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EMERGY ASSESSMENT OF INTEGRATED PRODUCTION SYSTEMS OF GRAINS, PIG AND FISH IN SMALL FARMS IN SOUTH BRAZIL

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ABSTRACT

The present study uses emergy methodology to evaluate environmental aspects of integrated production systems of grains, pig and fish in small farms in the South region of Brazil. New emergy parameters that use partial renewability factor of each input were used to improve emergy accounting. These parameters were already applied to different case-studies and are very appropriate for use in emergy assessment of integrated agricultural systems. The following indicators were calculated for the integrated production system of grains, pig and fish: Transformity: 948,000 sej/J; Renewability: 24%; Emergy yield ratio: 1.44; Emergy investment ratio: 2.28; Environmental loading ratio: 3.13 and Emergy exchange ratio: 6.8. These values were compared with results calculated for grains, pig and fish production subsystems working in a separated way. The results obtained signalize that an integrated system has better emergy efficiency, is more sustainable and is less stressful on the environment in comparison with separated production subsystems. The emergy indicators presented are discussed in the text and they will be useful in further work to assist the formulation of public policy.

1. INTRODUCTION

The emergy accounting methodology has been developed over the last three decades as a tool for environmental policy and to evaluate the quality of resources based on the dynamics of complex environmental and economic systems (Ulgiati and Brown, 1998; Odum, 1996; 1983). In recent years, research results using emergy have been presented in several studies, including emergy evaluation of ecosystems and economic systems (Brown and Ulgiati, 2004; Higgings, 2003; Brown and Buranakarn, 2003; Yang et al., 2003; Lefroy and Rydberg, 2002; Qin et al., 2000; Panzieri et al., 2002; 2000; Ulgiati and Brown, 1998) and emergy theory research (Herendeen, 2004; Hau and Bakshi, 2004; Brown et al., 2004; Bastianoni and Marchettini, 2000). However, there are few emergy studies that evaluate integrated agricultural production systems. The South region of Brazil is composed by Rio Grande do Sul, Santa Catarina and Paraná States. The studied area was in the West region of Santa Catarina State. Santa Catarina is the second southernmost State of Brazil (27ºS and 51ºW) and its West region is characterized by a large agro-industry, historically supported, in cooperative basis, by small agricultural production units. Such agro-industry was developed in the last five decades and became the greatest agro-industrial site for pork and poultry production in Brazil (Silvestro et al., 2001). During the last twenty years, these agro-industries intensified the vertical expansion of production in the attempt to reduce costs, but the increase of production has decreased the number of agricultural producers associate at these cooperatives.

The direct consequence was the pollution of groundwater/surface water resources caused by the production of huge amounts of animal manure. Therefore, in order to assist public polices, the correct appreciation of this complex scenario is fundamental. Such analysis as presented herein would serve as a tool to avoid the pollution problems in others regions of Brazil with similar production systems. In this regard many people and environmental agencies are already discussing the sustainability of intensive production systems. As a consequence of environmental concerns, we decided to apply the emergy method to evaluate the environmental aspects of integrated production system of grains, pig and fish in small farms in the South region of Brazil. Furthermore, the emergy indicators calculated in the analysis were used to suggest some better management practices useful for farmers to improve the environmental performance of farming systems.

1.1 Description of the farming systems

The West region of Santa Catarina State occupies an area of 25.3 thousand km^2 extending from central highlands to the border of Argentina. The population is about 1.17 million inhabitants, 37% of whom are located in rural areas. The region is mainly composed of mountains, with only 33% of the area appropriate for annual cultures. This region is characterized by the presence of very small farms according to Brazilian standards, where 90% of these farms are smaller than 50 ha. The rural area's population is composed mainly by descendants of European colonists (Italians, Germans and Portuguese), who came to Brazil during the last 150 years.

These factors induced the formation of an agricultural sector characterized by a diverse production on familiar basis. Main agricultural products are: pork and poultry (managed by agro-industries integrated with small farmers), corn, soybean, wheat and beans (Testa et al., 1996; Boll and Garádi, 1995). In these small farms in the south region of Brazil the integration of production occurs by using corn as the main component for pig diet. Pig manure is used to fertilize corn, wheat and soybean plantations. Furthermore, in several farms, part of this manure is used to feed fishes cultured in small earthen excavated ponds.

The systems of pig production adopted in West region of Santa Catarina State are characterized by high level of confinement, resulting in a great amount of manure, which is consequently concentrated in a small area. Traditionally, the immigrants breed pigs in the lower parts of the properties, close to the watercourses, while the corn was planted in the higher parts of the properties. Therefore, manure that was not used in the crops was allowed to drain directly in to the rivers. Concentration of animals per unit of area was small at that time and considering a diverse production, pollution by manure accumulation was not a concern. The problem of pollution started to be more serious with the adoption of confinement systems in the 70´s, keeping animal production close to the watercourses (Guivant, 1997). With the introduction of such specialized system on a large scale basis, the environmental problems caused by manure pollution were enhanced.

The emergy analysis was applied to the integrated farm as a whole system and also to grains, pig and fish production subsystems working in a separated way. While considering separated subsystems, the recycle appears in the emergy accounting as an external flow of economy (F) with its relative renewability.

2. EMERGY METHODOLOGY

The description of emergy methodology is given in details by Odum (1996) and by other authors (Brown and Ulgiati, 2004; Ulgiati and Brown, 1998). The first step is drawing an energy diagram of the system. This is necessary to organize the relationships between the main components and process of a system of interest, and also to depict the ecosystem environmental basis and its connection to the larger economy. The diagrams are constructed using the energy systems language, which is a symbolic modeling language. This language presents network properties of systems, holistically using symbols with specific meanings (Odum, 1996; 1983). A system diagram of a typical small farm located in the South region of Brazil that produces grains, pig and fish in integrated way is showed in Figure 1.

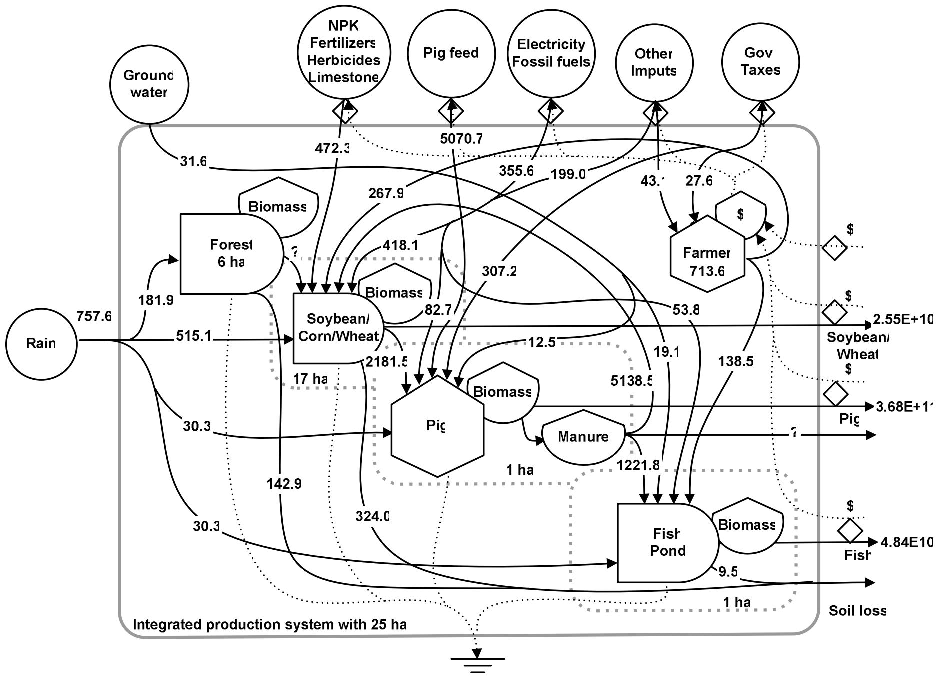

Figure 1. System diagram of a typical small farm located at the South region of Brazil that produces grains, pig and fish in a integrated way. In this figure are signalized all emergy flows values ($x10^{13}$ sej/year), including internal flows values, as well the separated subsystems that compound the integrated system. The outputs (soybean, wheat, pig and fish) are in J/year. The farm has a total area of 25 ha where legal reserve area comprehends 6 ha. The subsystem of grains production occupies 17 ha, pig production occupies 1 ha and fish production occupies 1 ha

In this figure are shown all emergy flows values (in sej/year), including internal ones, as well the subsystems that compound the integrated production system.

The second step for the emergy assessment is to organize the different inputs in emergy evaluation tables. The preparation of the emergy evaluation tables is based on diagrams and they allow calculating the emergy indicators. For the emergy calculations based on the emergy evaluation tables, the materials and services were not totally considered as nonrenewable resources.

The partial renewability of resources was first considered by Ulgiati et al. (1994), and then further explored by Ortega et al. (2005; 2002), Ortega and Polidoro (2002) and Ulgiati et al. (2004). The approach is considered an evolution in emergy methodology, as a significant step forward to a better assessment of a system sustainability based on its renewable emergy basis. Table 1 shows the classification of emergy flows to assess the partial renewability of materials and services with more details.

Table 1. Classification of Emergy flows used in environmental accounting

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

In Table 2 the emergy indicators proposed by Odum (1996) were slightly modified in order to evaluate more properly the sustainability of resources, by considering renewability of each one of the resources used. Solar emergy and transformity, together with other indicators and ratios calculated from emergy evaluation tables, are used to evaluate efficiency and the environmental impact of assessed systems, and to make policy recommendations for long-term sustainability.

Table 2. Emergy indicators used in environmental accounting

Indicators	Expression	Signification
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 system
Emergy yield ratio (EYR)	$Y/(M_N+S_N)$	The ratio of the emergy of the output divided by the emergy of those inputs that are fed back from outside the system
Emergy investment ratio (EIR)	$(M_N+S_N)/(R+M_R+S_R+N)$	The ratio of emergy of purchased inputs divided by the emergy of free inputs
Environmental loading ratio (ELR)	$(M_N+S_N+N)/(R+M_R+S_R)$	The ratio emergy from purchased and nonrenewable nature inputs, to the emergy from renewable resources
Emergy exchange ratio (EER)	Y/[($)x(sej/$)]	The ratio of the delivered emergy by the system to economy divided by the emergy received by the sells of products

3. RESULTS AND DISCUSSION

In this emergy assessment we calculated emergy indicators of transformity, renewability, emergy yield ratio, emergy investment ratio, environmental loading ratio emergy exchange ratio to evaluate environmental aspects of integrated production systems of grains, pig and fish in small farms in the South region of Brazil and to compare with results obtained for the grains, pig and fish production subsystems working in a separated way. Also, it is shown how intensification on pig production changes the emergy indicators of the integrated system.

3.1 Emergy assessment of the farming systems

The results of emergy assessment of the integrated production system and of the separated grains, pig and fish production subsystems are presented, respectively, in Tables 3, 4, 5 and 6. In these tables all the inputs were converted to solar emergy using transformity values available in literature, after carefully checking their applicability to the specific case under study. Values of goods and services supplied to the system were multiplied by suitable renewability factors, in order to split them into their renewable and nonrenewable components.

Table 3. Emergy evaluation of integrated production systems of grains, pig and fish (emergy flows x10^{13} sej/ha/year)

Note	Item	Renewability fraction	Unit	Unit/ha/year	sej/unit	Reference for sej/unit	Renewable emergy flow	Nonrenewable emergy flow	Total emergy flow
Renewable inputs (R)									
1	Sun	1	J	5.08E+09	1.00E+00	Definition	0.00	0.00	0.00
2	Wind	1	J	6.21E+04	2.45E+03	Odum et al., 2000	0.00	0.00	0.00
3	Rain	1	J	9.78E+10	3.10E+04	Odum et al., 2000	303.03	0.00	303.03
Nonrenewable inputs (N)									
4	Ground water	0	J	4.94E+08	2.55E+05	Bastianoni et al., 2000	0.00	12.60	12.60
5	Soil loss	0	J	1.54E+10	1.24E+05	Brandt-Williams, 2002	0.00	190.58	190.58
Materials (M)									
6	Corn	0.17	g	4.95E+06	2.08E+09	Ortega et al., 2002	174.88	853.83	1028.71
7	Soybean meal	0.17	g	2.55E+06	3.26E+09	Ortega et al., 2002	141.56	691.14	832.70
8	Nutrient mix	0.05	g	2.75E+05	6.08E+09	Estimated	8.35	158.63	166.97
9	Limestone	0.05	g	4.56E+05	1.68E+09	Brandt-Williams, 2002	3.83	72.78	76.61
10	Phosphate	0.05	g	1.12E+04	3.70E+10	Brandt-Williams, 2002	2.07	39.28	41.35
11	Potash	0.05	g	2.12E+04	2.92E+09	Brandt-Williams, 2002	0.31	5.90	6.21
12	Nitrogen	0.05	g	1.28E+04	4.05E+10	Brandt-Williams, 2002	2.59	49.23	51.82
13	Herbicides	0.05	g	5.25E+03	2.49E+10	Brandt-Williams, 2002	0.65	12.40	13.05
14	Other materials	0.05	US$	1.55E+01	3.70E+12	Coelho et al., 2003	0.29	5.46	5.74
15	Fossil fuels	0.05	J	1.13E+10	1.11E+05	Brandt-Williams, 2002	6.28	119.30	125.58
16	Fingerlings	0.05	US$	2.82E+01	3.70E+12	Coelho et al., 2003	0.52	9.91	10.43
17	Installation depreciation	0.05	US$	7.51E+01	3.70E+12	Coelho et al., 2003	1.39	26.39	27.78
18	Equipment depreciation	0.05	US$	9.60E+01	3.70E+12	Coelho et al., 2003	1.78	33.73	35.51
19	Electricity	0.05	J	6.20E+08	2.69E+05	Brandt-Williams, 2002	0.83	15.83	16.66
20	Family costs	0.05	US$	4.65E+01	3.70E+12	Coelho et al., 2003	0.86	16.36	17.22
21	Government taxes	0.05	US$	2.98E+01	3.70E+12	Coelho et al., 2003	0.55	10.47	11.02
Services (S)									
22	Unqualified manpower	0.50	J	3.63E+08	7.56E+06	Brandt-Williams, 2002	137.13	137.13	274.27
Total emergy (Y)							786.90	2448.34	3235.24
Outputs (O)									
23	Fish		J	1.95E+09					
23	Pig		J	1.48E+10					
23	Soybean		J	1.55E+10					
23	Wheat		J	1.96E+09					
23	Total		J	3.42E+10					

Table 4. Emergy evaluation of grains production subsystem working in a separated way (emergy flows x10[13] sej/ha/year)

Note	Item	Renewability fraction	Unit	Unit/ha/year	sej/unit	Reference for sej/unit	Renewable emergy flow	Nonrenewable emergy flow	Total emergy flow
Renewable inputs (R)									
1	Sun	1	J	5.08E+09	1.00E+00	Definition	0.00	0.00	0.00
2	Wind	1	J	6.21E+04	2.45E+03	Odum et al., 2000	0.00	0.00	0.00
3	Rain	1	J	9.78E+10	3.10E+04	Odum et al., 2000	303.03	0.00	303.03
Nonrenewable inputs (N)									
4	Soil loss	0	J	1.54E+10	1.24E+05		0.00	190.58	190.58
Materials (M)									
5	Manure	0.18	g	2.46E+07	1.23E+09	Calculated	544.19	2479.09	3023.28
6	Limestone	0.05	g	6.70E+05	1.68E+09	Brandt-Williams, 2002	5.63	106.98	112.61
7	Phosphate	0.05	g	1.64E+04	3.70E+10	Brandt-Williams, 2002	3.04	57.74	60.78
8	Potash	0.05	g	3.12E+04	2.92E+09	Brandt-Williams, 2002	0.46	8.67	9.13
9	Nitrogen	0.05	g	1.88E+04	4.05E+10	Brandt-Williams, 2002	3.81	72.37	76.18
10	Herbicides	0.05	g	7.72E+03	2.49E+10	Brandt-Williams, 2002	0.96	18.23	19.19
11	Fossil fuels	0.05	J	1.55E+10	1.10E+05	Brandt-Williams, 2002	8.54	162.31	170.86
12	Installation depreciation	0.05	US$	4.30E+01	3.70E+12	Coelho et al., 2003	0.80	15.13	15.93
13	Equipment depreciation	0.05	US$	1.26E+02	3.70E+12	Coelho et al., 2003	2.34	44.40	46.74
14	Electricity	0.05	J	4.38E+08	2.69E+05	Brandt-Williams, 2002	0.59	11.18	11.77
15	Governmental taxes	0.05	US$	4.52E+00	3.70E+12	Coelho et al., 2003	0.08	1.59	1.67
Services (S)									
16	Unqualified manpower	0.50	J	2.06E+08	7.56E+06	Brandt-Williams, 2002	77.91	77.91	155.83
Total emergy (Y)							951.37	3246.20	4197.58
Output (O)									
17	Corn		J	1.26E+11					
17	Soybean		J	2.26E+10					
17	Wheat		J	2.87E+09					
17	Total		J	1.52E+11					

Table 5. Emergy evaluation of pig production subsystem working in a separated way (emergy flows x10^{13} sej/ha/year)

Note	Item	Renewability fraction	Unit	Unit/ha/year	sej/unit	Reference for sej/unit	Renewable emergy flow	Nonrenewable emergy flow	Total emergy flow
Renewable inputs (R)									
1	Sun	1	J	5.08E+09	1.00E+00	Definition	0.00	0.00	0.00
2	Wind	1	J	6.21E+04	2.45E+03	Odum et al., 2000	0.00	0.00	0.00
3	Rain	1	J	9.78E+10	3.10E+04	Odum et al., 2000	303.03	0.00	303.03
Nonrenewable inputs (N)									
4	Ground water	0	J	4.89E+09	2.55E+05	Bastianoni and Marchettini, 2000	0.00	124.70	124.70
Materials (M)									
5	Corn	0.17	g	2.54E+08	2.08E+09	Ortega et al., 2002	8992.79	43905.98	52898.77
6	Soybean meal	0.17	g	4.68E+07	3.26E+09	Ortega et al., 2002	2593.66	12663.14	15256.80
7	Nutrient mix	0.05	g	7.20E+06	6.08E+09	Estimated	218.88	4158.72	4377.60
8	Other materials	0.05	US$	3.87E+02	3.70E+12	Coelho et al., 2003	7.17	136.19	143.36
9	Fossil fuels	0.05	J	9.54E+09	1.10E+05	Brandt-Williams, 2002	5.25	99.74	104.98
10	Installation depreciation	0.05	US$	9.18E+02	3.70E+12	Coelho et al., 2003	16.98	322.59	339.57
11	Equipment depreciation	0.05	US$	2.51E+02	3.70E+12	Coelho et al., 2003	4.64	88.23	92.87
12	Electricity	0.05	J	5.07E+09	2.69E+05	Brandt-Williams, 2002	6.81	129.48	136.29
13	Governmental taxes	0.05	US$	6.06E+02	3.70E+12	Coelho et al., 2003	11.21	212.99	224.20
Services (S)									
14	Unqualified manpower	0.50	J	3.76E+09	7.56E+06	Brandt-Williams, 2002	1423.15	1423.15	2846.30
Total emergy (Y)							13583.57	63264.90	76848.46
Output (O)									
15	Pig		J	3.68E+11					

Table 6. Emergy evaluation of fish production subsystem working in a separated way (emergy flows x10^{13} sej/ha/year)

Note	Item	Renewability fraction	Unit	Unit/ha/year	sej/unit	Reference for sej/unit	Renewable emergy flow	Nonrenewable emergy flow	Total emergy flow
Renewable inputs (R)									
1	Sun	1	J	5.08E+09	1.00E+00	Definition	0.00	0.00	0.00
2	Wind	1	J	6.21E+04	2.45E+03	Odum et al., 2000	0.00	0.00	0.00
3	Rain	1	J	9.78E+10	3.10E+04	Odum et al., 2000	303.03	0.00	303.03
Nonrenewable inputs (N)									
4	Ground water	0	J	7.50E+09	2.55E+05	Bastianoni and Marchettini, 2000	0.00	191.25	191.25
5	Soil loss	0	J	7.69E+09	1.24E+05	Brandt-Williams, 2002	0.00	95.29	95.29
Materials (M)									
6	Manure	0.18	g	7.88E+07	1.55E+09	calculated	2200.14	10022.86	12222.99
7	Fossil fuels	0.05	J	9.54E+09	1.10E+05	Brandt-Williams, 2002	5.25	99.74	104.98
8	Fingerlings	0.05	US$	7.05E+02	3.70E+12	Coelho et al., 2003	13.04	247.82	260.87
9	Installation depreciation	0.05	US$	2.27E+02	3.70E+12	Coelho et al., 2003	4.20	79.89	84.09
10	Equipment depreciation	0.05	US$	8.00E+00	3.70E+12	Coelho et al., 2003	0.15	2.81	2.96
11	Electricity	0.05	J	2.98E+09	2.69E+05	Brandt-Williams, 2002	4.01	76.16	80.17
12	Governmental taxes	0.05	US$	6.10E+01	3.70E+12	Coelho et al., 2003	1.13	21.44	22.56
Services (S)									
13	Unqualified manpower	0.50	J	1.80E+09	7.56E+06	Brandt-Williams, 2002	680.64	680.64	1361.28
Total emergy (Y)							3207.12	11497.53	14704.65
Output (O)									
14	Fish		J	4.84E+10					

The aggregate emergy flows of the assessed systems are presented in Table 7. The total of the renewable emergy flow value (R), nonrenewable emergy flow value (N), services emergy flow value (S) and materials emergy flow value (M) were calculated by summing the respective fractions of each input flow.

Table 7. Aggregate emergy flows of the integrated production system and of the grains, pig and fish production subsystems working in a separated way

Emergy flows (sej/ha/year)	Integrated production system	Grains production subsystem	Pig production subsystem	Fish production subsystem
Renewable resources (R)	3,03E+15	3,03E+15	3,03E+15	3,03E+15
Nonrenewable resources(N)	2,03E+15	1,91E+15	1,25E+15	2,87E+15
Nature contribution (I)	5,06E+15	4,94E+15	4,28E+15	5,90E+15
Renewable materials (M_R)	3,47E+15	5,70E+15	1,19E+17	2,22E+16
Nonrenewable materials (M_N)	2,12E+16	2,98E+16	6,17E+17	1,05E+17
Total materials (M)	2,47E+16	3,55E+16	7,36E+17	1,28E+17
Renewable services (S_R)	1,37E+15	7,79E+14	1,42E+16	6,81E+15
Nonrenewable services (S_N)	1,37E+15	7,79E+14	1,42E+16	6,81E+15
Total services (S)	2,74E+15	1,56E+15	2,85E+16	1,36E+16
Feedback from economy (F)	2,74E+16	3,70E+16	7,64E+17	1,41E+17
Total emergy (Y)	3,25E+16	4,12E+16	7,68E+17	1,47E+17

Table 8 presents the emergy indicators obtained considering partial renewabilities of material and services and not considering partial renewabilities of material and services (in this case, considering material and services as totally nonrenewable resources) for the integrated system. This evidences the differences produced in the emergy indicators by use of renewability factor in emergy accounting. The renewability factor of each input used in this paper was based in previous papers of soybean and corn production in Brazil (Ortega et al., 2005; 2002). The incorporation of renewability factor in order to improve emergy accounting by splitting the renewable and nonrenewable shares the material and services is especially valid considering the use of renewable inputs purchased at the local or regional economy, such as, corn, soybean, manure and services. Consequently, the incorporation of the renewability factor should be added to the set of the possibilities of applying the emergy methodology in order to assess sustainability.

Table 8. Emergy indicators calculated considering partial renewabilities of material and services and do not considering partial renewabilities of materials and services for integrated production system of grains, pig and fish

Emergy indicators	Integrated production system considering partial renewabilities	Integrated production system without considering partial renewabilities
Tr	948,000	948,000
EYR	1,44	1,18
EIR	2,28	5,42
ELR	3,13	9,72
%R	24,2	9,3
EER	6,8	6,8

Table 9 present the emergy indicators calculated for the integrated production system and for the grains, pig and fish production subsystems working in a separated way considering methodologies proposed by Odum (1996) and by Bastanoni and Marchettini (2000).

Table 9. Emergy indicators calculated for integrated production system and for grains, pig and fish production subsystems working in a separated way considering methodologies proposal by Odum (1996) and Bastanoni and Marchettini (2000)

	Emergy indicators					
	Tr	**EYR**	**EIR**	**ELR**	**%R**	**EER**
Emergy indicators calculated according Odum, 1996						
Soybean	2,096,000	1.44	2.28	3.13	24	6.8
Wheat	16,548,000	1.44	2.28	3.13	24	6.8
Pig	2,188,000	1.44	2.28	3.13	24	6.8
Fish	16,662,000	1.44	2.28	3.13	24	6.8
Transformity calculated according Bastanoni and Marchettini, 2000						
Integrated system	948,000	1.44	2.28	3.13	24	6.8
Emergy indicators calculated for subsystems working in a separated way						
Grains	277,000	1.37	2.68	3.41	23	12.7
Pig	2,087,000	1.22	4.61	4.66	18	7.9
Fish	3,040,000	1.31	3.21	3.59	22	15.0

The Transformity (Tr) measures how much emergy is taken to generate one unit of output. It indicates the hierarchical position of an item in the thermodynamic scale of the biosphere and can be regarded as a quality factor from the point of view of biosphere dynamics. It provides a measure of the emergy efficiency of production (Brown and Ulgiati, 2004) and is used to convert resources of different types to emergy of the same type. In a way, the transformity also suggests the renewability of a product, because its value depends on the convergence of renewable and nonrenewable inputs over time and spatial scales. The higher the transformity, the higher the need for environmental support to the process and the product. A higher requirement for a limited support translates into a lower renewability. This global assessment is better understood if the fraction of renewable input is quantified, as it is suggested in this paper.

The calculation of the transformity value for the integrated production system of grains, pig and fish was first made using traditional emergy methodology proposal by Odum (1996) (dividing the total emergy required by the system by the energy of each product). We obtained the following transformities for the outputs: soybean: 2,096,000 sej/J; wheat: 16,548,000; pig: 2,188,000 sej/J and fish: 16,662,000 sej/J. These values are not in accordance with literature and common sense demonstrating that this is not the best method for calculating transformity of a complex system with internal integration of activities and co-production. This problem was already studied by Bastianoni and Marchettini (2000), who propound a new approach to calculate transformity of systems with co-production. The transformity is calculated dividing the total emergy required by the system (Y) by the sum of the energies of all outputs of co-production. According to these authors, the calculation of transformity summing the energies of all outputs allows a better comparison between systems with co-productions and systems with independent productions with the same outputs. Therefore, the integrated production system's product was firstly grossly identified as the total available energy of pig, fish and grains produced, in Joules. Using this method, the transformity value obtained to integrated production system of grains, pig and fish was 948,000 sej/J. Furthermore, we calculated the transformities of grains, pig and fish production subsystems working in a separated way. With this method we obtained following transformities: grains 277,000 sej/J; pig; 2,087,000 sej/J and fish 3,040,000 sej/J. So, the transformity calculated for integrated production system is lower than the pig and fish production subsystem and higher than the grains production subsystem. Literature transformity values for animal production systems are normally found around 1,000,000 sej/J and for grains production between 100,000 - 200,000 sej/J (Ortega et al., 2005; Brandt-Williams, 2002; Odum and Odum, 2001; Odum, 1996). The transformity values calculated for integrated production system (using methodology proposal by Bastianoni and Marchettini, 2000) and for subsystems working in a separated way are higher than the literature values but are yet in accordance with them. Transformity results obtained indicate that the integrated production system is more efficient in energy conversion in comparison with the pig and the fish production subsystems working in a separated way. This suggests that integrated systems can produce more products using same emergy.

The renewability percentage (%R), or degree of sustainability, is the percentage of renewable emergy used by the system. In the long run, production systems with a high percentage of renewable emergy are likely to be more sustainable and prevail (they are more able to survive to the economical stress) than those with use a high portion of nonrenewable emergy (Brown and Ulgiati, 2004; Lefroy and Rydberg, 2002). The %R of the integrated system was 24% or, in other words, 76% of the emergy used comes from nonrenewable resources (N+F). For the pig production subsystem %R was only 18%, for the fish production subsystem %R was 22% and for the grains production subsystem %R was 23%. These results show that the integrated system is more sustainable than the separated subsystems. The adoption of more sustainable techniques by farmers, which might take profit from the use of natural energy sources, could improve system's sustainability. Increase in the integration of the production systems, energy cascading and so on are some of the first steps to be made in the direction of sustainability.

The emergy yield ratio (EYR) is the ratio of the total solar emergy divided by the emergy value of purchased inputs. The ratio is a measure of the ability of a process to exploit and hopefully make available local resources by investing outside resources. It provides a quantification of appropriation of local resources by a process, which can be read as a potential additional contribution to the main economy, gained by investing resources already available. The lowest possible value of the EYR is 1, which indicates that a process delivers same amount of emergy that was provided to drive it, and that is unable to usefully exploit any local resource. Therefore, process whose EYR is 1 or only slightly higher do not provide significant net emergy to the economy and only transform resources that are already available from previous process. In so doing, they act as consumer process more than creating new opportunities for system's growth. Primary energy sources themselves (crude oil, coal, natural gas) usually show EYR greater than 5. Secondary energy sources and primary materials, like cement and steel, show EYR in the range from 2 to 5, indicating moderate contribution to the economy. (Brown and Ulgiati, 2004; 2002). The EYR for the integrated production system was 1.44, for the grains production subsystem EYR was 1.37, for the pig production subsystem EYR was 1.22 and for the fish production subsystem EYR was 1.31. These values are similar to other soybean production systems of Brazil (ranged 1.18 - 1.78) (Ortega et al., 2002), soybean production systems of Italy (ranged 1.98 - 2.32) (Panzieri et al., 2000) and corn production systems of Italy (ranged 1.19 - 1.53) (Ulgiati et al. 1994). These EYR values obtained for the integrated production system and for the separated production subsystems do not suggest yet a good ability in exploiting and making local resources available by investing outside resources, and require further improvement. However, the integrated production system has high contribution to the main economy due to the better exploitation of local resources in comparison with the separated subsystems assessed.

The emergy investment ratio (EIR) is the ratio of purchased resources to renewable and nonrenewable local inputs. However, EYR = (N+R+F)/F = 1+(N+R)/F = 1+1/[F/(N+R)] = 1+1/EIR. Therefore EIR and EYR are the same index written in a different way. Nevertheless, the utilization of EIR in an emergy assessment sometimes makes discussion easier and facilitates the understanding. EIR evaluates if a process is a good user of the emergy that is invested, in comparison with alternatives (Brown and Ulgiati, 2004). The EIR for the integrated production system was 2.28 and it is the lowest of the assessed systems. This value indicates that purchased inputs used in the integrated production system were 128% larger than locally available (R+N) emergy sources. For the grains production subsystem the EIR was 2.68, for the fish production subsystem the EIR was 3.21 and for the pig production subsystem the EIR was 4.61. A lower EIR value may represent more effective systems with better use of renewable internal emergy sources, where the renewable energy can be replenished to continually feed the system. The present global trends indicate that less energy at low cost will be available in the future. Agriculture could face problems due to market opening in consequence of globalization (Campbell, 1998). Thus, production systems based on nonrenewable natural resources may not be able to compete with systems characterized by lower economic investment (F) and bigger nature contribution (R+N), and they might be unsustainable in the coming future. New technical designs combined with regional planning and fair trade rules must be considered to evaluate and conduct development strategies for systems that presently require higher nonrenewable inputs.

When a process requires environmental services, it exerts a “load” on the environment. Environmental loading is the concept that once an environmental service is used by a process, it is not available for another process. In the most general case, the environment has a finite renewable capacity to support economic processes and human endeavors but in doing so this capacity is used or consumed. If a process consumes all the renewable support functions, then other processes cannot be added to the support base at the same time without seriously degrading the local environment. Thus, there is a carrying capacity limit to the economic development (Brown and Ulgiati, 2002; 1997). Carrying capacity can be determined based on the emergy requirements for a given population or the emergy intensity of a given economic development. The carrying capacity of an environment is determined by that environment’s ability to supply the required emergy. Therefore, the emergy loading ratio (ELR) is an approach to access the carrying capacity of a production system (Brown and Ulgiati, 2002; 2001; 1997). The ELR is given by the ratio emergy from purchased and nonrenewable local inputs, to the emergy from renewable resources. It is an indicator of the pressure of a transformation process on the environment and can be considered a measure of ecosystem stress due to a production (transformation activity). The ELR is clearly able to make a difference between nonrenewable and renewable resources, thus complementing the information that is provided by the transformity. ELRs around two or less are indicative of relatively low environmental impacts (or processes that can use large areas of a local environment to “dilute impacts”). ELRs between three and ten are indicative of moderate environmental impacts, while ELRs ranging from ten up to extremely high values indicate much higher environmental impacts due to large flows of concentrated nonrenewable emergy in a relatively small local environment (Brown and Ulgiati, 2004). The ELR obtained for the integrated production system was 3.13, for the grains production subsystem was 3.41, for the fish production subsystem was 3.59 and for the pig production subsystem was 4.66. These values are similar to corn (ranged 2.49 - 5.63) and wheat (3.4) production systems of Italy (Ulgiati et al. 1994). The ELR for the integrated production system is the lowest between the evaluated systems, indicating that this system exert lowest pressure on the environment. Therefore, our results show that the integrated production system is a better alternative way of production in comparison with the subsystems working in a separate way. Furthermore, this indicator suggests that the integrated production system (which has a lower ELR) could allow a higher number of pig per hectare than a pig production subsystem working in a separated way.

The emergy exchange ratio (EER) is calculated as the total solar emergy of a product or flow, divided by the solar emergy value of the currency paid for it. In other words it is the ratio of emergy exchanged in a trade or purchase (what is received to what is given). The EER is always expressed relative to one of the trading partners and it is a measure of the relative trade 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 EER value calculated for the integrated production system was 6.8, indicating that the system gives 6.8 times more emergy to buyers of its products than the value received by sales. The EER value for the pig production subsystem was 7.9, for the grains production subsystem was 12.7 and for the fish production subsystem was 15.0. These results demonstrate that the prices received by the products of the farming system underestimate their environmental value. Consequently, the prices of agricultural products should be higher than those determined by market rules.

Results of emergy indicators demonstrate that pig feed production and pig production in an integrated system is more environmentally healthy than produce in separated subsystems. This statement is supported by the better emergy indicators calculated for the integrated production system.

The fish production is noteworthy in the integrated production system evaluated. Aquaculture helps to increase system's capacity by using the manure produced by the pig production. Furthermore, the fish are one important energy output of this system, requiring a minimal of additional nonrenewable inputs to drive this production system. Consequently, aquaculture contributes to a better use of the emergy flows and recycling, improving emergy indicators of the integrated production system. Nevertheless, it must be clear that aquaculture is not a way to solve the problem of accumulation of manure in a high intensive pig production system. Actually, fish production system is just another component of an integrated farm design.

3.2 Emergy considerations about intensification of the farming systems

The animal carrying capacity must be considered in the assessment, since there are limits for intensification in pig production. A great amount of manure concentrated in a small area could contaminate soil and hydric resources. Some European countries have environmental problems due to nutrients pollution (eutrophication) caused by big concentrations of animal manure on the soil. Countries like the Netherlands, France and Denmark, have specific legislations to control animal production, and there are limits for the number of animals allowed per unit of area. Producers that exceed these limits are penalized (Jongbloed et al., 1999). For example, Denmark has established a limit of 30 growing-finishing pigs per hectare of land. In the Netherlands, the limit is about 15 growing-finishing pigs per hectare (Jongbloed et al., 1999). In Germany, this number is 6 growing-finishing pigs per hectare. Brazil still does not have a specific legislation. However, Brazilian literature recommends 40 - 45 m^3/ha/year of liquid manure (Scherer al., 1994). It corresponds to the manure produced by 17 pigs (2.55 m^3 of liquid manure per pig per year). Therefore, the amount of pigs breed in integrated small farms in the South region of Brazil evaluated by this paper is in accordance with Brazilian standard. Nevertheless, pork processing industries are responsible for the increase of intensity in pig farming. So, these industries must consider the limits of animal carrying capacity and assume their responsibility for the environmental damages caused by pig production. These issues should be discussed with the environmentalists and the representatives of the pork meat industries in order to find alternatives to solve the waste accumulation. Emergy assessment can help in farm planning, in proposals for the implementation of a regional agreement and to promote a more appropriate and auspicious carrying capacity to guarantee environmental and economic sustainability of pig production chain. As a brief example, we calculated the emergy indicators of the integrated production system of grains, pig and fish using three different intensities: 6, 15 and 30 pigs/ha (corresponding to amounts of Germany, Netherlands and Denmark legislations, respectively) and varying all inputs used to drive these productions too. The results obtained for these three hypotheses are presented in Table 10.

Table 10. Emergy indicators of the integrated production system of grains, pig and fish using three different intensities: 6, 15 and 30 pigs/ha

	Emergy indicators					
Integration rate	Tr	EYR	EIR	ELR	%R	EER
Integrated system with 6 pigs/ha	818,000	1.60	1.66	2.53	28	7.7
Integrated system with 15 pigs/ha	948,000	1.44	2.28	3.13	24	6.8
Integrated system with 30 pigs/ha	1,091,000	1.33	3.06	3.80	21	6.2

These results shows that more pigs per hectare will result in worse emergy indicators for the system, except by better EER values (indicating better advantages in exchange with main economy with more pig per hectare). Once the same area is considered in the three different pig densities used, the amount of renewable inputs (R) is the same. Thus, as it was already expected, the increase in the number of pig per hectare increase also the proportion of nonrenewable resources (F) used. In a more general way, these results show clearly that the intensification of pig production result in the increasing of transformity (lower efficiency of the ecosystem), EIR (lower use of renewable internal emergy sources) and ELR (higher ecosystem stress and the pressure on the environment), and decreasing of EYR (lower of system's ability to use the local resources investing from outside) and %R (lower sustainability). This occurs because the corn produced in the farm becomes insufficient with intensification of pig production. Therefore, additional corn must be bought for complete pig's diet, increasing the system's dependence for purchased resources and jeopardizes the environmental and economic performance of the farm. The results signalize that in order to decrease this dependence on nonrenewable resources, the farming system should keep only the animals that can be fed by the "on site" produced corn, in order to close the integration cycle of materials in the farm. By producing all the pig feed in the corn and soybean crops, the system can make internal recycle of materials between grains crops and pig production in a more efficient way, with lesser use of external nonrenewable resources. On the other hand, the intensification in pig production increases the dependency of the system in the external nonrenewable resources (F).

4. CONCLUSION

Emergy analysis has proven to be a useful tool to study agricultural systems by focusing on economic and environmental loads. Emergy analysis has also allowed useful indicators to assess long-term sustainability of several agricultural systems, and provides new insights about the relation between farms, environment and main economy too. The incorporation of renewability factor in each input in order to improve calculations of emergy indicators is especially valid considering the use of renewable inputs purchased at the local or regional economy, such as, corn, soybean, manure and services. This leads to a better description of agricultural complex systems.

Results of emergy assessment indicate quantitatively that the integrated production system have better efficiency in emergy conversion, are the most able to use the local resources investing from outside, have the best use of renewable internal emergy sources, produce lowest ecosystem stress and pressure on the environment and are most sustainable in comparison with the grains, pig and fish production subsystems working in a separated way. Therefore, increase in the integration of the production systems, energy cascading and so on are some of the first steps to be done in the direction of sustainability.

Furthermore, the emergy indicators obtained through this study indicate that integrated production systems are able to reduce (thanks to recycling of materials) the use of external inputs. However, it is necessary to plan the amount of pigs produced per year in accordance with the area of the farm. Emergy methodology proved to be useful in farm planning and to simulate future actions. Thus, the development and adoption of such integrated agricultural techniques should be strongly encouraged, up to the level at which they remain environmentally healthy. The ELR showed that the integrated production system can be less stressful to the environment and more sustainable than grains, pig and fish production subsystems working in a separated way. However, the results signal that efforts must be made to improve recycling and integration of the subsystems and to reduce intensification in the pig production too. To improve the emergy indicators and also the sustainability of the assessed systems, efforts must be made to be less dependent on nonrenewable inputs. Among these nonrenewable inputs some are highly stressful, such as chemical fertilizers, herbicides, pesticides, petroleum fuels, electricity, heavy machinery and mainly pig feed components and manure. Furthermore, integrated production systems should be self-sufficient, achieving the correct balance between pig production and corn production to close the integration cycle of materials into the system. Results obtained show that less intensification in pig production promotes an improvement of the environmental aspects of the farming system. Nevertheless, to fully incorporate other off site aspects, such as ground water pollution, hydric basin occupation and land use, a larger scope analysis and the incorporation of negative externalities produced by the system would be required. The results should be helpful for decision making towards a sustainable and environmentally sound development of agriculture.

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