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Exploring the sustainable horticulture productions systems using the emergy assessment to restore the regional sustainability

Elisa Sayoko Nakajima*, Enrique Ortega

Ecological Engineering Laboratory, Food Engineering School, State University of Campinas, SP, Brazil

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ABSTRACT

This paper shows the environmental behavior of different horticultural production systems. Emergy assessment was applied for the analysis of three family-managed horticultural farms located in Ibiúna County and one horticultural subsystem of Yamaguishi Eco-Village in Jaguariúna County, both located in the state of São Paulo, Brazil. For Ibiúna and Jaguariúna farms the total Emergy varied from 2.36E+16 to 9.59E+16 seJ ha^{-1} $year^{-1}$, the Transformity ranged from 1.58E+06 to 4.98E+06 seJ J^{-1}, the Renewability from 17% to 55%, the Emergy Yield Ratio from 1.14 to 2.24 and the Emergy Investment Ratio ranged from 0.81 to 4.76. The Environmental Loading Ratio values showed a large variation, for organic production from 0.81 to 1.54 and for the conventional production from 4.77 to 4.88. Emergy Exchange Ratio showed a wide variation from 0.03 to 3.49. These results were compared to those obtained in an emergy analysis of five organic horticultural systems located in the highlands of Rio de Janeiro, a study performed by Nobre Junior (2009). The analysis of the whole set of results is that the renewability of Rio de Janeiro's systems is higher than Ibiúna and Jaguariúna systems because these last systems respond to the pressures of market to decrease prices increasing the volume of production using industrial aggressive inputs in a more intensive way. The conclusion will be made available to Ibiúna city government and population in order to promote a transition to Agroecological Systems involving the recovery of soil biota and native vegetation, recycling urban wastes and lowering pesticides and chemical fertilizers use.

1. Introduction

The development of the chemical industry focused on agrochemicals has been an important factor to increase the crop productivity in the last decades; but on the other hand, the intensive use of agrochemicals has become a major threat to the environment and to the social structure (Hole et al., 2005). Considering the ecological and social criticism to the energy-intensive model it has being developed organic techniques in many countries (Stolze and Lampkin, 2009).

In Brazil, during the 70 s, the chemical industry offered a technological package to small farmers in order to promote "economic development". The intensification of the use of fertilizers, pesticides and machinery did result in an increase of crop productivity (kg ha^{-1} $year^{-1}$), but it did not result in more income for the farmers (Lima Neto, 2001).

On the other hand, the world is now questioning the growing dependence of modern farming on non-renewable resources, as agrochemicals. Farm chemicals are questioned on grounds of cost but their widespread use also has implications for animal health, food quality and safety and environmental quality (Altieri, 1999).

The organic farming is an important strategy for sustainable agriculture as it avoids the use of costly industrial chemicals and improves the food crops quality and it provides control along the entire production chain through the certification process required (Castellini et al., 2006). Nevertheless, a discussion on the contribution of organic agriculture to the future of world agriculture is whether organic agriculture can produce sufficient food to feed the world. The yield in high level organic production can be critical. In particular to the role of legumes, due a crop rotation, a critical issue will be to which extent sufficient nutrients for this crop can be supplied (Ponti et al., 2012).

The organic production models based on the substitution of chemical inputs for biological ones has become a trend in the search for a more sustainable ecological agriculture (Guzmán et al.,

* Corresponding author. Faculdade de Engenharia de Alimentos, Universidade Estadual de Campinas (UNICAMP), Rua Monteiro Lobato no. 80, Campinas, Sao Paulo CEP 13083-862, Brazil. Tel.: +55 19 35214058; fax: +55 19 35214027.
E-mail addresses: sayokonakajima@hotmail.com, esayoko@fea.unicamp.br, sayokonakajima@gmail.com (E.S. Nakajima).

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2000). The agro ecological movement has emerged to meet both environmental and social issues for small farmers in Latin America (Altieri, 1999). In Brazil, recently family farming began to gain public recognition; until the 90 s it was considered a segment of marginal importance to the concerns of a society focused on the big agriculture based in monoculture (Altieri, 2002; Lima Neto, 2001).

In Ibiúna, a city located 70 km from São Paulo, a big city in Brazil standards, agriculture is a traditional activity. The county has about 73,400 inhabitants and two-thirds of its population lives in the rural area (SEADE, 2009). In recent years, some family farmers concerned with the excessive use of pesticides, soil degradation and motivated by the potential market for organic products decided to adopt the organic farming (Prefeitura Municipal de Ibiúna, 2008). Ibiúna is part of the "green belt" composed by a group of cities which provides most of the horticultural production that supplies São Paulo city needs. Ibiúna is also responsible for the conservation of the Jurupará forest park which is recognized by UNESCO as a biosphere reserve for the Atlantic Mountains rain forest.

The assessment of the alternative and conventional horticultural systems is important to provide information to decision makers who aim to maintain environmental services and to reduce environmental impacts in that region. There are several forms to assessment the sustainability of agricultural systems, among of them the Emergy which is total energy used to produce biosphera resource. The Emergy evaluation is environmental accounting methods which uses the thermodynamic basis of all forms of energy, resources and human services, and converts them into equivalents of one form of energy, usually solar emergy.

Emergy evaluation has been used to assess agricultural systems. Zafiriou et al. (2012), have studied the white asparagus production in Greece among conventional, integrated and organic farming systems and also the effect of farming to greenhouse gas emissions to decide best management strategies. Hansen et al. (2001) examined a need to expand and develop organic farming system in line with increasing demands for organic food and growing environmental concerns in Denmark in the light of European Policies. In China the agricultural diversification using more intensive techniques was evaluated using emergy indicators (Zhang et al., 2012), the results showed that although economically feasible, the intensification of agricultural activities became environmentally unsustainable. Lu et al. (2010) evaluated the integrated emergy, energy and economic evaluation of rice and vegetable production systems and the studies showed that long-term rice was the best choice for sustainable development, followed by rotation systems. The emergy assessment of a soybean biodiesel production chain in Brazil showed that the agricultural step uses the highest amount of non-renewable resources (Cavalet and Ortega, 2009). The sustainability assessment of a large-scale ethanol production from sugarcane in Brazil was calculated using fossil fuel embodied energy analysis and emergy assessment adopting Life Cycle Analysis (LCA) concepts and considering two production phases, farming and industrial processing, resulting in a low renewability (Pereira and Ortega, 2010). In Sicily, it was applied to evaluate resource use, productivity, environmental impact and overall sustainability in red orange production and the results showed better performance for the system in which the use of economic resource is more intense (La Rosa et al., 2008). Agostinho et al. (2008) used emergy analysis in association with Geographical Information System (GIS) for comparison of three small farms, located in Amparo County, in São Paulo state, Brazil, the results showed that the agroecological farm was more sustainable and that it could be used as a model for small farms in their transition to ecological agriculture. Wood et al. (2006) compared environmental impacts in an organic and a conventional farm and the results showed that direct energy use, energy related emissions, and greenhouse gas emissions are higher for the organic farm than for the compared conventional farm. Nevertheless, the indirect contributions for all factors are much higher for the conventional farms. Bos et al. (2014) compared organic and conventional performance related an energy use and Greenhouse gas emissions and they obtained similar results.

Ibiúna region is facing socio-environmental problems. Horticultural producers desire a change from conventional to more ecological production systems. The aims of this research is to explore what are the options for horticultural production considered more sustainable, by comparing energy performance of small family-managed horticulture farms.

The research was realized in three properties of Ibiúna: (1) a farm with two subsystems (organic and conventional), (2) an exclusively organic farm, (3) an exclusively conventional farm, and finally, one farm in Jaguariúna County (4) a horticulture subsystem of a complex agroecological farm (Eco Vila Yamaguishi). At the end of this research, the results is compared with those obtained by Nobre Junior (2009) in the emergy assessment of horticulture systems in Rio de Janeiro in order to provide a better profile of horticulture in the Southeast of Brazil.

2. Methodology

Emergy evaluation was applied for four properties of the State of São Paulo, with data base of the year 2008. Fig. 1 shows the location of Ibiúna and Jaguariúna in São Paulo state, Brazil.

2.1. Emergy evaluation

Emergy evaluation is a form of environmental accounting that considers the energy flows of a system, in terms of the amount of energy previously used, directly or indirectly, expressed in a single base: solar emergy, expressed as solar equivalent Joules (seJ) (Odum, 1996; Ulgiati and Brown, 2004). Emergy analysis demands to follow some steps described in the following lines:

2.1.1. Construction of emergy diagram

The system diagram schematically depicts all the inputs, the internal processes as well as the outputs which are essential in the emergy methodology for understanding a system.

2.1.2. Building Emergy evaluation tables, derived directly from the diagrams

When building Emergy evaluation table, each row in the table represents an input of energy from the diagram of the system under study and each row is multiplied by it respective Unit Emergy Value (UEV) to express each inputs as emergy flow. In first lines, it is analyzed the contribution of nature (I), $I = R + N$ where nature's renewable resources are represented by word R and non-renewable by N. Below, in the following lines it is described contribution of resources from the economy (F), $F = M + S$ where M represents the materials and S the services. At the end of the table, it is determined the value of the total emergy used by the system (Y), $Y = I + F$. All the flows are measured in solar equivalent Joules per hectare year. In this work the emergy indicators is calculated according to Odum (1996) and also considering the partial renewability of economic inflows proposed by Ortega et al. (2002), manifested in the Materials (M_R), and in the Services (S_R), as showed in Table 1.

2.1.3. Emergy indicators calculation

The emergy indicators are calculated as described below:

Transformity (Tr): Intensity of energy embodied in the product. It measures the amount of solar equivalent emergy (seJ) used to

Fig. 1. Location of Ibiúna and Jaguariúna in São Paulo state.

generate a certain amount of produced energy (Ep). This indicator assesses the ecosystem efficiency. Always, the smallest transformities indicate higher efficiencies.

Specific Emergy (S_pE_m): Emergy investment per unit mass *output*. Specific emergy is usually expressed as solar emergy per gram (seJ/g).

Renewability (Ren): Percentage of renewable energy in the total emergy used. It indicates the degree of sustainability of a productive system.

Emergy Yield Ratio (EYR): the ratio between the total emergy and the emergy resources stemmed from economy. The ratio is a measure of how much an investment enables a process to exploit local resources in order to further contribute to the economy.

Emergy Investment Ratio (EIR): Evaluates how of the ecosystem responds to the emergy invested from economy, it allows comparing alternatives that use the same natural resource.

Environmental loading ratio (ELR): It is the pressure that the system exerts on the environment. A value below 2 indicates a low pressure, values from 2 to 10 a moderate pressure and values above 10 indicate a great pressure on the ecosystem.

Emergy exchange Ratio (EER): The unitary value means a balance exchange (EER = 1). If EER has a value lower than unity, the producer has an advantage over the buyer; if the value is greater than one then the consumer takes advantage of the producer.

2.2. Studied areas

The three farms studied in Ibiúna County sell their products directly to stores and also by means of a farmers' cooperative that supplies the metropolitan region of the cities of São Paulo, Campinas and Sorocaba, they are:

(1) **Novo Mundo:** a farm with two parcels: an organic, established since the year 2000 and a conventional production system which uses chemical inputs in intensive form. To reduce chemicals in the conventional production some organic techniques were being applied.
(2) **João Dias:** an area of the five hectares, a size that represents the production scale of 29% of the total of the horticultural producers in Ibiúna. It is an organic farm family administered where farmers live within the property and participate of rural work. During the year for short periods of time, when the site needs more manpower the owners hire a few workers.
(3) **Nakajima:** a horticulture conventional production system of 29 ha, which represents the production scale of 12% of total of the producers of the Ibiúna County. It is the most common model of management in the region, where families live within the properties and hire workers during all the year.

The farm studied in Jaguariúna County:

(4) **Yamaguishi:** an agro ecological rural property that includes a horticulture subsystem. This farm is an ecological village that has 19 adults and 5 children as permanent residents. All the adults perform activities in the farm, both in agricultural and administrative tasks. The farm is organized as a business enterprise and hires 12 workers who do not live in the farm. The systems diagram of Yamaguishi Eco village system can be seen in Takahashi et al., 2008.

Table 2 shows the geographic coordinates and main characteristics of each system. All the systems studied produce vegetables such as lettuce, cabbage, tomatoes, parsley, chives, chard, broccoli, carrots, endive, escarole, spinach, mint, basil and more.

2.3. Data collection

The questionnaire presented in Appendix A was applied to obtain data from the administrators. Data related to production,

Table 1
Emergy Indicators used in this work.

Indicators	Equation	Reference
Solar Transformity (Tr)	Tr = Y/Ep	Odum, 1996
Renewability (Ren)	$R = (R + M_R + S_R/Y)x100$	Ortega et al., 2002
Emergy Yield Ratio (EYR)	$EYR = Y/(M_N + S_N)$	Ortega et al., 2002
Emergy Investment Ratio (EIR)	$EIR = (M_N + S_N)/(R + N + M_R + S_R)$	Ortega et al., 2002
Environmental Loading Ratio (ELR)	$ELR = (N + M_N + S_N)/(R + M_R + S_R)$	Ortega et al., 2002
Emergy Exchange Ratio (EER)	EER = Y/(US$* seJ/US$)	Odum, 1996

(a) Ep (total energy produced).
(b) MR(renewable fraction of materials).
(c) SR(renewable fraction of services).
(d) MN(non-renewable fraction of materials).
(e) SN(non-renewable fraction of services).

Table 2
Geographic coordinates of the properties and characteristics.

Properties	Geographic location			Area (ha)	System of production
	Latitude	Longitude	Altitude		
Novo Mundo	23°45′29″S	47°14′18″W	939 m	25,5	Organic
				53,8	Conventional
João Dias	23°47′03″S	47°05′46″W	922 m	5	Organic
Nakajima	23°40′23″S	47°20′46″W	862 m	29	Conventional
Yamaguishi	22°42′24″S	47°59′50″W	621 m	10	Agroecological

inputs, infrastructure, products, packaging and product sales were collected in interviews held with the producers who also allow the researchers to obtain field data and invoice forms for further calculations related to the present research.

3. Results and discussion

The diagram in Fig. 2 describes the organic production. On the right, are the contribution of nature, as sun, rivers, wind and rain. On the top of figure are the inputs of resources from the economy, like materials and services. Inside of the square, is represented the organic production system with seeding that following for two ways a green house or a bed. The products are packaged and transported to sell, and these products can also be food to the family and employees. Inside the organic production system there is also a process of organic compound composting with materials from outside. The diagram in the Fig. 3 describes conventional production systems, wherein the main difference with the organic production is use of chemical fertilizers and absence of composting process.

The emergy flows evaluation is shown in Tables 5 to 9 of Appendix B. The aggregated emergy flows are shown in Table 3. The emergy indices obtained are presented in Table 4.

The emergy indices calculated in this research were compared to those obtained by Nobre Junior (2009) that evaluated five small horticultural systems in the highland region of Rio de Janeiro. In his study, all the properties are agroecological systems with small area (less than 1 ha), surrounded by native forests and all of them use basically local resources and trade products in local markets. A very different behavior in comparison with Ibiúna and Jaguariúna systems which are devoted to supply vegetables to very well structured markets in broader regions.

Fig. 4, shows that, in terms of ecosystem's efficiency, Yamaguishi village develops the best use of resources. In terms of conventional production the results show that the Nakajima farm is more efficient but it has the lowest renewable transformity index among the studied farms in Ibiúna once it depends on nonrenewable inputs. It is possible to explain this behavior because the productivity of this farm is higher comparing to other studied horticulture farms.

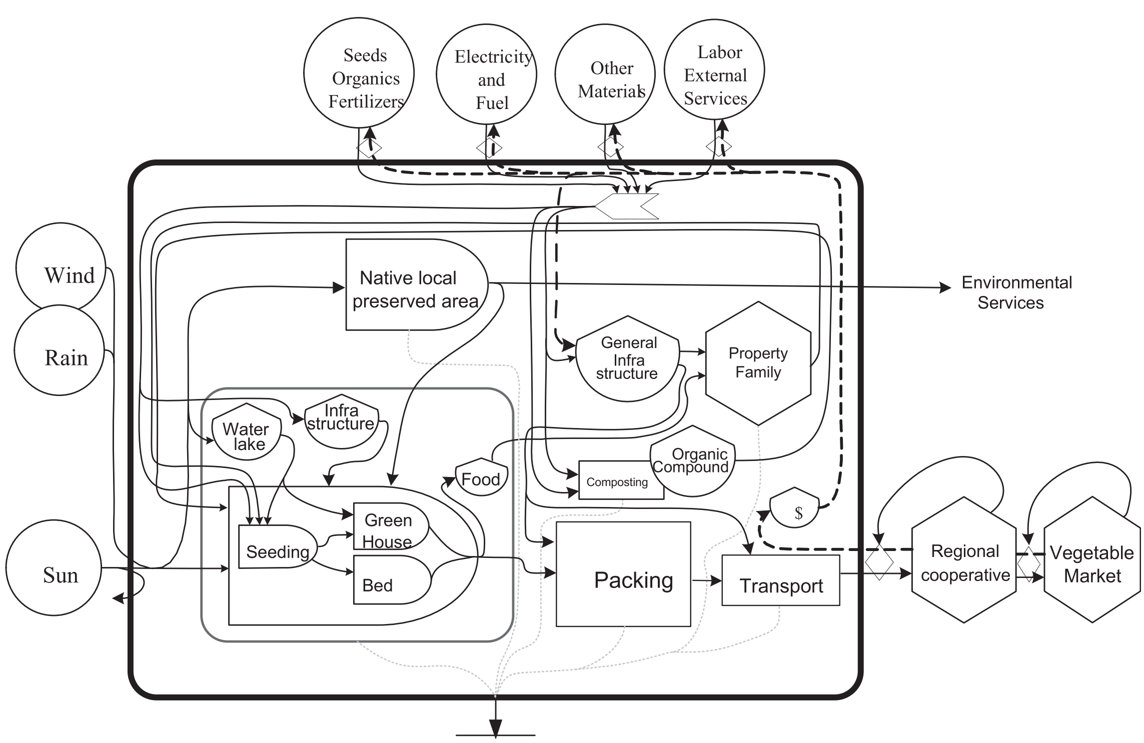

Fig. 2. Organic production diagram.

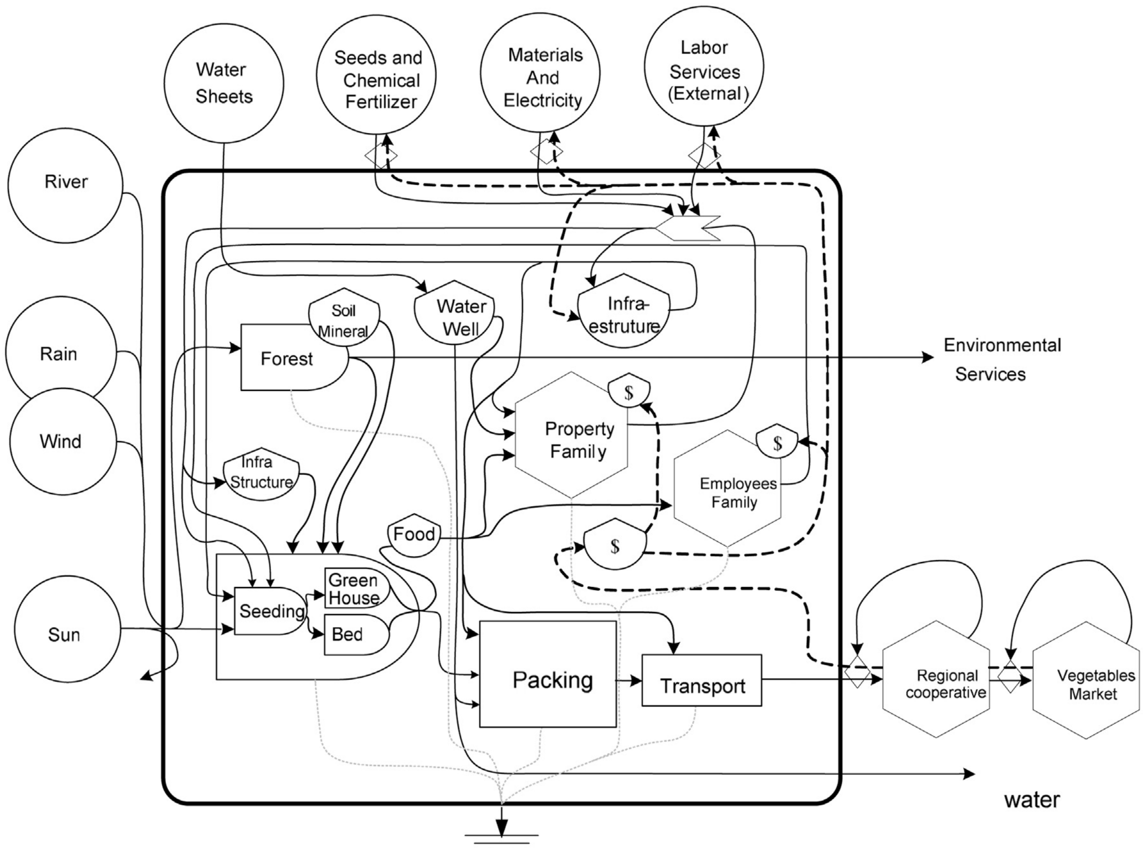

Fig. 3. Conventional production diagram.

In Fig. 5, the emergy indices of organic, conventional and agroecological horticultural systems is organized according to the degree of energy invested in farming (EIR) and as result the performance trends of horticultural system are revealed. This graph shows that some emergy indices decrease with energy intensification, a decline is observed in renewability and EYR. On the other hand the ELR increases with intensification of farming. The reason is that the systems studied in Ibiúna and Jaguariúna uses external resources in order to obtain high productivity, even in the case of organic production in Yamaguishi ecological farm that showed to be quite dependent on external economy resources. The main difference in the Rio de Janeiro highland farms (Nobre Junior, 2009) is a lower dependence on external economy pressures and as the market's demands are not as strict as in São Paulo there is no need to increase the productivity to attend such demand.

In the case of EER, Fig. 5 shows that the values for São Paulo systems are low, except Novo Mundo conventional system (EER = 3.51). This means that São Paulo organic system has emergy gains in their exchange with consumers and that Rio's producers are losing emergy in their commercial trade.

The complete set of values in Fig. 5 reveals that the farmers are forced to provide a high volume of production at low prices to maintain profit. Then the farmers increase the productivity using more chemicals. The less intensive systems are more ecological and

Table 3
Aggregated Emergy flows in seJ ha^{-1} $year^{-1}$x 1E+13.

Inputs and services		Ibiuna				Jaguariuna
		Novo Mundo		Joao Dias	Nakajima	Yamaguishi
		Organic	Conventional	Organic	Conventional	Agroecological
R	Renewable natural resources	644	644	1194	618	294
N	Non-renewable natural resources	3	3	3	28	3
I	Nature contributions	647	647	1197	647	297
M	**Materials**	2357	4704	2725	1401	355
M_R	Renewable materials and energy	268	172	718	170	24
M_N	Non-renewable materials and energy	2088	4532	2007	1231	332
S	**Services**	3334	4236	1153	3317	1708
S_R	Renewable services	1581	847	376	123	986
S_N	Non-renewable services	1752	3389	777	3194	722
F	Economy Resources	5690	8940	3878	4718	2064
Y	Total (Y)	6337	9587	5075	5364	2361
	Energy Produced in J	2.15E+10	2.04E+10	1.69E+10	2.14E+10	1.49E+10

Table 4
Emergy Indicators obtained in this work and studied in Highland Area of Rio de Janeiro.

Indicator	Ibiuna [a]				Jaguariuna[a]	Rio Janeiro[b]				
	Novo Mundo		Joao Dias	Nakajima	Yamaguishi	1	2	3	4	5
	Organic	Convent.	Organic	Convent.	Agroeco					
Tr (seJ J^{-1})	2.95E+06	5.51E+06	2.97E+06	2.90E+06	1.58E+06	3.14E+07	1.67E+07	6.27E+06	3.06E+07	2.32E+07
Specific Emergy (seJ kg^{-1})	4.34E+12	4.29E+12	5.81E+12	2.41E+12	3.48E+12	1.99E+10	1.59E+10	2.56E+10	2.62E+10	1.82E+10
EYR	1.65	1.21	1.82	1.14	2.24	2.45	5.99	3.48	6.65	6.82
EIR	1.54	4.76	1.21	4.71	0.81	0.69	0.2	0.4	0.18	0.17
ELR	1.54	4.77	1.22	4.88	0.81	0.69	0.2	0.4	0.18	0.17
Ren %	39.34	17.34	45.09	16.99	55.21	59.11	83.28	71.25	84.95	85.34
EER	1.05	3.49	0.55	1.42	0.03	1.93	6.12	2.29	12.09	7.68

[a] This study.
[b] Nobre Junior (2009).

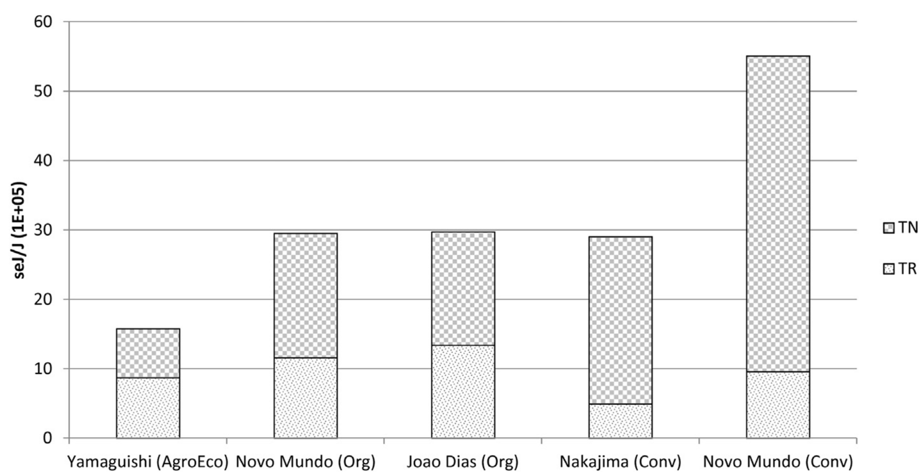

Fig. 4. Transformity graphic.

they are able to obtain renewable material from nature at no cost. They also use lower quantities of non-renewable resources from the economy and their products contain more renewable emergy obtained at no monetary cost. Nevertheless the price of products should be higher to balance the exchange to the final clients EER = 1.

3.1. Analysis of the complete set of horticultural systems

The farms studied in São Paulo sell their products to big marketing systems which are very powerful and pressure price and volumes. They demand high productivity from the farmers, and this condition implies in using more chemicals from the industrial system.

To become more sustainable it would be necessary to reduce dependence on chemical inputs from the economy and using more environmentally friendly techniques. Although studies such as Nobre Junior (2009), Pereira and Ortega (2010) and Agostinho and Ortega (2012) indicate this possibility, there is huge difficulty in reversing the conventional agrochemical production to the organic or agroecological models. One factor to be considered is that, even a conventional producer converting their production to organic system, he needs to wait from two to three years for their product to be considered organic. This period is necessary to attend the requirements of the Brazilian legislation for organic products, is the reversing time for the soil become free of residuals of the chemicals fertilizers and pesticides.

Sociological studies realized in Ibiúna consider that organic farmer articulation contributes to a better dynamics of organic production while it improves the question of the regional economy, product quality and integrating social, cultural and environmental issues (Bellon and Abreu, 2006).

The contacts made with farmers during this research revealed that despite farmers know that the agrochemicals can be a risk for their health if not properly used and that their excessive usage may destroy the soil's biota and pollute water resources, they know that the transition to organic farm demands a great investment and that they will not have support from public policy during this process; the farmers need to have savings to begin this process in their farms. The transition requires having part of their land unavailable for production in order to initiate the conversion process and this means for the producers the possibility to facing a long period of time with lower outcome and income.

Currently, according to Ortega et al. (2009) the solution implies in the adoption of new production models (integrated ecological systems for food, energy and environmental services production). Within a more conventional perspective, the Brazilian government has been promoting the adoption of technologies of integrated monoculture systems to produce food, energy and environmental services (carbon sequestration) and these kinds of systems are demanding the payment of environmental services to farmers. The payment for environmental services has been practiced in many countries of the world (Hansen et al., 2001; Lesjak, 2008).

As result of this discussion, it is recommended to elaborate a proposal of public policy to promote agroecological farming transition in Ibiúna because it was revealed that these systems show better environmental and social performance and could be more attractive for the future generations.

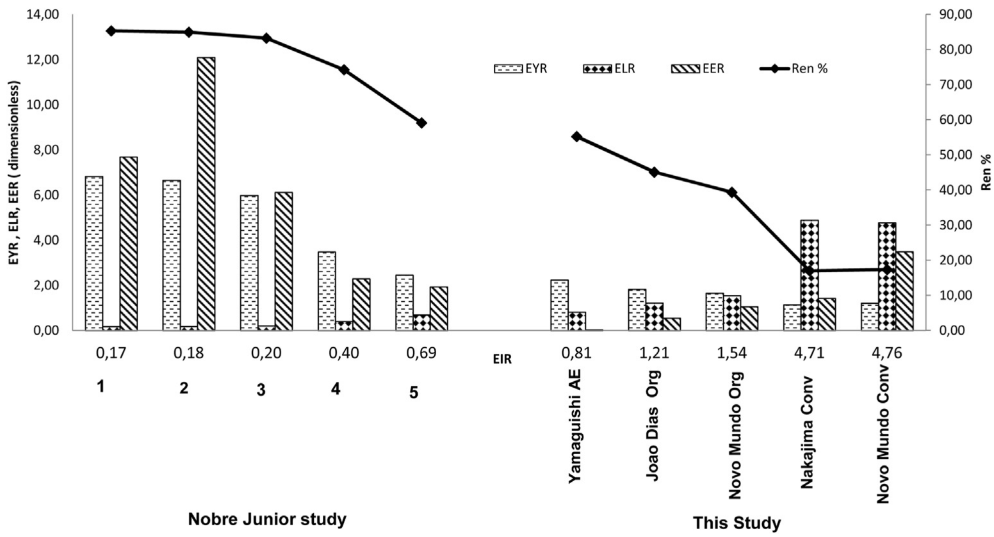

Fig. 5. Emergy indicators comparison.

4. Conclusion

This research shows that organic and agroecological systems have better thermodynamical behavior than the conventional agrochemical farms. The sustainability, analyzed in terms of renewability, shows that the values obtained in this study is worse than values of the Rio de Janeiro systems, where the farm activities are less intense and the producers do not depend on deals imposed by market.

The environmental and economic public policies in Ibiúna should be able to provide technical assistance to farmers, in addition to financial support and environmental services payment that will make it feasible to reverse the present chemical intensification condition.

In order to achieve a more sustainable horticultural production along with a meaningful environmental contribution in Ibiúna, it is necessary to promote more environmental production systems, because these show better environmental performance and are potentially attractive for future generations. It is also necessary to promote a discussion in the County, to generate public policies in order to development of a local organization of ecological agriculture and, after this, introduce the education on ecological and economics approach using biophysical systems as well as sociological analysis of the kinds of rural production. The producers' forces must be ally to the community and government to develop strategies to counteract the forces of the markets that demand high productivity and consequently high demand of chemicals.

The emergy assessment used in this study can be applied in other regions to explore the farming systems sustainability, in order to promote a transition to agroecological systems.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2014.07.030.

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