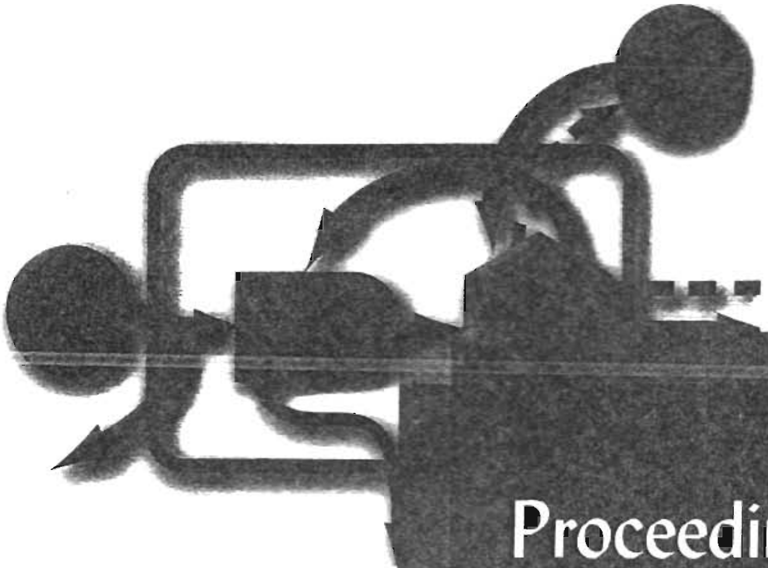
EMERGY SYNTHESIS 2

Theory and Applications of the Emergy Methodology



Proceedings of the Second Biennial Emergy Conference

Edited by
Mark T. Brown

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David Tilley
Sergio Ulgiati

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Proceedings from the Second Biennial Emergy Analysis Research Conference, Gainesville, Florida, September, 2001.

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Sustainability assessment of slash-and-burn and fire-free agriculture in Northeastern Pará, Brazil

Rodrigues, G. S.; Kitamura, P. C.; Sá, T. D. de A.; Vielhauer, K.

ABSTRACT

Slash and burn agriculture, largely dependent on the duration of the fallow period to restore the productivity of the land, is extensively practiced by small landholders in Pará State, Brazil. Due to a mounting demographic pressure, fallow periods have been shortened, and signs of agronomic and ecological failure such as decreasing crop yields and structural and compositional depletion of the secondary vegetation have been observed. In order to circumvent these problems, fire-free agricultural management practices have been proposed. Among these practices, the most important are the (i) use of a bush-chopper for mulching (instead of burning) the biomass, (ii) enrichment of the secondary vegetation with nitrogen-fixing, fast growing trees to improve nutrient recovery/fixation during the fallow period, and (iii) soil fertilization following mulching, for optimal crop absorption of nutrients. A system overview of these management practices shows that most of the inputs for production correspond to free contributions from the environment. The release of nutrients contributed by the slash-and-burn operation represents a major input to yield, reaching almost one half of all nonrenewable contribution in this system. As this major input is replenished by fallow, with no requirements from the economy, the slash-and-burn system shows a larger emergy yield ratio. On the other hand, the input of fertilizer required in the fire-free management, added to the purchased labor and services needed for mulching, result in a higher environmental loading ratio, and a smaller emergy yield ratio for this system. Hence, due to dependency on purchased inputs, the fire-free management shows a smaller sustainability index. In order to meliorate the adoption perspective of fire-free agriculture, incentives could be paid for soil organic matter buildup, as compensation to carbon sequestration under a policy scenario of global climate change prevention.

INTRODUCTION

Similarly to virtually all old colonization areas in the Brazilian Amazon, the agricultural occupation of the Northeastern region of Pará State is based on staple crops grown on soils prepared by the slash-and-burn of the secondary forests. Following a short (typically one year) productive period, the area is abandoned for vegetation regeneration, and new areas covered with secondary forests are slashed-and-burned, completing the shifting cultivation cycle (Holscher et al., 1997). A fast growing population and consequent increased pressure on land use in the region in the last decades has caused the agronomic and ecological failure of this production system. In order to circumvent this problem, fire-free management practices have been introduced under the German-Brazilian research program "Studies of Human Impacts on Forests and Floodplains in the Tropics - SHIFT" as follows:

(i) *slash-and-mulch* (as opposed to slash-and-burn) the secondary vegetation, a process made possible by the introduction of a tractor-driven biomass chopper;

(ii) secondary vegetation enrichment with fast-growing, nitrogen-fixing tree species, to improve biomass accumulation for mulching and charcoal/firewood/timber production; and

(iii) early (post-mulching) soil fertilization coupled with crop rotation/association that allow the development of one additional harvest cycle per five-year period.

The fire-free agricultural management system should bring about, on the one hand, economic improvements to the farmers, by allowing agricultural intensification without soil degradation; and on the other, betterment of environmental quality and natural resources conservation, resulting in important social benefits to the local communities. These advantages are expected due to the possibility of cultivating the land for two consecutive years instead of only one, followed by just three fallow years instead of four or five. Besides, the enriched secondary forest yields usable wood materials, being also economically attractive, whereas the conventional slash-and-burn system remains economically unproductive during the whole fallow period.

There are also drawbacks associated with the fire-free management system. Most of the benefits are manifested in the long run, and are only partially perceived in monetary terms. Fire-free management involves higher investment costs due to the mechanic mulching operation and fertilizer application, needed to compensate the delayed release of nutrients from the mulch, as compared with the prompt nutrient release from the ashes returned to the soil in the slash-and-burn system (Kato & Kato, 1999). A research challenge resides in assessing the balance between the environmental and social (as well as some private) benefits, and the private costs to the farmer, of the fire-free agricultural management system proposed by the SHIFT-Capoeira project. A system's ecology approach based on emergy evaluation (Odum, 1996) has been proposed as an option to carry out this comparative assessment (Rodrigues et al., 2001). The main advantage of applying this method is that it allows consideration of all needed resources, inputs, and flows using solar energy units as a common currency, facilitating the comparison of management practices with contrasting resource inputs and final product outputs. This paper reports on the findings of such an evaluation.

METHODS

The first step for the emergy evaluation of both the conventional slash-and-burn and the proposed fire-free agricultural production was the overall delimitation and characterization of "typical shifting cultivation systems" (Table 1). This was accomplished by constructing emergy flow diagrams of the production systems using system's language symbols (Figures 1 and 2; Christianson, 1986). Several assumptions were made in order to compose the typical slash-and-burn and fire-free management systems upon which the diagrams were drawn, as follows:

Table 1. Typical small landholder's shifting cultivation agricultural systems in Northeastern Pará State (Brazil), showing activities in a yearly basis

	Slash-and-burn production system	**Fire-Free production system**
Year 1	Slash-and-burn, Sow corn, Plant cassava, Harvest corn, Cultivate	Cut/chop/mulch/fertilize, Sow corn, Plant cassava, Plant seedlings, Harvest corn, Cultivate
Year 2	Harvest cassava, Fallow	Sow 2nd corn crop, 2nd cultivation, Harvest corn, Harvest cassava
Year 3	Fallow	Fallow
Year 4	Fallow	Fallow
Year 5	Fallow, Back to year 1	Harvest charcoal, Harvest firewood, Harvest timber, Back to year 1

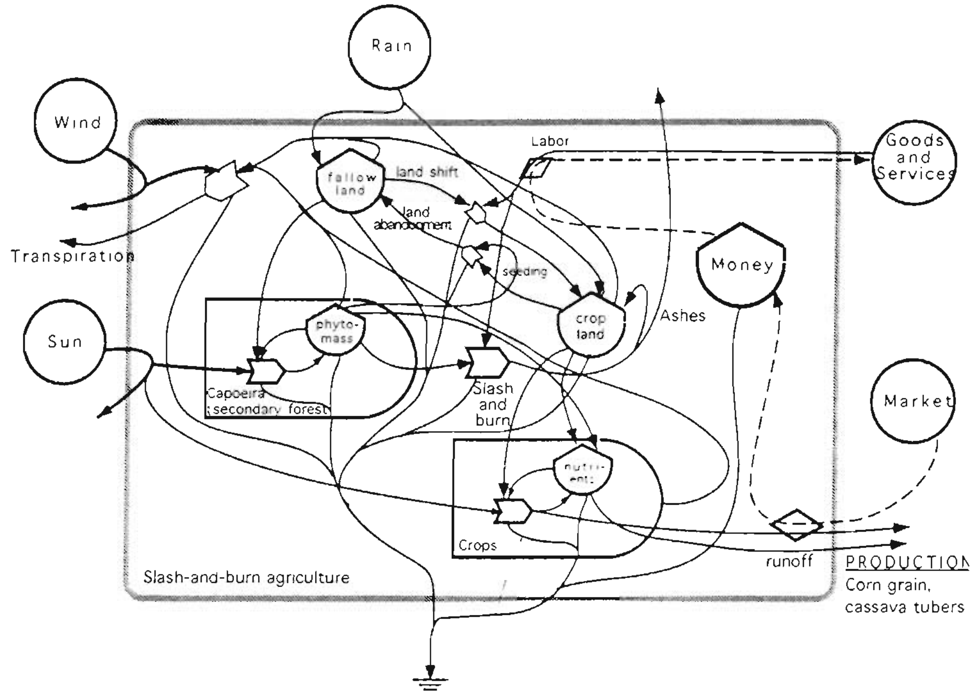

Figure 1. *System diagram of the slash-and-burn agricultural production system*

i. The systems are driven by energy inputs from natural and man-made sources on a similar basis of natural resources, represented by fallow and cropland;

ii. These land uses are interchanged into each other according to management practices, that is, cropland becomes fallow land by abandonment, and fallow land is converted into cropland either by slash-and-burn or slash-and-mulch;

iii. The renewable energy flows derived from nature used up in production, including sunlight, rain water, and winds can be summed up as transpiration associated with primary production; while the losses of soil organic matter and nutrients in the ashes resulting from burning are used up in production as nonrenewable inputs;

iv. Money (flow expressed by dashed lines) is exchanged for the harvest (yield) to pay for labor, services, and man-made resources;

v. The main differences between the production systems studied are represented by the use of mechanized slash-and-mulch operation, fertilizer input, and secondary vegetation enrichment, which result in production of wood materials in addition to crops; as opposed to slash-and-burn, for which no market inputs are needed and no marketable production from the secondary vegetation is obtained.

Based on the systems diagrams, emergy evaluation tables were formulated with all inputs, flows, and outputs of the systems. Data on inputs and flows for one hectare (ha) of these typical systems on a yearly basis were obtained from the reports of the SHIFT-Capoeira project, on information offered directly by project researchers, and from selected references, as cited in the notes to each Table. Finally, systems' performances were evaluated using ratios and indices derived from these flows, as proposed by Ulgiati et al. (1995) and Odum (1996).

RESULTS AND DISCUSSION

Slash-and-burn Agricultural Production

The diagram representing the slash-and-burn system presented in Figure 1 shows the important emergy flow associated with the burning operation and Table 2 summarizes the data. This flow represents 24% of the total yield in this system, and as much as 46% when only the nonrenewable flows (those that differ between the systems) are considered (Table 2). This large contribution is provided by the capacity of the secondary vegetation to replenish these storages during the fallow period, without any additional nonrenewable resource depletion or input from the economy. The Environmental Loading Ratio (sum of purchased and nonrenewable inputs by renewable inputs – a measure of environmental impact) for the slash-and-burn system is, thus, relatively small (1.04: Table 5), even when compared to organic agricultural production in Brazil (1.75) (Comar, 2000).

Table 2. SHIFT - Capoeira PROJECT SUSTAINABILITY ASSESSMENT

EMergy Evaluation Table of the Slash-and-burn Production System

Note	Item	Unit	Data (units/yr)	Unit Solar EMERGY (sej/unit)	Solar EMERGY (E13 sej/yr)	Em$ **Value** ($/yr)
RENEWABLE RESOURCES						
1	Sun	J	6.94E+13	1	7	8
2	Rain	J	1.13E+11	1.80E+04	204	243
3	Wind	J	5.19E+09	1.50E+03	1	1
4	Et	J	4.19E+10	1.82E+04	76	91
NONRENEWABLE STORAGES						
5	Net Topsoil losses	J	3.62E+09	7.38E+04	27	32
6	Nutrient loss- burning	J	3.66E+14		37	44
Sum of free inputs (sun, rain, wind omitted)					140	167
PURCHASED INPUTS						
Operational inputs						
7	Fuel	J	0.00E+00	6.60E+04	0.00	0.00
8	Phosphate	g P	0.00E+00	1.78E+10	0.0	0
9	Labor	J	2.01E+09	8.10E+04	16	19
10	Services	$	0.00E+00	8.40E+12	0	0
Sum of purchased inputs			- -		16	19
PRODUCTION AND TRANSFORMITIES						
11	Corn	kg/yr	8.60E+02	1.68E+12		
12	Cassava	kg/yr	5.60E+03	2.57E+11		
13	Charcoal	kg/yr	0.00E+00			
14	Firewood	kg/yr	0.00E+00			
15	Timber	kg/yr	0.00E+00			
16	Total Yield	g dry weight	2.43E+06	5.94E+08	156	186
17	Production	J	4.47E+10	3.22E+04		

Footnotes given at the end of this chapter.

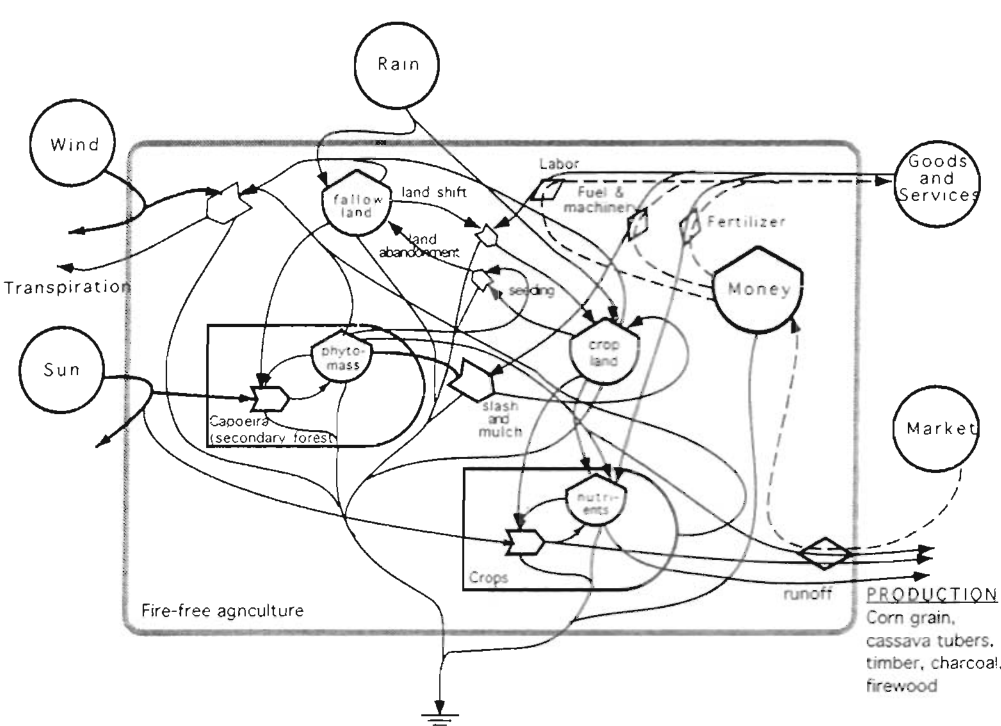

Figure 2. *System diagram of the fire-free agricultural production system*

The yield in this system is represented by one corn grain and one cassava crop, per five year shifting cultivation cycle, which go to the market in exchange for money to pay for the labor employed. No additional interactions with the market occur, as no fuels or machinery or fertilizers are used. Even with such small inputs, the specific emergy of the production (or its transformity) is comparable to that obtained in other agricultural systems, when the total weight of produce harvested in the five-year cycle is considered in a yearly basis. Thus, due to the non-intensive use of resources, the Empower Density for the slash-and-burn production system was only 1.56E+15 sej/ha/yr, which corresponds to approximately one eighth of that observed in grain corn production in Florida (Brandt-Williams, 2001), or one-fourth of that observed in organic agriculture in Brazil (Comar, 2000).

Most important for policy considerations regarding the slash-and-burn agriculture in Northeastern Pará is the very low Emergy Investment Ratio of this system (sum of purchased by non-purchased inputs, 0.12; Table 5). It will be difficult to convince small landholders to change a traditional management practice that, even with a relatively small Empower Density (that corresponds to total yield) brings such a surplus on investment. With such small investment ratio, the Emergy Yield Ratio of the slash-and-burn system is considerably high (9.56), some six-fold higher that observed in organic agriculture in Brazil (Comar, 2000). Consequently, and confirming the historical trend of centuries of shifting cultivation in the region, a high Emergy Sustainability Index is obtained for this system, as perceived by the small landholders.

Fire-free Agricultural Production

The diagram representing the fire-free production system presented in Figure 2 shows a prominent emergy flow associated with the mechanized mulching operation. In addition to labor, fuels and machinery are obtained as services, and at least phosphate fertilizer is needed to compensate for the immobilization of nutrients in the soil microbial biomass developed on the mulch (Kato & Kato, 1999). The emergy flows supporting a typical fire-free agricultural system are summarized in Table 3. These inputs from the economy are paid for with the output of wood products from the secondary vegetation, besides grain corn and cassava obtained in two crops instead of only one, which is made possible by the input of fertilizers.

Even though a similar erosion rate was considered for both agricultural production systems studied, slightly larger emergy expenditure related to soil loss occurs in the fire-free as compared with the slash-and-burn system, due to a greater soil carbon content in the former. As there are no nutrients lost in burning, however, the total environmental contribution for fire-free agricultural production is a little smaller. On the other hand, 15% of the total yield in this system is represented by the input of purchased fertilizer. The total expenditure in purchased inputs reaches almost 40% of the emergy yield.

Table 3. SHIFT - Capoeira PROJECT SUSTAINABILITY ASSESSMENT

EMergy Evaluation Table of the Fire-Free Production System

Note	Item	Unit	Data (units/yr)	Unit Solar EMERGY (sej/unit)	Solar EMERGY (E13 sej/yr)	Em$ Value ($/yr)
RENEWABLE RESOURCES						
1	Sun	J	6.94E+13	1	7	8
2	Rain	J	1.13E+14	1.80E+04	204	243
3	Wind	J	3.90E+12	1.50E+03	1	1
4	Et	J	4.19E+10	1.54E+04	76	91
NONRENEWABLE STORAGES						
5	Net Topsoil losses	J	4.70E+09	7.38E+04	35	41
6	Nutrient loss by burning	J	0.00E+00		0	0
	Sum of free inputs (sun, rain, wind omitted)				111	132
PURCHASED INPUTS						
Operational inputs						
7	Fuel	J	8.11E+05	6.60E+04	0.01	0.01
8	Phosphate	g P	1.50E+04	1.78E+10	26.7	32
9	Labor	J	2.65E+09	8.10E+04	21	26
10	Services	$	2.50E+01	8.40E+12	21	25
	Sum of purchased inputs				69	82
PRODUCTION AND TRANSFORMITIES						
11	Corn	kg/yr	1.60E+03	1.05E+12		
12	Cassava	kg/yr	1.04E+04	1.62E+11		
13	Charcoal	kg/yr	0.00E+00			
14	Firewood	kg/yr	6.90E+03	2.44E+11		
15	Timber	kg/yr	0.00E+00			
16	Total Yield	g dw/yr	1.04E+07	1.62E+08	180	214
17	Production	J	1.81E+11	9.29E+03		

Footnotes given at the end of this chapter.

This dependency of the fire-free management on external nonrenewable resources results in a larger Environmental Loading Ratio than the slash-and-burn system, and an Emergy Yield Ratio three times smaller. Hence, even when one considers the larger marketable weight of produce obtained with the two consecutive corn and cassava harvests and the wood products collected after the fallow period in this system, the sustainability, or the surplus perceived by the farmer in relation to the production effort, is quite smaller. This is expressed in the smaller transformity of the produce (the real wealth perceived by the farmer) obtained in the fire-free system. In other words, even with a larger Empower Density (larger total yield), the specific emergy (sej/kg) of the corn or the cassava in the fire-free system is almost 60% smaller. Also, the larger Emergy Investment Ratio of the fire-free system causes a smaller profitability. With an emergy dollar value in total production corresponding to Em$214.00/ha/yr (sej/$ ratio of 8.4E+12 for the Brazilian economy – Odum, 1996) and a market expenditure of Em$82.00, the profitability of the fire-free system reaches Em$132.00/ha/yr, as compared with Em$167.00/ha/yr in the slash-and-burn system.

These results imply that, from a policy-making point of view, additional motivations must be offered to farmers if they are to consider altering their traditional management practices toward fire-free management. First, the fire-free agricultural production system must include alternative, environmentally cost effective ways of providing the services and resources needed for production. For instance, promoting collectivism in the ownership and utilization of machinery, and biological means of providing phosphorus after mulching, could drastically reduce costs. Second, additional value could be perceived from the resources managed within the system (e.g., the organic matter incorporated into the soil) and transferred from society to the farmers, compounding incentives that could not be obtained when practicing slash-and-burn.

Carbon Sequestration and Incentives for Fire-free Management

The profuse literature on the costs and benefits of fire-free agricultural management points out advantages perceived in different scales, and by various actors involved in societal interest in production and conservation in the Amazon and elsewhere. One such benefit is the sequestration of carbon in the soil organic matter, which could contribute to mitigate the emission of greenhouse gases to the atmosphere promoted by burning. The sequestered carbon could be tradable in the market of environmental commodities and pollution permits being forwarded by the proposed Kyoto Agreement on Global Change (Kitamura & Rodrigues, 2000).

In order to perform an evaluation of the potential contribution of the fire-free production system to carbon sequestration, a somewhat different perspective is needed. Some important storages and flows that occur within the boundaries of the fire-free and the slash-and-burn systems simultaneously to agricultural production were not included in the previous analysis, due to the systems delimitation presented in Figures 1 and 2. For example and in conformity with theory, the large emergy flow contained in the mulch was not computed in the fire-free production system, because it is not consumed (for it is actually stored within the system), and therefore is not a contribution to production. However, if the buildup of soil organic matter (SOM – Table 4) could be regarded as an additional product of the system, tradable in an "environmental commodity market," radical changes would occur in the systems' performance indices.

A comparison of the slash-and-burn and the fire-free management systems including the buildup of SOM as a marketable commodity is presented in Table 5. This table summarizes the systems' indices, now including the changes of stored SOM (Table 4) as additional production. As a result of fallow (7 year period, Vlek et al., 1999), as much as 158 T/ha of SOM is accumulated in the fire-free system, a 42 T/ha increase over the non fallow land. In emergy terms this storage buildup would represent the largest product of the system, and would increase the Emergy Yield Ratio sevenfold. The slash-and-burn system would benefit as well under this carbon sequestration compensation scenario, because even when the above ground portion of the secondary vegetation is burned, some surplus below ground organic matter is accumulated (approximately 7 T/ha, Vlek et al., 1999). An

Table 4. Emergy evaluation of carbon sequestration in slash-and-burn and fire-free agricultural management systems.

Carbon Sequestration Assessment SLASH-AND-BURN production	
SOM buildup	
SOM content (g/ha, 0-100cm) = (g C/g soil)*(soil density * 1E6 cm3/m2 * 10000 m2/ha)	
SOM in control soil=	1.16E+08 (Vlek et al., 1999)
SOM in topsoil (g C/g soil)=	0.008 (Vlek et al., 1999)
SOM in topsoil (g/ha)=	1.23E+08
Energy cont./g organic=	5.40 kcal/g
Annual energy:	2.45E+10 (7 yr fallow study)
Carbon Sequestration Assessment FIRE-FREE production	
SOM buildup	
SOM content (g/ha, 0-100cm) = (g C/g soil) * (soil density* 1 E6 cm3/m2 * 10000 m2/ha)	
SOM in topsoil (g C/g soil)=	0.0104 (Vlek et al., 1999)
SOM in topsoil (g/ha)=	1.58E+08
Annual energy:	1.37E+11 (7 yr fallow study)

Emergy Yield Ratio twice as large would be obtained in this system when considering SOM buildup as production.

Quite expectedly, under this scenario the farmer would perceive an enormous advantage, for compensation would be offered for a resource still in place within the system. The total emergy dollar value of the fire-free production in this case would amount to Em$1,340.00/ha/yr, up from Em$132.00 when only the normal crops and wood materials made up the output of the system. The emergy dollar profit of the slash-and-burn system would reach Em$382.00/ha/yr, also a considerable improvement. In both cases, of course, the sustainability index is largely increased.

This hypothetical analysis suggests that in a carbon sequestration compensation scenario, in which society at large would assist with incentives for environmental conservation in agriculture and forestry, fire-free management practices would be greatly advantageous, and could contribute to improve the sustainability of land use in the Amazon.

CONCLUSION

The emergy analysis performed on the basis of the defined typical slash-and-burn and fire-free agricultural production systems showed that while production in the former is primarily based on free environmental inputs, the latter is highly dependent on purchased inputs. This difference is crucial, and makes it advantageous to the farmers to rely on burning to clear and fertilize the land for planting. Significant efficiency improvements would be required in the mulching operation, as well as in nutrient fixation/ recovery, to make the fire-free production system competitive.

Evaluations of actual farms practicing these different management systems should be carried out to check for possible feedback reinforcements used by farmers to improve efficiency. Also, the engagement of farmers in special social arrangements that might foster the collective use of resources and equipment should receive special attention. Finally, a local community-wide evaluation could shed light onto other, off farm advantages, both environmental and economic, that could compensate for the increased resources demanded by fire-free agriculture.

Table 5. Summary emergy evaluation of the slash-and-burn and the fire-free agricultural management systems including soil organic matter buildup as production. Refer to Tables 2 and 3 for details, and Table 4 for soil organic matter buildup evaluation.

Carbon Sequestration Assessment Production System -	Slash-and-burn		Fire-free	
	Solar EMERGY (E13 sej/yr)	Em$ Value ($/yr)	Solar EMERGY (E13 sej/yr)	Em$ Value ($/yr)
Renewable Inputs	76	91	76	91
Nonrenewable storages	64	76	35	41
Soil organic matter (SOM) buildup	181	216	1014	1207
Purchased inputs	16	19	69	82
Production (not accounting for SOM buildup)	156	186	180	214
Production (SOM buildup is included as production)	337	401	1194	1422

INDICES	SYSTEM'S RESULTS	
% Renewable	0.49	0.42
Environmental Loading Ratio	1.04	1.36
Emergy Investment Ratio	0.12	0.62
Emergy Yield Ratio	20.68	17.27
Emergy Yield Ratio excluding SOM buildup	9.56	2.60
Nonrenewable/Renewable	0.83	0.81
Empower Density	3.37E+15	1.19E+16
Emergy Sustainability Index	19.80	12.68

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REFERENCES

Bastos, T. X.; & Pacheco, N. A. 1999. Características agroclimatólogicas do município Igarapé-Açu. Anais do Seminário sobre Manejo da Vegetação Secundária para a Sustentabilidade da Agricultura Familiar da Amazônia Oriental. Belém. 51-58.

Block, A.; Lucke, W.; Denich, M.; Vlek, L. G. 1999. The newly developed bush chopper "Tritucap" in field test, research on working capacity and working quality under capoeira conditions. Anais do Seminário sobre Manejo da Vegetação Secundária para a Sustentabilidade da Agricultura Familiar da Amazônia Oriental. Belém. 109-111.

Brandt-Williams, S. L. 2001. Folio #4: Emergy of Florida Agriculture. Handbook of Emergy Evaluation: A Compendium of Data for Emergy Computation Issued in a Series of Folios. Center for Environmental Policy, University of Florida, Gainesville. 40p.

Brown, M. T.; & Bardi, E. 2001. Folio #3: Emergy of Ecosystems. Handbook of Emergy Evaluation: A Compendium of Data for Emergy Computation Issued in a Series of Folios. Center for Environmental Policy, University of Florida, Gainesville.

Comar, V. 2001. Emergy evaluation of organic and conventional horticultural production in Botucatu, São Paulo State, Brazil. In Emergy Synthesis: theory and Applications of the Emergy Methodology. 181-195.

Christianson, R. A. 1986. Simulating land rotation in plantations at Jari, Brazil. *In* Energy Systems Overview of the Amazon Basin. Odum, H.T.; Brown, M. T.; & Christianson, R. A. Center for Wetlands, University of Florida, Gainesville. 153-159.

Holscher, D.; Ludwig, B.; Moller, R. F.; Folster, H. 1997. Dynamic of soil chemical parameters in shifting agriculture in the eastern Amazon. Agriculture, Ecosystems and Evironment, 66:153-163.

Jonsson, A. 2000. Energy balance of a traditional and a modified land use system in the Eastern Amazon basin, Brazil, as a case study. M. Sc. Thesis, Georg-August University. Gottingen, Germany. 93p.

Jonsson, A.; Vielhauer, K.; Denich, M.; & Vlek, P. L. G. 1999. Energy balance of traditional and modified land-use systems in the Eastern Amazon basin, Brazil, as a case study. Anais do Seminário sobre Manejo da Vegetação Secundária para a Sustentabilidade da Agricultura Familiar da Amazônia Oriental. Belém. 66-68.

Kato, M. S. A.; & Kato, O. R. 1999. Preparo de área sem queima, uma alternativa para a agricultura de derruba e queima da Amazônia Oriental: aspectos agroecológicos. Anais do Seminário sobre Manejo da Vegetação Secundária para a Sustentabilidade da Agricultura Familiar da Amazônia Oriental. Belém. 35-37.

Kato, M. S. A.; Kato, O. R.; Denich, M.; Vlek, P. L. G. 1999. Disponibilidade de fósforo em sistema de mulch, no Nordeste Paraense. Anais do Seminário sobre Manejo da Vegetação Secundária para a Sustentabilidade da Agricultura Familiar da Amazônia Oriental. Belém. 116-119.

Kitamura, P. C.; & Rodrigues, G. S. 2000. Avaliação de tecnologia e manejo para o desenvolvimento sustentável da agricultura familiar. PPG-7 Meeting. Belém.

Odum, H. T. 1986. Energy analysis overview of Brazil. *In* Energy Systems Overview of the Amazon Basin. Odum, H.T.; Brown, M. T.; & Christianson, R. A. Center for Wetlands, University of Florida, Gainesville. 64-81.

Odum, H. T. 1996. Environmental Accounting. Emergy and Environmental Decision Making. John Wiley / Sons, Inc. New York, 370p.

Rodrigues, G. S. ; Kitamura, P. C.; Meyer, Leandro, F. F. ; Denich, M.; Sá, T. D. de A. 2001. Integration of information on fallow systems toward supporting public policies. Proceedings of the German-Brazilian Workshop on Neotropical Ecosystems, Hamburg, in press.

Sommer, R.; Vlek, P. L. G.; Folster, H.; Sa, T. D. de A. 1999. Slash-and-mulch to reduce nutrient losses in shifting cultivation in the eastern Amazon. Anais do Seminário sobre Manejo da Vegetação Secundária para a Sustentabilidade da Agricultura Familiar da Amazônia Oriental. Belém. 80-82.

Ulgiati, S., Brown, M. T.; Bastianoni, S.; & Marchettini, N. 1995. Emergy-based indices and ratios to evaluate the sustainable use of resources. Ecological Engineering, 5:519-531.

Vielhauer, K.; & Sa, T. D. de A. 1999. Efeito do enriquecimento de capoeira com árvores leguminosas de rápido crescimento para a produção agrícola no Nordeste Paraense. Anais do Seminário sobre Manejo da Vegetação Secundária para a Sustentabilidade da Agricultura Familiar da Amazônia Oriental. Belém. 27-34.

Vlek, P. L. G.; Sommer, R.; Vielhauer, K.; & Serrao, A. 1999. The carbon and nutrient balance under slash-and-burn agriculture and its alternatives in the Amazon. Mimeographed, 19p.

Footnotes to Table 2

1	Sun, J			
	Annual energy =	(Avg. Total Annual Insolation kcal/cm2/yr)(Area)(1-albedo)		
	Insolation:	1.95E+02	kcal/cm2/yr	(Odum et al. 1986)
	Albedo:	0.15		
	Annual energy:	6.94E+13		
2	Rain, J	(mm/yr)(Area)(1E6g/m3)(4.94J/g)(1 - runoff)		
	mm/yr	2470	(Bastos & Pacheco, 1999)	
	Runoff coefficient:	7.00E-02		
	Annual energy:	1.13E+11		
3	Wind, J			
	Density of air =	1.30E+00	Kg/m3	
	Average wind velocity =	1.40E+00	mps	Bastos & Pacheco, 1999
	Geostrophic wind =	2.33E+00	mps	Observed wind is about .06 of geostrophic wind
	Drag coefficient =	1.00E+-3		
	Annual energy =	(area)(air density)(drag coeff.)(velocity^3)		
		(___m^2)(1.3 kg/m^3)(1.00E-3)(___mps)(3.14E7 s/yr)		
	Annual energy =	5.19E+09	J/yr	
4	Evapotranspiration, J	(g/m2)(J/g)(area)		
	Et: 848 mm/yr	8.48E+05	g/m2	(Bastos & Pacheco, 1999)
	Annual energy:	4.19E+10		
5	Net Topsoil loss J (erosion rate * SOM)(5.4 kcal/g)(4186 J/kcal)			
	Erosion rate =	2000	g/m2/yr	
	% organic in soil =	0.0080	(Vlek et al., 1999)	
	Annual energy:	3.62E+09		
6	Nutrient loss by burning, JLost C, N, P, K, Ca (43.4T/ha DM, Sommer et al., 1999) * transformity (Odum 1996)			
	Total nutrient loss (J/ha) =(g/ha N, P, K, Ca*%retained*J/g)/5yr			
	Total Biomass Loss (J/ha) = g C*3.6Kcal/g*4186J/kcal			
	Annual energy:	3.66E+14		
7	Fuel, J per ha (diesel, machinery operation)	(gal/ha*1.51E5 J/gal /5yr)		
	Gallons:	0.00E+00		
	Total energy:	0.00E+00		

8	Phosphate fertilizer (g)		
	Annual consumption:	0.00E+00	(Kato & Kato, 1999; Kato et al. 1999)
9	Labor, J	(pers-hours/ha/yr)*(3500 kcal/day)*(4186J/Cal)	
	pers-hours:	1.37E+02	(Jonsson et al. 1999; Jonsson, 2000)
	* Adapted from passion fruit/cassava crops - includes slash/burning, cultivating-2/5, harvesting 2/5		
	Total energy:	2.01E+09	
	Transformity:	8.10E+04	(uneducated labor - Odum, 1996)
10	Services, $ per ha	* Estimated cost for machinery operation	
	$/yr:	0.00E+00	(Vielhauer, 2000 - personnal communication)
	Production (kg/ha/yr) All production figures for 5 years production cycle		
11	Corn (4300 kg in 5 years)	8.60E+02	(Vielhauer & Sa, 1999; Kato & Kato, 1999; Vielhauer, 2000 – personal com)
12	Cassava (28,000 kg in 5 years)	5.60E+03	(Vielhauer & Sa, 1999; Kato & Kato, 1999; Vielhauer, 2000 - personal com)
13	Charcoal	0.00E+00	
14	Firewood	0.00E+00	(Vlek et al. 1999; Vielhauer, 2000 – personal communication)
15	Timber	0.00E+00	
16	Total Yield	* as total energy investment for production	
	Dry weight =		
	Corn	7.48E+05	13% humidity, 13.6% protein, 7.9% fat, 78.5% carbohydrates
	Cassava	1.68E+06	70% humidity, 9% protein, 1% fat, 90% carbohydrates (assume = potato)
	Charcoal	0.00E+00	2% humidity, twice energy content of firewood assumed
	Firewood	0.00E+00	15% humidity, 4.0kcal/g (Brown & Bardi, 2001)
	Timber	0.00E+00	15% humidity, 4.0kcal/g
17	Product in Joules	* as total energy in product	
	protein at 24KJ/g, fat at 39KJ/g, carbohydrates 17KJ/g		(Brown & Bardi, 2001)
	Energy content =	4.47E+10	J

Footnotes to Table 3

Notes	* only those items different from table 1a.		
5	Net Topsoil loss J (erosion rate * SOM)(5.4 kcal/g)(4186 J/kcal)		
	Erosion rate =	2000	g/m2/yr
	% organic in soil =	0.0104	(Vlek et al., 1999)
	Annual energy:	4.70E+09	
6	Nutrient loss by burning, J		
	Total nutrient loss (J/ha)=		(g/ha N, P, K, Ca*%retained*J/g)/5yr
	Total Biomass Loss (J/ha) = g C*3.6Kcal/g*4186J/kcal		
	Annual energy:	0.00E+00	

7 Fuel. J per ha (diesel. machinery operation) (gal/ha*1.51E5 J/gal /5yr)
Gallons: 5.37E+00 (Block et al. 1999)
Total energy: 8.11E+05
8 Phosphate fertilizer (g)
Annual consumption: 1.50E+04 (Kato & Kato. 1999: Kato et al. 1999)
9 Labor. J * (pers-hours/ha/yr)*(3500 kcal/day)*(4186J/Kcal)
pers-hours: 1.81E+02 (Jonsson et al. 1999: Jonsson. 2000)
* Adapted from passion fruit/cassava crops - includes mulching. growing seedlings. cultivating-2/5. harvesting 4/5
Total energy: 2.65E+09
Transformity: 8.10E+04 (uneducated labor - Odum. 1996)
10 Services. $ per ha * * Estimated cost for machinery operation
$/yr: 2.50E+01 (Vielhauer. 2000 - personnal communication)
Production (kg/ha/yr) All production figures for 5 years production cycle
11 Corn (4.000 kg in each of 2 harvests in 5 years) 1.60E+03 (Two crops) (Vielhauer & Sa. 1999: Kato & Kato. 1999: Vielhauer. 2000 - personal com.)
12 Cassava (26.000 kg in each of 2 harvests in 5 years) 1.04E+04 (Two crops) (Vielhauer & Sa. 1999: Kato & Kato. 1999: Vielhauer. 2000 - personal com.)
13 Charcoal 0.00E+00
14 Firewood (34.500 kg in 5 years) 6.90E+03 (Vlek et al. 1999: Vielhauer. 2000 – personal communication)
15 Timber 0.00E+00
16 Total Yield * as total energy investment for production
Dry weight =
Corn 1.39E+06 13% humidity. 13.6% protein. 7.9% fat. 78.5% carbohydrates
Cassava 3.12E+06 70% humidity. 9% protein. 1% fat. 90% carbohydrates (assume = potato)
Firewood 5.87E+06 15% humidity. 4.0kcal/g (Brown & Bardi. 2001)
17 Product in Joules * as total energy in product
protein at 24KJ/g. fat at 39KJ/g. carbohydrates 17KJ/g (Brown & Bardi. 2001)
Energy content = 1.81E+11 J