market opening in consequence of globalization (Campbell and Laherrère, 1998). Thus, production systems based on non-renewable natural resources may not be able to compete with systems characterized by lower economic investment (*F*) and greater renewable nature contribution (*R*), and might become unsustainable in the coming future. Três Lagos can be considered to have a good EIR investment ratio, although about 81% of its natural resources come from non-renewable resources, while for Duas Cachoeiras farm this percentage is only 39%. This result indicates that Três Lagos farm is highly dependent on non-renewable natural resources, and therefore is not sustainable over a long period.

### 3.1.5. *Emergy exchange ratio*

The emergy exchange ratio (EER = *Y*/(sales × emergy/money)) is calculated by dividing the total solar emergy of products by the emergy received in the sales. The EER measures the advantage of one partner over the other, providing a measure of who "wins" and who "loses" in economic trade (Brown and Ulgiati, 2004, 2001).

The calculated EER value for Duas Cachoeiras farm was 4.3, while for Santa Helena farm and Três Lagos farm it was 2.9 and 14.0, respectively. The indicator was greater than one for the three properties, indicating that all supply more emergy to the consumer than they receive in exchange—or, in other words, they have received less emergy than they have used to produce goods. Três Lagos presented the worst performance while Santa Helena presented the best one. Duas Cachoeiras farm adds value to its products, but does not receive back all emergy that was employed in the production. Farm product prices usually underestimate their real cost, and should therefore be higher than those currently determined by the market.

### 3.1.6. *Emergy loading ratio*

The emergy loading ratio (ELR) is an index of pressure that the system carries out on the environment and can be considered as a measure of ecosystem stress. ELR values lesser than 2 indicate low impact on the environment; values between 2 and 10 mean that the system cause a moderate impact; up to 10 mean that the system cause big impact (Brown and Ulgiati, 2004). For the agroecological model, represented by Duas Cachoeiras farm, the environmental impact was small (0.69). For the conventional model, the result was a moderate impact (1.94 for Santa Helena farm and 3.92 for Três Lagos farm). Agroecology makes possible the use of more renewable resources.

### 3.1.7. *Ternary diagram*

To assist environmental decision making based on emergy analysis, a ternary diagram proposed by Giannetti et al. (2006) was used (see Fig. 7).

The emergy ternary diagram has three components: *R*, *N* and *F*. Each corner of the triangle represents a component and each side a binary system. The composition of any system plotted on a ternary diagram can be determined by reading from zero along the basal line at the bottom line of the diagram to 100% at the vertex of the triangle (Giannetti et al., 2006). The size of dots in Fig. 7 is proportional to the emergy used (*Y*), showing that Três Lagos farm (3) uses a greater amount of emergy than the other two farms. The diagram shows that Duas Cachoeiras (1) and Três Lagos (3) use approximately the same small percentage of nonrenewable purchased emergy (6%) but Duas Cachoeiras uses a greater amount of renewable inputs (59%), while Três Lagos uses more nonrenewable natural inputs (74%). This explains the position on the ternary diagram of these two farms closer to *R* and *N* vertices, respectively.

Emergy sustainability index (ESI) measures the potential contribution of a resource or process to the economy per unit of environmental loading (Brown and Ulgiati, 2004). ESI

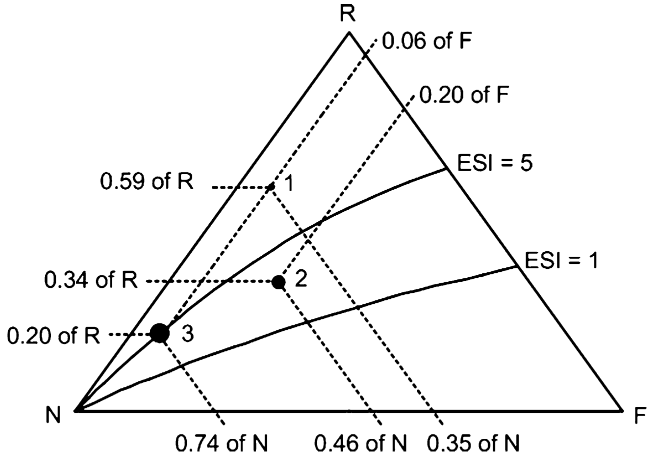

**Fig. 7 – Ternary emergy diagram for assessment of farms in 2003. (1) Duas Cachoeiras farm; (2) Santa Helena farm; (3) Três Lagos farm; *R*, renewable resources; *N*, non-renewable natural resources; *F*, non-renewable economic resources; ESI, emergy sustainability index.**

indicates the system benefit/cost ratio; e.g., the benefit proportioned by a process to the economy in relation to its environmental impact. Fig. 7 shows that Santa Helena (2) presents the lowest ESI value, even though it uses a lower amount of non-renewable natural resources than Três Lagos (3). In order to obtain better performance, Santa Helena (2) should reduce the use of economic inputs. Duas Cachoeiras (1) presented the best performance, but Santa Helena (2) and Três Lagos (3) farms also obtained an ESI higher than one, indicating that they contribute to economy through low environmental load.

## 3.2. *Comparing vegetation coverings*

Initially, the Geographical Information System was used to prepare a map of land use. After that, was realized an emergy analysis of vegetation covering by annual culture, orchard, pasture, and forest of Duas Cachoeiras farm. Table 15 presents the emergy indicators for these subsystems.[1]

### 3.2.1. *Transformity*

Forest areas have the lowest transformity (120,000 seJ/J), indicating high efficiency and low use of non-renewable economic resources (7% of total emergy used). The pasture revealed a transformity of 405,000 seJ/J, and 75% of the total emergy used was derived from non-renewable natural resources. Orchard area presented the greatest transformity, 980,000 seJ/J, and 95% of its total emergy input was due to human economy services. Annual culture showed an intermediate transformity (305,000 seJ/J) and reasonable use of renewable natural resources, due to incorporation of agroecological practices.

### 3.2.2. *Renewability factor*

Forest area presented the best renewability (85%) while pasture showed the worst (18%). Orchard and annual culture obtained a good value (70% and 44%, respectively). Pasture renewability can be improved through the reduction of soil loss, since it is responsible for approximately 75% of all emergy used and is considered a natural non-renewable resource. In orchard and annual culture areas, the use of labor and materials (for maintenance) could decrease. The results obtained indicate that forest, annual cultures, and orchard areas are highly sustainable due to the ecological practices and management.

### 3.2.3. *Emergy yield ratio*

Forest area presented the best emergy yield ratio (20.22), while orchard showed the worst (3.37). Pasture and annual culture presented respectively 14.49 and 8.23. It is important to point out that for pasture, 75% of all emergy used is derived from soil loss, while for the annual culture area this percentage fells down to 43%. In order to obtain a better performance, the orchard should reduce the use of resources purchased from the economy (external labor and materials for maintenance) and should increase the use of renewable resources (higher number of plants per area). Forest uses the lowest amount of purchased resources (7% of total emergy), followed by pasture (17%), annual cultures (20%) and orchard (95%), suggesting a sequence of covering with lower dependency on external inputs.

### 3.2.4. *Emergy investment ratio*

For this indicator, the forest area demonstrates that for each unit of emergy of natural resources only 0.05 units of economic resources are necessary, meaning low production cost. Therefore, their products could be competitive in an ideal market (without subsidies and hidden externalities). Orchard area had the worst performance (0.42), since this area needs more economic resources (mainly labor and maintenance materials). Annual culture and pasture areas presented good performances, 0.14 and 0.07, respectively, but it is important to point out that 43% of the total of emergy used in annual culture came from a non-renewable natural resource (soil loss), while pasture area used 75% and forest used 9% of the same kind of source. Thus, the pasture area would have to decrease soil losses through the use of terraces with natural vegetation lines, in order to improve environmental performance.

### 3.2.5. *Emergy exchange ratio*

Due to market forces that tend to reduce the prices of agricultural products, emergy exchange ratio (EER) of all subsystems indicate that more emergy is being supplied through the products than being received back as payment. In an ideal situation, the EER is equal to 1—in this case, the exact amount of emergy used to yield a product should be received back in exchange.

As it can be seen in Table 15, the forest presented the best performance (2.53) of all subsystems, followed by pasture (3.17), annual culture (5.67) and orchard (6.03). In order to improve this indicator, vegetation covering should become more efficient in energy transformation and should add value to its products, through certification or through the use of different sales channels such as organic/agroecological stores or food markets.

### 3.2.6. *Emergy loading ratio*

Pasture is the vegetal covering that causes the greatest environmental impact (4.43). The others systems, annual culture, orchard and forest resulted in lower values: 1.25, 0.43 and 0.17, respectively. The forest and orchard systems uses more renewable resources than non-renewable ones then their ELR values are lesser than 1, thus, these systems are extremely sustainable.

### 3.2.7. *Ternary diagram*

A ternary diagram for Duas Cachoeiras vegetation covering was also made (Fig. 8), in the same way as for emergy indicators in the farm comparison.

Again, the size of dots represents the amount of emergy used by the system. Thus, orchard (2) used more emergy that the others. The diagram indicates that subsystems (3) and (4) use approximately the same percentage (5%) of non-renewable purchased resources; however, subsystems (4) use lower amounts of non-renewable natural resources (9%) and

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[1] To receive the emergy analysis table of Duas Cachoeiras farm vegetation covering, contact Enrique Ortega at <ortega@fea.unicamp.br>.

**Table 15 – Emergy indicators calculated considering the renewability factor of material and services for the vegetation covering of Duas Cachoeiras farm—year 2003**

| Emergy indicators | Annual culture 4.3 ha | Orchard 0.3 ha | Pasture 1.44 ha | Forest 7.75 ha |
|---|---|---|---|---|
| Tr (seJ/J) | 305,912 | 982,761 | 405,403 | 119,840 |
| %R | 44.44 | 69.81 | 18.42 | 85.59 |
| EYR | 8.23 | 3.37 | 14.49 | 20.22 |
| EIR | 0.14 | 0.42 | 0.07 | 0.05 |
| EER | 5.67 | 6.03 | 3.17 | 2.53 |
| ELR | 1.25 | 0.43 | 4.43 | 0.17 |

greater amounts of renewable emergy (86%), resulting in a better performance of emergy indicators. For the sustainability index, forest (4) obtained the best performance, although annual culture (1) and orchard (2) also have a high value. Pasture (3) was in the $2.5 < ESI < 5$ range, indicating that it may have a great contribution to the economy at low environmental impact. It's important to note that the systems plotted in the ternary diagram are distant to the *F* vertex because this is a characteristic of small family farms model of agricultural production that uses low quantities of nonrenewable resources from economy and high quantities of renewable flows from nature. The systems (1) and (3) are nearest to the *N* vertex due to soil loss.

### 3.3. *Best Management Practices (BMPs) to improve farming systems*

The emergy analysis was successfully used with in the diagnosis of the properties studied in this work. However, for a more comprehensive work, it is necessary to suggest practices and public policies in order to improve farm performance. Cavalett et al. (2006) suggested some Best Management Practices for integrated farm systems for corn, swine, and fish production in the South of Brazil. According to the authors, "BMPs are the best means of preventing environmental problems while allowing production to be held in an economically efficient manner." In a broad sense, BMPs aim to reduce the dependency on economic inputs, to reduce the usage of non-renewable natural resources, to improve the system's efficiency in the transformation of potential available energy, and to promote the conservation of environmental services.

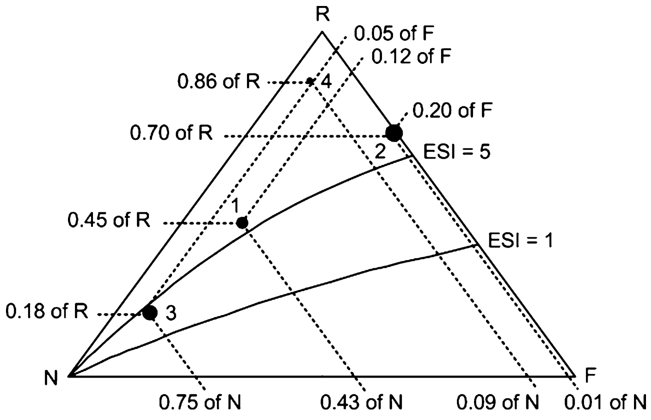

**Fig. 8 – Ternary diagram for emergy assessment of Duas Cachoeiras farm covering in 2003. (1) Annual culture; (2) orchard; (3) pasture; (4) forest; *R*, renewable resources; *N*, non-renewable natural resources; *F*, non-renewable economic resources; ESI, emergy sustainability index.**

According to the results obtained in this research, the following BMPs can be suggested to small family farms for better environmental and economic performances:

(a) Reduce the usage of chemical inputs (until elimination) through the promotion of recycling, crop rotation, crop diversity, composting and mulching with the use of local manure and crop residues.
(b) Establish economical and environmental incentives to farmers in order to promote the preservation of natural forests. This will increase the area of legal reserve in the system and, consequently, will help to decrease soil loss, improve biological control of plagues, and increase the rain water infiltration in the ground.
(c) Correct land use, considering its declivity, properties and climate conditions. This will decrease soil erosion and increase rain water percolation in aquifer and watershed.
(d) Take into consideration the needs of people in the region and the agricultural watershed potential.
(e) Obtain certification to testify that farmers that follow ecological procedures have high sustainability and can have greater profit per unit of area. By using emergy indicators, certification could suggest the proper price for each product (Cavalett et al., 2006).

Great efforts from the government, from research institutions, and from technical assistance agents will be necessary to demonstrate the great potential of ecological agriculture to farmers through Best Management Practices. Besides the BMPs, some ideas for the elaboration of public policies were suggested:

(a) Promote the adoption of agroecological farming concepts in critical watershed areas in order to increase water quality and quantity. Ecological farms do not use hazardous chemical inputs, thus improving soil structure and increasing rain water infiltration in the ground.
(b) Promote the adoption of Agroecology in agrarian reform settlements, because it lowers the dependency on external economic resources, establishes better interaction with the environment, has great product diversity, and is a water producing system.

All the BMPs and suggestions described above have two objectives: (a) to improve the economic yield of agricultural producers and (b) to increase environmental services that are in full decline (66% in accordance with MEA (2005)) and whose value was estimated in US\$ 33 trillion (33.00E + 12)/year for the planet (Costanza et al., 1997).

## 4. Conclusion

The combination of emergy analysis with the Geographical Information System improved the data quality of farm diagnosis, since it allowed a more precise calculation of soil loss – soil is a very important non-renewable natural resource.

GIS allowed us to estimate the amount of rain water infiltrated into the ground. Percolated water was considered a co-product of the agricultural ecosystem.

The utilization of the renewability factor is adequate, since local resources could have intermediate or high renewability values. This characteristic made these resources “more sustainable” in comparison to resources from other regions and to those that undergo more industrial transformations and need to be moved over long distances. With this concept, we have a better description of small family farms, improving the proposals of environmental resources usage through Best Management Practices. Duas Cachoeiras farm had a better performance in almost all emergy indicators compared to the other two farms, which use chemical agricultural production. The agroecological system revealed: (a) good efficiency in energy transformation (low value of transformity); (b) less dependency on economic resources, because only 11% of total emergy used comes from this source; (c) high sustainability, with a renewability of 59%; (d) low environmental impact (ELR = 0.69) and a greater sustainability index compared to the other systems. Thus, the expansion of agroecological production models should be promoted and encouraged to promote social welfare, economic profit, and good relationship with the environment.

Through emergy analysis, we could where the system is out of balance in relation to nature, making it possible to suggest management practices to improve farm performance. The use of the GIS and the renewability factor resulted in a greater precision in emergy analysis, but for the diagnosis to be complete, it is necessary to consider the negative and positive externalities produced by the systems.

Emergy analysis of the vegetation covering, which can be called “spatial emergy analysis”, must be studied to allow its application in future projects concerning the analysis of larger systems (watersheds, for example), where the acquisition of input and output data demands time and money, and many times do not exist. An adequate satellite image or air photograph in good scale could assist in the application of “spatial emergy analysis” in watersheds.

The emergy assessment combined with GIS has proved to be a useful tool in performing environmental accounting of production systems, since it takes into consideration the contribution of nature beyond production means, labor, and services, according to different spaces. The emergy methodology can be very helpful in developing administrative tools, which are needed for planning more sustainable development, according to the Agenda 21 recommendations.

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## Appendix A. Calculations and references to Table 10

| | | |
|---|---|---|
| 1 | Sun | Isolation = 5.29 kW/m$^2$ year<br>Albedo = 20%<br>Energy = (isolation) × (100-albedo)<br>Conversion = (kW/m$^2$ year) × (3.6E + 6 J/1 kW) × (1E + 4 m$^2$/ha) × ((100 − 20)/100)<br>Energy = 1.52E + 11 J/ha year |
| 2 | Rain | Rainfall = 1.25 m$^3$/m$^2$ year<br>Water energy = 5000 J/kg<br>Water density = 1000 kg/m$^3$<br>Conversion = (m$^3$/m$^2$ year) × (kg/m$^3$) × (J/kg) × (1E + 4 m$^2$/ha)<br>Energy = 6.25E + 10 J/ha year |
| 3 | Wind | Air density = 1.3 kg/m$^3$<br>Annual average of wind velocity = 5.55 m/s<br>Geotropic wind = 3.33 m/s 60% of 5.55<br>Drag coefficient = 0.001 adimensional<br>Conversion = (29.7E + 4 m$^2$/29.7 ha) × (kg/m$^3$) × (m/s)$^3$ × 0.001 × (3.16E + 7s/year)<br>Energy = 1.52E + 10 J/ha year |
| 4 | Water spring | Outflow of the springs = 35659 m$^3$/year |

Appendix A (*Continued*)

| | | |
|---|---|---|
| | | Water used in system = 1.36E + 4 $m^3$/year<br>Conversion = ($m^3$/year) × (1/29.7 ha) × (1000 kg/$m^3$)<br>× (5000 J/kg)<br>Energy = 2.29E + 9 J/ha year |
| 5 | River water | Time of pump use = 0.50 h/day<br>Outflow = 1.00 l/s<br>Outflow = 6.48E + 2 $m^3$/year<br>Conversion = ($m^3$/year) × (1/29.7 ha) × (1000 kg/$m^3$)<br>× (5000 J/kg)<br>Energy = 1.09E + 8 J/ha year |
| 6 | Nitrogen | Mass flow = 313.2 kg/ha year |
| 7 | Phosphate rock | Mass flow = 44.0 kg/ha year |
| 8 | Potash | Mass flow = 194.6 kg/ha year |
| 9 | Limestone | Mass flow = 21.7 kg/ha year |
| 10 | Biomass | Biomass flow = 247335 kg/year<br>Biomass energy = 4 kcal/g<br>System area = 29.7 ha<br>Conversion = (kg/year) × (kcal/g) × (4186 J/kcal) × (1/area)<br>× (1000 g/kg)<br>Energy = 1.39E + 11 J/ha year |
| 11 | Soil loss | Soil loss = 33,000 kg soil/ha year<br>Organic matter = 0.04 kg organic matter/kg soil<br>Organic matter energy = 5400 kcal/kgo m<br>Conversion = (kgsoil/ha year) × (kgm o /kgsoil)<br>× (kcal/kgo m)<br>× (4186J/kcal)<br>Energy = 2.98E + 10 J/ha year |
| 12 | Equipment depreciation | Depreciation = 10,963.36 R$/year<br>Monetary flow = 123.04 US$/ha year |
| 13 | Fuel (includes diesel, gasoline and lubricants) | Consumption = 500 l/year<br>Density = 0.75 kg/l<br>Fuel energy = 1000 kcal/kg<br>Conversion = (l/year) × (1/29.7 ha) × (kg/l) × (kcal/kg)<br>× (4186 J/kcal)<br>Energy = 5.29E + 7 J/ha year |
| 14 | Electricity | Consumption = 3200 kW/year<br>Conversion = (kW/year) × (1/29.7 ha) × (1000 W/kW)<br>× (3600 s/h)<br>Energy = 3.88E + 8 J/ha year |
| 15 | Materials | Consumption = 1150 R$/year<br>Conversion = (R$/year) × (1/29.7 ha) × (US$/3R$)<br>Monetary flow = 1.29E + 1 US$/ha year |
| 16a | Simple labor (a) | Number of people = 1<br>Paid wage = 260 R$/people month<br>Annual expense = 3120 R$/year<br>Conversion = (R$/year) × (US$/3R$) × (1/29.7 ha)<br>Monetary flow = 3.50E + 1 US$/ha year |
| 16b | Simple labor (b) | Number of people = 2<br>Paid wage = 130 R$/people month<br>Annual expense = 3120 R$/year<br>Conversion = (R$/year) × (US$/3R$) × (1/29.7 ha)<br>Monetary flow = 3.50E + 1 US$/ha year |
| 17 | Family labor | Number of people = 2<br>Paid wage = 260 R$/ people month |

Appendix A (*Continued*)

| | | |
|---|---|---|
| | | Annual expense = 6240 R$/year<br>Conversion = (R$/year) × (US$/3R$) × (1/29.7 ha)<br>Monetary flow = 7.00E + 1 US$/ha year |
| 18 | Maintenance | Expense = 900 R$/year<br>Conversion = (R$/year) × (1/29.7 ha) × (US$/3R$)<br>Monetary flow = 1.01E + 1 US$/ha year |
| 19 | Governmental tax | Expense = 200 R$/year<br>Conversion = (R$/year) × (1/29.7 ha) × (US$/3R$)<br>Monetary flow = 2.24 US$/ha year |
| 20 | Service | Expense = 120 R$/year<br>Conversion = (R$/year) × (1/29.7 ha) × (US$/3R$)<br>Monetary flow = 1.35 US$/ha year |
| 21 | Phone | Expense = 1440 R$/year<br>Conversion = (R$/year) × (1/29.7 ha) × (US$/3R$)<br>Monetary flow = 1.62E + 1 US$/ha year |

## Appendix B. Calculations and references to Table 11

| | | |
|---|---|---|
| 1 | Sun | Isolation = 5.29 kW/$m^2$ year<br>Albedo = 20%<br>Conversion = (isolation) × (100-albedo)<br>Conversion = (kW/$m^2$ year) × (3.6E + 6 J/kW) × (1E + 4 $m^2$/ha) × ((100 − 20)/100)<br>Energy flow = 1.52E + 11 J/ha year |
| 2 | Rain | Rainfall = 1.25 $m^3/m^2$ year<br>Water energy = 5000 J/kg<br>Water density = 1000 kg/$m^3$<br>Conversion = ($m^3/m^2$ year) × (kg/$m^3$) × (J/kg) × (1E + 4 $m^2$/ha)<br>Energy flow = 6.25E + 10 J/ha year |
| 3 | Wind | Air density = 1.3 kg/$m^3$<br>Annual average of wind velocity = 5.55 m/s<br>Geotropic wind = 3.33 m/s 60% of 5.55<br>Drag coefficient = 0.001 adimensional<br>Conversion = (1.56E + 5 $m^2$/15.6 ha) × (kg/$m^3$) × $(m/s)^3$ × 0.001 × (3.16E + 7 s/year)<br>Energy flow = 1.52E + 10 J/ha year |
| 4 | River water | Time of pump use = 3.00 h/day<br>Pump outflow = 1.00 l/s<br>Outflow = $3.89 \times 10^3$ $m^3$/year<br>Conversion = ($m^3$/year) × (1/15.6 ha) × (1000 kg/$m^3$) × (5000 J/kg)<br>Energy flow = 1.25E + 9 J/ha year |
| 5 | Biomass | Biomass flow = 125,925 kg/year<br>Biomass energy = 4 kcal/g<br>System area = 15.6 ha<br>Conversion = (kg/year) × (kcal/g) × (4186 J/kcal) × (1/area) × (1000 g/kg)<br>Energy flow = 1.35E + 11 J/ha year |
| 6 | Soil loss | Soil loss = 59,000 kg soil/ha year<br>Organic matter = 0.04 kg organic matter/kg soil<br>Organic matter energy = 5400 kcal/kgo m<br>Conversion = (kgsoil/ha year) × (kgo m /kgsoil) × (kcal/kgo m) × (4186 J/kcal)<br>Energy flow = 5.33E + 10 J/ha year |

Appendix B (*Continued*)

| | | |
|---|---|---|
| 7 | Equipment and installations depreciation | Depreciation = 22,329.00 R$/year<br>Monetary flow = 477.12 US$/ha year |
| 8 | Fuel (includes diesel, gasoline and lubricants) | Consumption = 1140 l/year<br>Density = 0.75 kg/l<br>Fuel energy = 1000 kcal/kg<br>Conversion = (l/year) × (1/15.6 ha) × (kg/l) × (kcal/kg) × (4186 J/kcal)<br>Energy flow = 2.29E + 8 J/ha year |
| 9 | Electricity | Consumption = 7500 kW/year<br>Conversion = (kW/year) × (1/15.6 ha) × (1000 W/kW) × (3600 s/h)<br>Energy flow = 1.73E + 9 J/ha year |
| 10 | Materials | Consumption = 2000 R$/year<br>Conversion = (R$/year) × (1/15.6 ha) × (US$/3R$)<br>Monetary flow = 4.27E + 1 US$/ha year |
| 11 | Fungicide | Expense = 519 kg/year<br>Conversion = (kg/year) × (1/15.6 ha)<br>Mass flow = 3.33E + 1 kg/ha year |
| 12 | Herbicide | Expense = 10.4 l/year<br>Density = 0.75 kg/l<br>Conversion = (l/year) × (kg/l) × (1/15.6 ha)<br>Mass flow = 5.0E-1 kg/ha year |
| 13 | Calcium | Expense = 5.00 l/year<br>Density = 0.75 kg/l<br>Conversion = (l/year) × (kg/l) × (1/15.6 ha)<br>Mass flow = 2.40E-1 kg/ha year |
| 14 | Calcium nitrate | Expense = 74 R$/year<br>Conversion = (R$/year) × (1/15.6) × (US$/3R$)<br>Monetary flow = 1.58 US$/ha year |
| 15 | Potassium nitrate | Expense = 100 R$/year<br>Conversion = (R$/year) × (1/15.6 ha) × (US$/3R$)<br>Monetary flow = 2.14 US$/ha year |
| 16 | Family labor | Number of people = 4<br>Paid wage = 260 R$/people month<br>Annual expense = 12,480 R$/year<br>Conversion = (R$/year) × (US$/3R$) × (1/15.6 ha)<br>Monetary flow = 2.67E + 2 US$/ha year |
| 17 | Governmental tax | Expense = 115 R$/year<br>Conversion = (R$/year) × (1/15.6 ha) × (US$/3R$)<br>Monetary flow = 2.46 US$/ha year |
| 18 | Service | Expense = 1102.46 R$/year<br>Conversion = (R$/year) × (1/15.6 ha) × (US$/3R$)<br>Monetary flow = 2.36E + 1 US$/ha year |
| 19 | Phone | Expense = 720 R$/year<br>Conversion = (R$/year) × (1/15.6 ha) × (US$/3R$)<br>Monetary flow = 1.54E + 1 US$/ha year |

## Appendix C. Calculations and references to Table 12

| | | |
|---|---|---|
| 1 | Sun | Isolation = 5.29 kW/m$^2$ year<br>Albedo = 20%<br>Conversion = (isolation) × (100-albedo) |

Appendix C (*Continued*)

| | | |
|---|---|---|
| | | Conversion = (kW/m$^2$ year) × (3.6E + 6 J/kW)<br>× (1E + 4 m$^2$/ha) × ((100 − 20)/100)<br>Energy flow = 1.52E + 11 J/ha year |
| 2 | Rain | Rainfall = 1.25 m$^3$/m$^2$ year<br>Water energy = 5000 J/kg<br>Water density = 1000 kg/m$^3$<br>Conversion = (m$^3$/m$^2$ year) × (kg/m$^3$) × (J/kg) × (1E + 4 m$^2$/ha)<br>Energy flow = 6.25E + 10 J/ha year |
| 3 | Wind | Air density = 1.3 kg/m$^3$<br>Annual average of wind velocity = 5.55 m/s<br>Geotropic wind = 3.33 m/s 60% of 5.55<br>Drag coefficient = 0.001 adimensional<br>Conversion = (2.53E + 5 m$^2$/25.3 ha) × (kg/m$^3$) × (m/s)$^3$<br>× 0.001 × (3.14E + 7 s/year)<br>Energy flow = 1.51E + 10 J/ha year |
| 4 | Water spring | Water spring outflow = 6312 m$^3$/year<br>Water used in the system = 5.05E + 3 m$^3$/year<br>Conversion = (m$^3$/year) × (1/25.3 ha) × (1000 kg/m$^3$)<br>× (5000 J/kg)<br>Energy flow = 9.98E + 8 J/ha year |
| 5 | Biomass | Biomass flow = 147866 kg/year<br>Biomass energy = 4 kcal/g<br>System area = 25.3 ha<br>Conversion = (kg/year) × (kcal/g) × (4186 J/kcal) × (1/area)<br>× (1000 g/kg)<br>Energy flow = 9.79E + 10 J/ha year |
| 6 | Soil loss | Soil loss = 118,400 kg soil/ha year<br>Organic matter = 0.04 kg organic matter/kg soil<br>Organic matter energy = 5400 kcal/kgo m<br>Conversion = (kgsoil/ha year) × (kgo m /kgsoil) ×<br>(kcal/kgo m)<br>× (4186 J/kcal)<br>Energy flow = 1.07E + 11 J/ha year |
| 7 | Equipment and Installation depreciation | Depreciation = 7854.01 R$/year<br>Monetary flow = 103.89 US$/ha year |
| 8 | Fuel (includes diesel, gasoline and lubricants) | Consumption = 1080 l/year<br>Density = 0.75 kg/l<br>Fuel energy = 1000 kcal/kg<br>Conversion = (l/year) × (1/25.3 ha) × (kg/l) × (kcal/kg)<br>× (4186 J/kcal)<br>Energy flow = 1.34E + 8 J/ha year |
| 9 | Electricity | Consumption = 12,600 kW/year<br>Conversion = (kW/year) × (1/25.3 ha) × (1000 W/kW)<br>× (3600 s/h)<br>Energy flow = 1.79E + 9 J/ha year |
| 10 | Materials | Consumption = 3000R$/year<br>Conversion = (R$/year) × (1/25.3 ha) × (US$/3R$)<br>Monetary flow = 3.95E + 1 US$/ha year |
| 11 | Vaccines and Remedies | Consumption = 1200 R$/year<br>Conversion = (R$/year) × (1/25.3 ha) × (US$/3R$)<br>Monetary flow = 1.58E + 1 US$/ha year |
| 12 | Simple labor | Number of people = 3<br>Paid wage = 260 R$/people month |

Appendix C (*Continued*)

| | | |
|---|---|---|
| | | Annual expense = 9360 R$/year<br>Conversion = (R$/year) × (US$/3R$) × (1/25.3 ha)<br>Monetary flow = 1.23E + 2 US$/ha year |
| 13 | Governmental tax | Expense = 100 R$/year<br>Conversion = (R$/year) × (1/25.3 ha) × (US$/3R$)<br>Monetary flow = 1.32 US$/ha year |
| 14 | Service | Expense = 500 R$/year<br>Conversion = (R$/year) × (1/25.3 ha) × (US$/3R$)<br>Monetary flow = 6.59 US$/ha year |
| 15 | Phone | Expense = 1000 R$/year<br>Conversion = (R$/year) × (1/25.3 ha) × (US$/3R$)<br>Monetary flow = 1.32E + 1 US$/ha year |

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