Biomass and Energy Assessment of Different Natural and Agricultural Systems in Brazil

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Summary

Biomass and energy evaluation was carried out in the Municipality of Teresópolis - Rio de Janeiro, Brazil. The following agricultural and natural systems were considered: (i) vegetables systems (leaf, fruit and mixed vegetables); (ii) citrus; (iii) ecological agro-forestry; (iv) cattle ranching, (v) silvopastoril systems, (vi) forest fragments and, (vii) forest in regeneration stage (1, 2 and 3 years old). The main primary agricultural production systems have in general low energy conversion ratio (6:1), and store only small quantities of biomass in the system (2.1 Mg C ha^{-1}). The ecological system has the most efficient use of energy (2:1), and saves great biomass quantity in the system (1.80E11 J ha^{-1} yr^{-1}). The cattle system presents the lowest values for all energy and biomass parameters causing largest environmental damage (aboveground biomass (AGB) = 0.49 ton DM ha^{-1}; Energy Ratio 461:1).

Key words

energy, renewable energy, farming systems, biomass, Teresópolis

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Introduction

A significant part of greenhouse gas (GHG) emissions in Brazil is associated with land conversion and high deforestations rates (Brown et al., 1996a). The tropical systems act as sinks for atmospheric CO_2 in form of large volumes of biomass per hectare (Lugo and Brown, 1992). Land clearing, which often causes the burning of the forest biomass, leads to net emissions of carbon dioxide and other GHGs (López, 2005). Various parts of the world are at different stages of agricultural development; therefore, energy-use practices vary widely (Peart, 1992).

Carbon sequestration by forest systems is a finite process. Biomass may eventually reach a maximum sequestration potential and no longer reduce the amount of CO_2 in the atmosphere. The time period required to reach such stage is not well known, but it has been speculated that such a limit is reached in the first 50-100 years following forest establishment (Silver, 2000).

Agricultural land might need to be considered a candidate for carbon trading in the future (Puig, 2005). Similarly, Schimel (2001) considers other possible mechanisms for carbon uptake like regrowth on abandoned agricultural land, fire prevention and longer growing seasons. The latter mechanisms are compounded by increased concentrations of carbon dioxide and nitrogen. Defries (2002) considers that carbon fluxes from tropical deforestation and regrowth are highly uncertain components in the contemporary carbon budget.

Secondary forests store approximately 94 Mg C ha^{-1} (Puig, 2005). Rates of above-ground C accumulation in plantations range from 0.8 to 15 Mg C ha^{-1} yr^{-1} (Lugo et al., 1988). Tropical forests store 206 Pg C in the soil (Eswaran et al., 1993). Brown et al. (1996b) calculated that approximately 2 Pg of C is lost annually from the conversion of tropical forest in to agriculture. Tropical secondary forests have a sequestration capacity of 3 Mg C ha^{-1} yr^{-1} (Brown and Lugo, 1990).

The main objective of the present study is to compare natural with agricultural systems through common energy and carbon indicators. For each of the natural and agricultural systems, the carbon sequestration capacity will be calculated as well as the energy ratio, the energy production, the energy consumption, and the energy accumulation.

Methodology

In the municipality of Teresópolis - Rio de Janeiro, located in the mountain region of the Atlantic Forest, the following agricultural and natural systems have been compared: (i) vegetables (leaf, fruit and mixed); (ii) citrus; (iii) ecological farming systems; (iv) cattle, (v) silvopastoril, (vi) forest fragment and (vii) forest in regeneration stage (1, 2 and 3 y. old). The National Park "Serra Dos Orgaos" was taken as reference natural system. During 18 months biomass production and partitioning was measured, all inputs and outputs of the systems were determined, and transformed in energy units.

Litter fall of four forest fragments of 9 ha, 23 ha, 39 ha and 62 ha was collected. Litter collectors of 1x1 m were installed

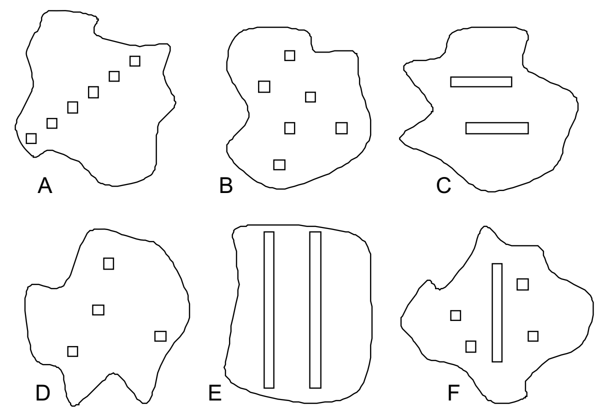

Figure 1. Plot design for litter collection and phytomass measurement parcels. A. Fragments, 6 collectors for fragment in diagonal position, to cover the borders and the central part. B. Forests in regeneration: 6 points of 2x2m at random. C. Flooded areas, vegetable material was collected in homogeneous plots of 2x4 m. D. Grasses, 4 collectors of 1x1m, were marked per lot. E. Agricultural system: given the production system on ridges 1.20x20 m plots were sampled. F. Silvopastoril system: plots of 10x40 m for forest species, combined with 4 marked areas of 1x1 m for determination of grass production

at soil level, 6 in each fragment along a diagonal transect (Fig. 1a). The samples were collected monthly, and were subdivided into leaves, branches and fruits. Taking advantage of the clearing activities in regeneration areas for agricultural purposes, small parcels of 2x2 m were marked that represent the heaps where farmers pile up the cleaned biomass. A total of 6 areas were evaluated at the rate of two plots for each of age categories one, two and three years respectively, making a total of 36 widely distributed plots (Fig. 1b). It was weighed only once. In the flooded areas distribution of vegetation was homogeneous, reason why only two plots of 2x4 m for each area were necessary (Fig. 1c). The phytomass was collected every four months. In grass area plots of 4 m^2 (2x2 m), the biomass was collected every three months, 1 m^2 each time (Fig. 1d). In the crop parcels the ridges were taken as plot parcels as commonly used for horticultural production. They were about 1.2 m wide and 20 m long (Fig. 1e). The phytomass was measured at harvest, and the total biomass production and its partitioning were determined as well as the percentage that stays in the systems and the quantity that leaves as commercial product. Finally, in the silvopastoril systems the grass methods of biomass collection with parcels of 10x40 m were adopted (Fig. 1f) to determine the forest species biomass. For most of these species the destructive method was applied taking advantage of the thinning. Total biomass was also calculated through volume measurements and its specific wood weight. The same methodology to determine biomass in agricultural and natural systems was used by Sonwa (2004), Mulindabigwi (2006), and Deng (2007).

The measurement of the energy content of the biomass was carried out in laboratory, for each agricultural product,

Table 1. General overview of the farming systems in the Muncipality of Teresopolis, Mata Atlantica, Brazil

	Eco-farm	Cattle	Silvopastoril	Fruit vegetables	Leaf vegetables	Mixed vegetables	Citrus
Area (%)*	0.1	83.7	2.3	2.9	5.8	2.2	2.8
Seeds quality	good	any	any	good	very good	very good	good
Fertilizers	any	any	any	high	high	high	low
Pesticides	any	any	any	high	high	high	any
Herbicides	any	any	any	middle	middle	middle	any
Anti-parasites	any	middle	middle	any	any	any	any
% Forest (average)	80	5	15	33	32	32	15
% Crops Area (average)	18	0	0	66	66	66	84
Fallow (months/yr)	2 to 6	0	0	0	0	0	0
Production Losses (%)	18	0	0	14	11	11	10
Market destination (%)	20	100	100	99	100	100	98
Irrigation	low	any	any	high	high	high	any
Principal product	diversified	meat	meat	chayote, tomato	salad, cabbage	chayote, salad	candarin
Diversity	3.19	0.01	0.08	2.01	2.18	2.22	0.1
Richness	96	8	34	21	19	21	8
Dominance	0.93	0	0.01	0.86	0.86	0.86	0.03
Evennes	0.7	0	0.03	0.73	0.74	0.73	0.05

* Percent of the total agricultural area in Teresópolis; Source: Author

distinguishing between branches, leaves and fruits. For forest systems, leaves, branches and wood were partitioned.

General overview of the agricultural systems together with their input level and some important agro-biodiversity indicators are described in Table 1. The following definitions have been taken into account, viz.; (i) *Energy Input* i.e. all energy inputs in the system in form of fertilizers, fuel, electricity, compost, and effective sun radiation. It is also considered as *energy Consumption;* (ii) *Energy production* for agricultural systems consisted of all biomass leaving the system (up to 95% for agricultural systems). For the natural systems, the yearly average biomass of the litter fall, including leaves, branches fruits and flowers, was considered; (iii) *Energy Ratio*, is the relation between the agricultural production and the energy input, and (iv) *Energy Accumulation* in farming systems represents the biomass that will remain in trees, bushes and soil of the respective system.

Findings and discusion

The agriculture in the region is characterized by intensive, small (less than one ha) but often irrigated horticultural production systems. This horticultural system has little or no interaction with the cattle and forest subsystems. The inputs such as organic and inorganic fertilizers are introduced into the system. The plants are generally produced from good quality seed. Most of the young plantlets are produced locally in specialized nurseries. The products of the system are marketed by different channels, mostly dominated by middlemen who take the production to the surrounding markets. The productive units generally opt for diversification market strategies, since the prices are fluctuating during the whole year.

In the municipality of Teresópolis, forests occupy the biggest area with 36.2%, followed by the grassland (31.1 %), bushes (18.8 %), the areas corresponding to rocks, open areas, colonies (11.4%), and with 2.6 % in the last position is the crop area. From the 1,793 ha under agricultural production in the municipality of Teresopolis, 74% (1,327 ha) are taken by cattle production (CPS) and 2% by silvopastoril systems (SPS). The average animal load is 11 animals per 10 ha. Extreme values of two up to 67 animals per 10 ha were found. In the humid season the average milk production is 7.5 l*day^{-1}, and in the dry season 4.5 l*day^{-1}. After 40 months of fattening the meat livestock produces approximately 165 kg of clean meat/head that are marketed through middlemen and sold in bordering markets. The remaining land use or 24% is occupied mainly by horticultural systems. The intensive horticultural systems are the most important economic activity and occupy circa 403 ha. Mainly five types of horticultural systems exist in the region as summarized in Table 1.

Of the 2,954 existent farms in Teresópolis, a little more than 2,500 have positive conditions for agricultural production. There are enough manpower to increase cultivation area or to intensify the production. On the average there are three people per farm unit, totally dedicated to production. The population growth in the region remained constant in the last years, with less than 1% of annual growth.

The more inefficient farming system in the municipality of Teresópolis is the cattle system, with an approximate stocking rate of 0.7 ha/TLU. This system requires 461 Joules of inputs (encompassing externalities) to produce one Joule in meat form. Hence, this production system has a poor capacity to accumulate energy in the system in the form of biomass. On the other hand, the ecological systems present a high capacity to store energy (1.80E11 Joules ha^{-1} yr^{-1}), followed by horticultural systems, and generally combined with a small forest percentage, storing energy up to 1.03E11 Joules ha^{-1} yr^{-1}. Contrary to the cattle on pure grassland, the silvopastoril systems present a good capacity to store biomass (2.6E10 to 5.56E10 Joules ha^{-1} yr^{-1}) (Fig. 2). Houghton et al. (1993) and Richter et al. (1999) showed similar storage rates.

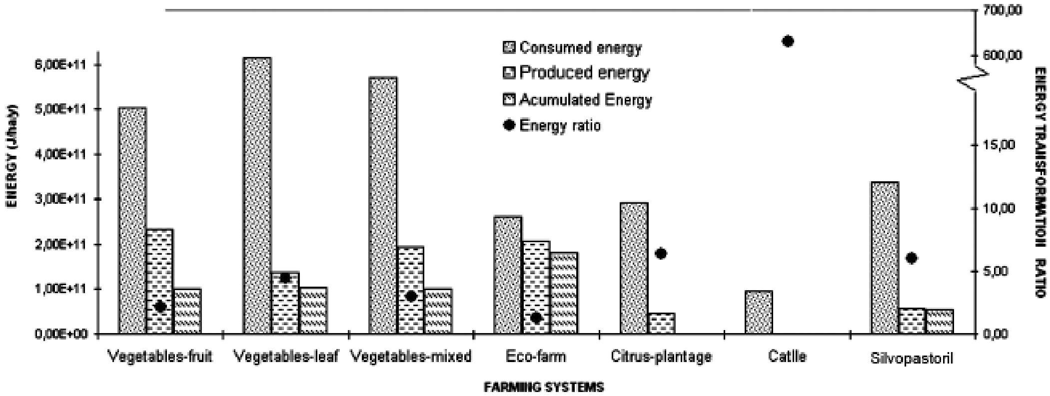

Figure 2. Production, consumption, accumulation and energy ratio of different farming systems in RJ-Brazil

The natural systems, like the mature forest of the National Park "Serra dos Orgãos" in the Atlantic Forest region, stores 272 Mg C per ha whilst bordering fragments in a secondary stage store only 87.3 Mg C. The latter two biotas have the capacity to sequestrate 11.65 and 3.01 Mg C y^{-1} (Table 3). The aquatic plants, dominated by *Typha domingensis*, are excellent producers of phytomass in the region. Annually they can produce up to 6.3 Mg of C, which is more than a three-year-old regeneration forest with an annual yield of only 2 to 4 Mg C. Surprisingly, horticultural production systems can produce annually as much as 27.8 Mg C ha^{-1} (Table 2), the larger part of it being exported though. There exists approximately a stock of 386844 ton phytomass dry matter in the studied micro-basin (53 km^2). The same area will produce annually 20,478 tons of dry matter representing 2.28E14 Joules (Table 2). The forest fragments and the forest areas in regeneration accumulate more than 92% of biomass in the system, while in agricultural systems 90% of the produced biomass comes out of the system.

In the Tables 3 and 4 the biggest stock of aboveground biomass per ha was found in the mature mountain forest with an approx. value of 606 ton dry matter (DM). To the contrary, the pastoral systems present a minimum value 0.49 ton DM ha^{-1}. Other farming systems in tropical regions have great capacity for stocking dry matter, as the case of "cocoa agroforest" in South Cameroon with a value of 451 ton DM ha^{-1} (Sonwa, 2004). The sugar cane system in Chiapas Mexico is the superior production system with a yearly average production of 48.6 ton DM (equivalent to 2.7.E06 J ha^{-1}).

Table 2. Average aboveground dry matter (AGDM) stock and yearly phytomass production of different biota in Teresópolis

	Area		AGDM	Phytomass Production		
	Area (%)	Area (ha)	DM (ton)	DM $ha^{-1}y^{-1}$ (ton)	DM $year^{-1}$ (ton)	Total (J yr^{-1})
Crops	2.6	138	4408	27.8	3833	2.59E13
Grassland	31.1	1654	1488	0.5 – 1.5	827	3.21E12
Forest Fragment	36.2	1925	373511	6.7*	12915*	2.28E14
Forest Regeneration	18.8	1001	7435	2.01- 4.42	2902	6.62E13
Others **	11.4	607	-	—	—	—
Total	100	5324	386844	3.85	20478	3,23E14

AGDM: above ground dry matter. * Litter fall; **Others: corresponds to buildings, streets, rocks, open soils, water, etc

Table 3. Aboveground dry matter (AGDM) stock and yearly phytomass production of different natural systems in Teresópolis compared with selected systems in the world

Natural Systems	AGDM (ton DM ha^{-1})	Phytomass Production (ton DM $ha^{-1}y^{-1}$)	Source
Forest Mata Atlântica (mountain)	606.3 9	26*	
Forest Mata Atlântica (transition)	617.8 9	—	
Forest Mata Atlá (high montane forest)	318.3 8	—	
Fragments Mata Atlântica	194.0 5	6.71 - 7.1*	
Regeneration 3y	7.4 3	4.42 - 6.6	
Water plants	11.6 5	12.7	
Forest fragment Chiapas-Mexico	269.9 5	—	[1]
Forest Uganda	26.1 0		[2]

AGFM: Above Ground Fresh Mater; AGDM: Above Ground Dray Mater; * Litter fall [1] Jende (2005), [2] Cleemput (2004)

Table 4. Aboveground dry matter (AGDM) stock and yearly phytomass production of different farming systems in Brazil, Cameroon and Mexico

Farming system	AGDM (ton DM ha^{-1})	Phytomass Production (ton DM $ha^{-1}y^{-1}$)	Energy Production (J ha^{-1})	Source
Ecological Farm (Mata Atl)	n.a.	28.0	1.6.E05	
Leaf Vegetables- Terê-Brasil	2.89	23.1	2.5.E05	
Fruit Vegetables- Terê-Brasil	19.42	38.8	9.0.E05	
Coffee Chiapas-Mexico	78.2	n.a.	n.a.	[1]
Cocoa Agroforest Cameroon	451.0	10.3	8.7.E03	[2]
Leek Bonn-Germany	6.9	34.7	1.8.E05	
Sugar Cane Chiapas-México	48.6	48.6	2.7.E06	[3]
Grass Mata Atlántica*	0.49	1.5	2.0.E03	

* Grassland for cattle and 1 year abandoned grasses; [1] Jende (2005), [2] Sonwa (2004), [3] Pohlan (2005)

In general, the agricultural systems have the capacity to produce around 23.1 to 38.8 ton DM ha^{-1} yr^{-1}, representing high to very high figures. In energy terms the highest value represents 9.0E5 Joules $ha^{-1}y^{-1}$.

Better combinations of plant, soil, water and nutrient management, with livestock or fish integrated into farming systems and with integrated pest management processes, are frequently achieving production increases of 50 to 100 percent or more in a wide variety of circumstances, including some that are agriculturally quite adverse (CIIFAD, 1999). Secondary forests and forest fallows are the most important form of C recovery in tropics due to the extensive area involved (Lugo and Brown, 1992). Controlled experiments have showed that primary productivity increases with plant species richness but often saturates at high diversity (Tilman, 2001).

The actual tropical land use have a significant impact on the global carbon cycle through increased rates of C emissions to the atmosphere and the loss of above- and belowground C accumulation and storage capacity. Current estimates suggest that approximately 1.6 (± 0.5) Pg (Petagram = 10^{15} g) of C are lost annually from the conversion of tropical forests (Brown et al., 1996b). In their aboveground biomass, secondary forests accumulate approximately 94 Mg C ha^{-1} (30 years old and 20 m high) (Puig, 2005). Tropical secondary forests have been reported to accumulate up to 5 Mg C ha^{-1} yr^{-1} during the first 10 to 15 years of regrowth, corresponding to a sequestration capacity of 2 to 3.5 Mg C ha^{-1} yr^{-1} (Brown & Lugo, 1990). Rates of above-ground C accumulation in plantations range from 0.8 to 15 Mg C ha^{-1} yr^{-1}, during the first 26 years following establishment (Lugo et al., 1988).

Eight years following deforestation, intensive pasture management in Brazil resulted in lower soil C pools than sites that were less intensively used (Buschbacher et al., 1988). Tropical forests store approximately 206 Pg C in the soil (Eswaran et al., 1993).

Conclusions

- Some agricultural systems can end up producing more phytomass than neighbouring natural systems as was the case with horticulture in the municipality of Teresópolis. However, the same horticultural systems use much more energy to produce the same quantity of energy as that produced by ecological systems, indicating a lower efficiency for energy conversion. Increasing energy use, climate change and the expected increases in the cost of energy underline the need to improve energy use efficiency.
- The primary agricultural production in Teresópolis is a good energy producer through conversion of natural energy sources into biomass. Fossil energy use efficiency is higher in ecological (low-input) crop production systems than in vegetables (high-input), and cattle systems. This is caused by the fact that in low-input systems, a relatively large amount of the used phosphor, nitrogen originates from non-fossil resources.
- High attention should be paid to the forest in regeneration state; from the energy point of view it was proven that the latter one considerably increases biomass stocks in the micro-basin. Pastoral systems unfortunately store and produce less energy. To the contrary, silvopastoril systems significantly increase the stock of carbon without reducing the forage production.

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