Energy for Sustainable Development 14 (2010) 194–199

Contents lists available at ScienceDirect

Energy for Sustainable Development

Bioenergy and sustainable development: The dilemma of food security and climate change in the Brazilian savannah

Marcus Vinicius Alves Finco [a,b,*], Werner Doppler [b]

[a] Department of Business Administration, Federal University of Tocantins, Brazil
[b] Institute of Agricultural Economics (490c), University of Hohenheim, Germany

ARTICLE INFO

Article history:
Received 8 November 2009
Revised 16 April 2010
Accepted 17 April 2010

Keywords:
Bioenergy
Food security
Climate change
Sustainable development
Brazilian savannah

ABSTRACT

The bioenergy has been greatly deliberated in Brazil. This has led the country to develop new policies and implement a biodiesel program (PNPB) in 2004 aiming at fostering the rural development and at the same time promoting a new and clean source of energy. Nevertheless, there is an ongoing international debate about the negative impacts of bioenergy, especially biofuels, such as, the consequences to native forests and on local food production. In this context, the present study aims to assess the relationship between small-scale oil seed activity and food production, as well as, with the deforestation of native forests. A cross-sectional study was conducted with small-scale farmers in the Brazilian savannah, in a transitional region between the Cerrado and the Amazon rain forest. A range of socio-economic and environmental indicators were collected among smallholders who cultivate *Jatropha curcas* and *Ricinus communis* and from them different scenarios were established, which estimated the impacts on climate change and on local food production due to oil seed activity. The results point towards a positive relationship between oil seed production and deforestation and a negative relationship between oil seed activity and local food production. The latter result, therefore, exacerbates local food insecurity. The research is unprecedented in the region and the results can be extremely effective in supporting regional and national government subsidies on clean energy that do not harm the local environment or food production; helping Brazil achieve regional sustainable development.

Introduction

Tropical forests are continuing to disappear at an alarming rate: between 1990 and 2005, the rate of deforestation averaged about 13 million hectares a year, occurring mostly in tropical countries.[1] Moreover, deforestation and forest degradation, mainly through conversion to pastureland, infrastructure development, and destructive logging and fires, account for nearly 20% of global greenhouse gas emissions (GHG). This is more than the entire global transportation sector and second only to the energy sector (IPCC, 2007). These trends are a result of land use change, mainly the expansion of agricultural land, which is in turn closely connected to the conditions of rural livelihoods, increasing demands for food, feed and fiber and, more recently, bioenergy (FAO/UNDP/UNEP, 2009; FAO, 2008c).

Bioenergy production affects the environment at local and global levels, impacting land and water resources, biodiversity and the climate. Although there are environmental impacts throughout the production chain – feedstock production, conversion and use – most impacts occur in the feedstock production stage and mirror those related to agricultural production in general. When land with high carbon content, such as, forest or peat land, is converted to biofuel production, for instance, the immediate resulting carbon balance is negative. With conversion, "carbon debts" are created that could take decades or even centuries to "repay" (Fargione et al., 2008; Searchinger et al., 2008). In addition, a comprehensive carbon balance assessment must take into account "indirect" land use change, which refers to emissions from lands in which biofuel feedstock replaces food crops (Frondel and Peters, 2007; FAO, 2008a,b).

While biofuels will only offset a modest share of fossil fuel energy use over the next decade, they will have much bigger impacts on agriculture and climate change. Allocating land to biofuel production means taking land away from other uses, such as, food or environmental preservation. The conversion of such lands to crop production will release carbon, which is sequestered in the soil, into the atmosphere, offsetting some of the carbon benefits of a renewable energy, like biofuels (Rajagopal and Zilberman, 2007; FAO, 2008d).

Based on the discussion above, the present study aims to assess the impacts of small-scale oil seed production in the native biome, as well as, in the local food production. For this purpose, an estimation of CO_2 (carbon dioxide) emitted due to deforestation of Brazilian Savannah (Cerrado) was done and carbon offset scenarios were established to estimate the economic yields by farmers through environmental

* Corresponding author. Institute of Agricultural Economics (490c), University of Hohenheim, Wollgrasweg 43, D-70599, Stuttgart, Germany. Fax: +49 711 459 23812.
E-mail address: marcus.finco@gmail.com (M.V.A. Finco).

[1] Brazil has 17000 km^2 of deforestation, on average per year, in the Brazilian Legal Amazon region (INPE, 2009).

0973-0826/$ – see front matter © 2010 International Energy Initiative. Published by Elsevier Inc. All rights reserved.
doi:10.1016/j.esd.2010.04.006

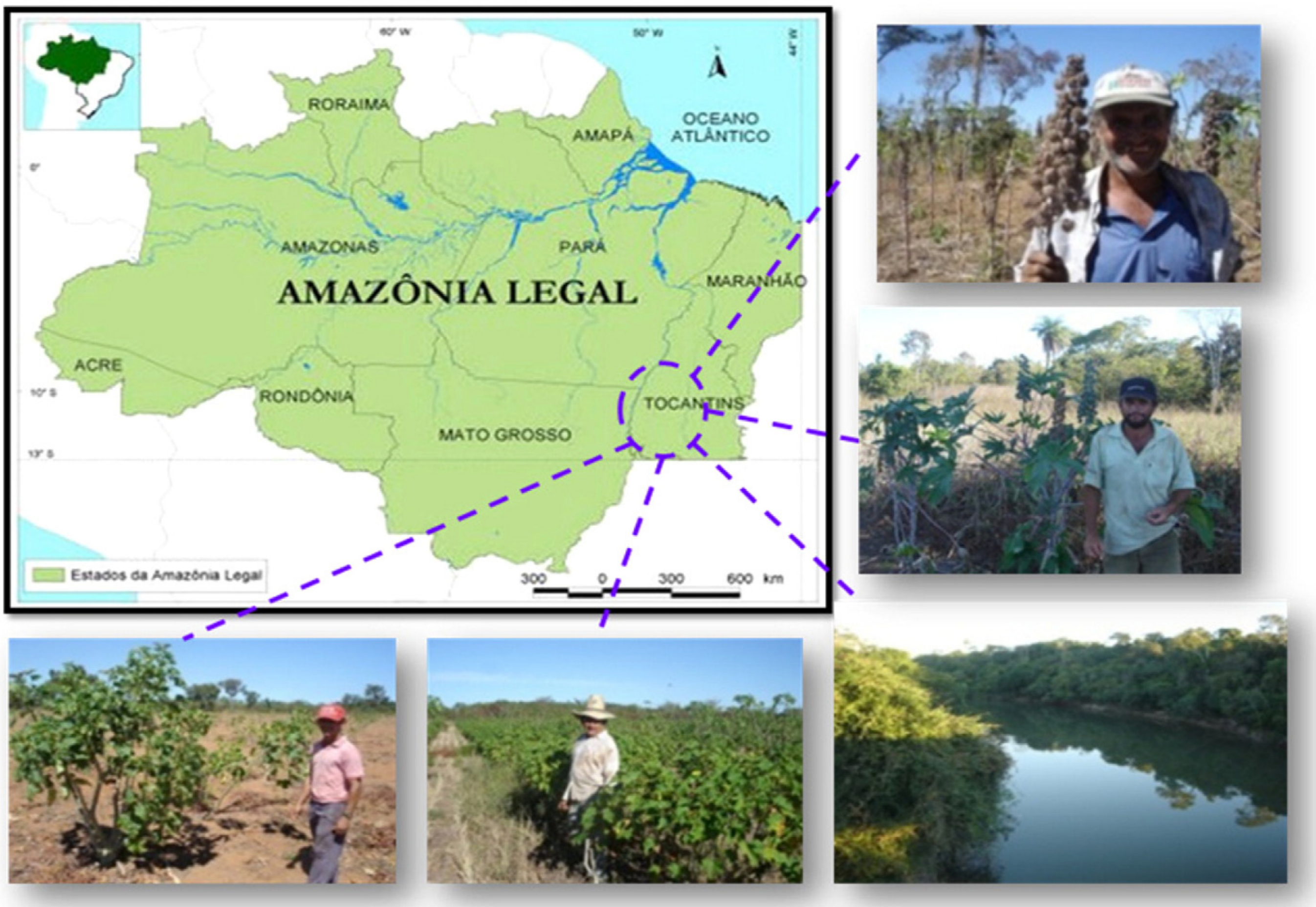

Fig. 1. Research area (Tocantins State, Brazilian Legal Amazon region).

services payment. In addition, different scenarios were established to estimate the impacts of oil seed activity on local food production.

Research area and methodological aspects

The research was carried out in Tocantins State, located in northern Brazil in a region well known as Brazilian Legal Amazon. The State is situated in a transition area, presenting climate and vegetation from Amazon rain forest (15% of the territory) and Cerrado (85% of the territory). This transition area, so-called Ecotone zone, is the home to traditional communities (family agriculture, indigenous, as well as, quilombolas[2]) and comprises rich biodiversity, which is responsible for numerous environmental services. For this reason, scientific studies and research in the area are extremely important. Often they are focused on understanding the different farming systems and their connections to the local economy and the very diverse environment.

Data collection necessary to create the database was formed through a comprehensive survey, which was carried out between April and September 2008 in two sub-study regions within Tocantins State. In one sub-study region, *Ricinus communis* (castor bean and also well known as mamona in Brazil) oil seed cultivated and in the other sub-study region *Jatropha curcas* (well known as pinhão manso in Brazil) is cultivated (Fig. 1).

Specific questionnaires were applied to smallholders, who were randomly selected: 27 in the case of *J. curcas* producers; and 25 in the case of *R. communis* producers. It is important to highlight that the selection of smallholders followed statistical procedures and that the sample can be considered representative since it comprises more than 90% of small-scale oil seed producers in the region in question. Parametric as well as non-parametric tests were used to demonstrate the statistical differences among the smallholders and the software STATA was used to support the statistical analysis.

Results and discussion

Deforestation and impacts on climate change

When inquired about the deforestation of native forests in order to cultivate oil seeds, 6 families (24%) in the *R. communis* group (RC) and 7 families (25.9%) in the *J. curcas* group (JC) responded positively, i.e. they have cut down the forest in order to start oil seed production. At first glance, these figures are not impressive, since roughly 75% of the remaining families have not deforested the biome to produce oil seeds. However, when taking into account the environmental services provided by native forests, especially the carbon sequestration and storage, this perspective might change.

Table 1 below demonstrates the quantity of carbon storage, per hectare, as well as, the carbon sequestered, per hectare per year, for Cerrado 'stricto sensu'[3] and Ecotone zone. It is important to mention that families in JC group are located in the Ecotone zone, i.e. the

[2] Descendants of African slaves.

[3] Cerrado 'stricto sensu' is considered the original Cerrado biome with no influence and/or transition to other biomes such as Amazon rain forest and Brazilian wetland (Pantanal), for instance (Merlin and Rezende, 2003).

Table 1
Carbon storage and carbon sequestered of Cerrado and Ecotone zone.

Biome	Carbon storage ($Mg\ CO_2\ ha^{-1}$)	Carbon sequestered ($Mg\ CO_2\ ha^{-1}\ y^{-1}$)
Cerrado	45[a]	3.86 up to 7.2[b]
Ecotone zone	112.5[a]	2.74 up to 5.4[b]

In the present study we considered the average quantity of carbon sequestered by a native forest, in a non-climax state. Although native forests can exhibit different values for carbon sequestration over time (sometimes even releasing carbon to the atmosphere rather than sequestering), the values presented herein are adapted from results found by Finco et al. (2006), and Rezende (2000) who estimated the carbon sequestration by native forests in biomes, such as, Cerrado, Amazon rain forest and the Ecotone zone.
Note: Figures are in CO_2 equivalent, the international measure for GHG emissions. 1 Mg is equivalent to 1 metric ton.
[a] Adapted from Fearnside (2006), and Fearnside and Barbosa (2003).
[b] Adapted from Finco et al. (2006), and Rezende (2000).

transition area between Cerrado and Amazon rain forest, which comprises vegetation from both biomes.

The Ecotone zone includes species from both Cerrado and Amazon rain forest and, therefore, has more capacity to store carbon when compared to Cerrado 'stricto sensu', even though the latter has a higher capacity to sequester carbon from the atmosphere. The range of carbon sequestration values reflects the fact that the entire process depends on several natural conditions, such as, humidity, quantity of rain and sun (Merlin and Rezende, 2003).

As illustrated in Table 2, families in RC group deforested 0.50 ha, on average, of Cerrado due to the oil seed activity and, therefore, released roughly 22.50 Mg CO_2 in the atmosphere. In the case of JC group, families deforested 0.72 ha, on average, of Cerrado and emitted 81.00 Mg CO_2 to the atmosphere.

However, in the aggregate, i.e. considering all smallholders in the group (RC and JC), the results show that roughly 12.5 ha of native forests were cut down in the case of *R. communis* producers and 19.5 ha in the case of *J. curcas* producers group.[4] Therefore, families who produce *R. communis* emitted more than 562 Mg CO_2 into the atmosphere and families who produce *J. curcas* released 2193 Mg CO_2. Moreover, since the native forest was cut down, between 48 Mg and 90 Mg $CO_2\ y^{-1}$ of carbon sequestration is lost in the case of RC producers and 53 Mg and 105 Mg $CO_2\ y^{-1}$, in the case of JC producers, i.e. families are emitting GHG to the atmosphere and at the same time are avoiding carbon sequestration. In this context, the production of oil seeds in the region in question began with a carbon debt, since the activity started vis-à-vis deforestation of native forests.

In addition to the impacts on climate change, forests also provide a range of ecosystem services, such as; water storage, increased rainfall, nutrient recycling, biodiversity and soil stabilization, and can help with flood control and boost agricultural productivity. Thus, the deforestation of native biomes due to oil seed activity generates many negative environmental consequences, even at the risk of species

[4] Although initially the amount of hectares deforested, due to oil seed activity, seems to be almost negligible (0.5 and 0.72 ha, on average, for RC and JC, respectively) one should bear in mind that: (i) herein we are dealing with local deforestation of native forests due to small-scale oil seed activity, which is not supported by the Brazilian program of biodiesel use and production (PNPB) and, therefore, should be seen with a much more critical eye and; (ii) our study focuses on farm and family level. In Tocantins State, where the research was carried out, there is the potential that more than 9 thousand farm families will be included in the biodiesel production chain through oil seed activity (potential oil seed producers). So, based on the results presented hitherto, if a family deforests part of the native forest aiming at cultivating oil seeds, one can be assured that with the addition of all 9 thousand families the total area of deforestation and, therefore, GHG emitted to the atmosphere will have a much greater impact. This is one of the reasons why REDD plus projects are important even at local level and small-scale farming. Nevertheless, we strongly suggest that other studies should be continued with larger sample to get more representative results, not just in the region in question but also in other regions within the Brazilian savannah.

Table 2
Total area of Cerrado and Cerrado deforested due to oil seed activity.
Source: Research results (2009).

Area (ha)	*Ricinus communis* producers		*Jatropha curcas* producers		
	Mean	SE	Mean	SE	*p*-value
Cerrado	4.26	1.17	9.25	1.25	<0.00
Cerrado deforested	0.50	0.23	0.72	0.24	0.67

Note:
SE = standard error of the mean.
Mann–Whitney test was applied to check statistical differences between means.

extinction since the entire chain of environmental services is compromised.

The payment for environmental services

The value of afforestation (planting forests) was internationally recognized in 1997, when it was included in the Kyoto Protocol agreement on global action to reduce the risk of human induced climate change. Historically, decreasing deforestation and forest degradation has been absent from international negotiations mainly because of difficulties in monitoring (FAO, 2008a). Despite this previous shortfall in policy, REDD plus was created, in which developing countries are given incentive to reduce deforestation and forest degradation. In this way, carbon stored in forests is given a monetary value and, thus, supports developing countries in investing in low carbon paths to sustainable development (Verchot and Petkova, 2009). Moreover, REDD plus includes some activities that might have serious implications for indigenous people, local communities and forests since it comprises "*Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries*" (FCCC/AWGLCA/2009/INF.1).

If cost-efficient carbon benefits can be achieved through REDD plus, CO_2 concentration increase could be slowed, effectively buying much needed time for countries to move to low emission technologies. Support of efforts to reduce emissions from deforestation and forest degradation have been expressed at the highest political levels (G8, UN General Assembly) and have been included in the Bali Action Plan of the United Nations Framework Convention on Climate Change (UNFCCC, 2009). In addition, during the last UNFCCC Conference of the Parties (COP 15) held in Copenhagen in December 2009, countries such as Australia, France, Japan, Norway and the United States of America, collectively dedicated around US$3.5 billion on fast-start climate change financing for REDD plus over the 2010 to 2012 period.

Although REDD plus is not yet formally established in the UNFCCC framework, some REDD plus credits are already being sold in voluntary markets and some initial finance is provided for pilot projects. The World Bank's Forest Carbon Partnership Facility, for instance, includes a readiness mechanism to help governments participate in REDD plus. In particular, it helps developing countries estimate their forest carbon stocks, establish national reference scenarios, calculate opportunity costs, and design monitoring, reporting and verification systems (UNFCCC, 2009).

Therefore, as land use change in the tropics is usually driven by people trying to maximize their economic gain, the farmers will also choose the most profitable option available. If REDD plus is to work as a real financial incentive, it must be robust enough to compete with other potential land uses. In this context, a country could accrue, for each hectare of forest saved from deforestation, a certain amount of money and use this number to compare the opportunity cost of using the land for agricultural purposes (Schlamadinger et al., 2004, 2005).

Table 3
Scenarios for REDD plus project.
Source: Research results (2009).

Project phases	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	RC	JC	RC	JC	RC	JC	RC	JC
1. Carbon storage (Mg CO_2 ha^{-1})[a]	45.00	112.50	45.00	112.50	45.00	112.50	45.00	112.50
2. Carbon sequestration (Mg CO_2 ha^{-1} y^{-1})[a]	3.86	2.74	3.86	2.74	7.20	5.40	7.20	5.40
3. [1 + 2 during 30 years (Mg CO_2 ha^{-1})]	160.80	194.70	160.80	194.70	261.00	274.50	261.00	274.50
4. Price of carbon (US$ per Mg CO_2)[b]	4.00	4.00	10.00	10.00	4.00	4.00	10.00	10.00
5. Revenue (US$ for 30 years project)	643.20	778.80	1608.00	1947.00	1044.00	1098.00	2610.00	2745.00
6. Revenue (US$ ha^{-1} y^{-1})	21.44	25.96	53.60	64.90	34.80	36.60	87.00	91.50

RC = *R. communis* group: JC = *J. curcas* group.
Scenario 1: low sequestered carbon, low price; scenario 2: low sequestered carbon, high price; scenario 3: high sequestered carbon, low price; and scenario 4: high sequestered carbon, high price.
[a] Based on Table 1.
[b] The prices of carbon credits (Mg CO_2) were based on Finco et al. (2006).

Based on the discussion above, as the 'forest standing' has no economic value to the smallholders, their opportunity costs might lead towards deforestation. A 'win-win' approach could be achieved by paying farmers to sequester carbon, which sets up a situation where: CO_2 is removed from the atmosphere (mitigation); high soil organic matter increases agro ecosystem resilience (adaptation); and improved soil fertility leads to better yields (production and income generation).[5] If a carbon market successfully allows the trade of sequestered carbon on the international market, deforestation of native forests in tropical countries might decrease. If deforestation is business-as-usual (or the baseline scenario), then the conservation of native forests by farmers would implement change and generate additional positive externalities. Thus, REDD plus project would create a stimulus for the conservation of native forests and increase the amount of carbon sequestered and, therefore, decrease the amount of carbon that is emitted to the atmosphere.

Nevertheless, the REDD plus project implemented and which will pay for environmental services, should adhere to certain prerequisites, such as, guaranteeing a reduction in GHG emissions compared to the baseline scenario (Nepstad et al., 2007; Jürgens et al., 2004). Once the REDD plus project is implemented additional positive externalities are generated and payment for environmental services can be made. The REDD plus project will most likely lead to a decrease in smallholder opportunity costs and increase the ability to maintain conservation practices. Even after the official commitment to reduce deforestation, in Amazon and in Cerrado, made by the Brazilian government during the 15th Conference of the Parties (COP 15) in Copenhagen[6], it is believed that the implementation of REDD plus project, which focuses on rewarding farmers through payment for environmental services, is a *sine qua non* condition to slow, halt or eventually reverse deforestation in Brazil.

Four different scenarios were established to estimate the economic yield for smallholders following the implementation of the REDD plus project: scenario 1 considers a low sequestered carbon and a low price of carbon credits, which herein are considered a *proxy* for environmental services; scenario 2 considers a low sequestered carbon, but high price of carbon credits; scenario 3 considers a high sequestered carbon, but low price of carbon credits; and scenario 4 considers a high sequestered carbon and a high price of carbon credits.

The results can be seen in Table 3.

Considering the low and high carbon sequestration rates according to Table 1 and the low and high prices of carbon credits (US$4 and US$10 per ton, respectively), one observes that according to the best/optimistic scenario (scenario 4), the yields earned by families in the RC group are around US$87 ha^{-1} y^{-1} or R$174 (Brazilian reais) ha^{-1} y^{-1}, and US$91.50 ha^{-1} y^{-1} or R$183 (Brazilian reais) ha^{-1} y^{-1} by families in the JC group. In order to better compare the yields from the REDD plus project and yields from farm activities, Table 4 shows the gross margin values, per year and per hectare, of different farm activities carried out by the same farm families.

As one can observe, even considering the best scenario of REDD plus project and, therefore, environmental services payment, conservation only has better economic returns when compared to bean cultivation in the both RC and JC groups. With the aim of visualizing the breakeven point, where the value of carbon credit generated by the REDD plus project will surpass the economic returns of other farm activities, simulations were produced. The results point out that: (a) for the RC group, US$12 per ton CO_2 will be enough to surpass rice activity, US$20 per ton CO_2 will be enough to surpass maize activity and only a carbon credit with a value above US$20 will surpass cassava activity; and (b) for the JC group, US$12 per ton CO_2 will be enough to surpass rice activity, US$15 per ton CO_2 will be enough to surpass maize activity and only carbon credits with a value higher than US$50 will be enough to surpass cassava activity in this group.[7]

However, as the economies of scale are an important issue in projects, such as, CDM and REDD plus, it is useful to simulate not the yields per hectare, but also the economic returns considering the total area of native forests in both groups. In this context, as a family in RC has, on average, 4.26 ha of Cerrado, the total yield generated by the REDD plus project is R$741.24 per year, which is enough to surpass any other farm activity. In the case of families in JC group, the trend is similar and the yields are even higher. As families have, on average, 9.25 ha of Cerrado, the total yield is R$1629.75 per year, which also surpasses any other farm activity carried out by the families. So, in order to maintain the oil seed activity, as well as, other crops without negative impacts on native forests, REDD plus projects should be fostered in the region in question.

Food production and food security

The food security of local communities is affected by the relationship between oil seed activity and food production. Therefore, it is necessary to present, *ex ante*, an overall picture of the total food consumption by families, as well as, the quantity of food produced by

[5] A similar project was carried out by Amazonas government in Brazil through the so-called 'bolsa floresta' where the regional government pays small-scale farmers for environmental services since farmers preserve native forest. More details can be seen in http://www.florestavivaamazonas.org.br/bolsa_floresta.php.

[6] During the High Level Segment of the 15th Conference of the Parties (COP 15) and the 5th Conference of the Parties serving as the meeting of the Parties of the Kyoto Protocol (CMP 5) held at Copenhagen, the government of Brazil indicated the nationally appropriate mitigation actions that Brazil intends to take to slow GHG emissions within the country such as: (i) reduction in Amazon deforestation (range of estimated reduction: 564 million tons of CO_2 in 2020); and (ii) reduction in Cerrado deforestation (range of estimated reduction: 104 million tons of CO_2 in 2020).

[7] The values of yields for REDD plus project presented in Table 4 are net values for the farmers, i.e. the costs related to forest conservation and monitoring are carried out by the local government and, therefore, the farmer is only receiving money to maintain the native forest as it is.

Table 4
Feedstock gross margin and REDD plus yields (R$/ha/year).
Source: Research results (2009).

Activity	*Ricinus communis* producers		*Jatropha curcas* producers		*p*-value
	Mean	SE	Mean	SE	
Rice	184.44	149.18	209.52	70.22	0.77
Maize	322.03	69.87	231.21	35.19	0.62
Cassava	356.04[a]	120.47	918.71[b]	789.55	<0.00
Bean	149.50[a]	47.80	26.17[b]	6.02	<0.00
REDD plus*	174.00	–	183.00	–	

Notes:
SE = standard error of the mean.
Different letters show significant difference between means according to Mann–Whitney test.
*Based on scenario 4 presented in Table 3.

them. This picture is important since it approximates of the quantity of food produced within the rural property and the quantity that must be purchased at the market.

In this context, Table 5 focuses on the most produced and consumed feedstock of local families.

As one can notice in Table 5, families in both groups (*R. communis* and *J. curcas*, RC and JC, respectively) have to buy a considerable part of the consumed food at local markets: 86% of rice, 90% of bean and 73% of cassava have to be purchased by smallholders in the RC group; and 65% of rice, 88% of bean and 29% of cassava have to be purchased by smallholders in the JC group. This demonstrates that families depend on local markets to fulfill their needs, i.e. relying only on self-production is not sufficient to feed the family and, therefore, families in the region in question can be considered net food buyers of food.

In addition, when asked about the area used to cultivate oil seeds, 11 families (44%) in RC group and 15 families (55.6%) in JC group responded they have changed the land use from an ordinary feedstock cultivation, such as, maize, rice, cassava to *Ricinus* and *Jatropha* production, respectively. Table 6 illustrates that at least 27% of the feedstock area in the RC group and 47% in JC group have been changed to the oil seed activity.

In addition to the figures presented in Tables 5 and 6, when families were inquired about food shortage during the year, 56% of smallholders in RC group responded positively, i.e. they suffer, in some level, of food deficit during the year, against 25.9% of smallholders in JC group whom responded similarly. Besides the difference in the figures, one can be assured that at least one fourth of the families in JC group face deficits on food consumption and what is more serious, more than a half of the families in RC group have to cope with food shortage during the year. These results raise an important question about human rights and highlight the ongoing discussion about the effect of biofuels on food insecurity.

Table 5
Amount of food consumed by families, per year.
Source: Research results (2009).

Quantity (kg)	*Ricinus communis* producers		*Jatropha curcas* producers		*p*-value
	Mean	SE	Mean	SE	
Total amount of rice consumption	276.80	26.43	204.44	9.09	0.06
Rice from the property	36.80	14.03	71.85	10.65	0.09
Total amount of bean consumption	87.36	9.28	78.22	6.84	0.34
Bean from the property	8.16	3.25	9.18	5.70	0.07
Total amount of cassava consumption	417.60	4.21	415.55	4.41	0.21
Cassava from the property	112.80	26.22	294.81	29.38	<0.00

Notes:
SE = standard error of the mean.
Mann–Whitney test was applied to check statistical differences between means.

Table 6
Total crop area and land changed to oil seed activity.
Source: Research results (2009).

Hectares	*Ricinus communis* producers		*Jatropha curcas* producers		*p*-value
	Mean	SE	Mean	SE	
Total crop area	2.66	0.63	2.87	0.51	0.44
Land changed to oil seed activity	0.74	0.20	1.37	0.26	0.08

Notes:
SE = standard error of the mean.
Mann–Whitney test was applied to check statistical differences between means.

Table 7 shows the relationship between oil seed activity and feedstock land converted oil seed production from two different scenarios. The first scenario (scenario A) is established based on the current land used, on average, to produce the main feedstock, such as, rice, maize, bean and cassava. This scenario reflects the current situation, i.e. the situation after the adoption of oil seed activity by families. In addition, the current production of feedstock, on average, is also presented for each group: RC and JC, respectively.

The second scenario (scenario B) represents a situation where families did not adopt oil seed activity. Here the estimation was based on all land that was used previously to produce feedstock, i.e. available land before the adoption of oil seed activity. Again, the potential production of feedstock, on average per family, is presented and one can observe the differences, expressed by Δ%.

As illustrated in Table 7, there was a conversion of land to oil seed production from all four feedstock production areas analyzed, especially regarding rice and cassava in the case of RC group (48.2% and 34.4%, respectively), and cassava and maize in the case of JC group (40% and 31.3%, respectively). These outcomes clearly demonstrate land use change towards oil seed production. These figures are also corroborated by the final feedstock production, per family per year. When one compares the two scenarios, one can observe that the food produced by families, on average, decrease vis-à-vis the adoption of the oil seed activity. As the Table shows, roughly 42% less cassava and 39.2% less rice are produced by families in RC group due to the oil seed activity; and roughly 37% less cassava and 33.9% less maize are produced by families in JC group also due to the oil seed activity, which increases food insecurity of households in the region in question.

Final remarks

Bioenergy and, especially, biodiesel is considered a renewable source of energy not only in Brazil, but also internationally. However, its production might be occurring without much needed caution, especially regarding negative impacts on climate change and on local food security. As presented in this paper, the oil seed production related to *J. curcas* and *R. Communis* has led to a land use change in two ways: (1) land used previously to cultivate crops is now being used to oil seed activity; (2) native forests are being cut down to produce oil seeds. This is especially due to the high opportunity cost of standing forests, as they currently generate no economic value.

Results suggest that the small-scale oil seed production in the region in question began with a carbon debt, since the activity was started up vis-à-vis the deforestation of the native forests. An alternative option could be the implementation of REDD plus or other projects, which encourage the reduction of emissions from deforestation and forest degradation in developing countries. These projects focus on diminishing smallholder opportunity costs through an exchange of payment for environmental services. At COP 15 in Copenhagen, the government of Brazil indicated the nationally appropriate mitigation actions that Brazil intends to take to slow GHG emissions within the country, such as, the reduction in Amazon and Cerrado deforestation. Nevertheless, we strongly suggest that

Table 7
Area and production scenarios with and without the oil seed activity.
Source: Research results (2009).

Activity	*Ricinus communis* producers					*Jatropha curcas* producers				
	Scenario A		Scenario B			Scenario A		Scenario B		
	Mean	SE	Mean	SE	Δ%	Mean	SE	Mean	SE	Δ%
Area (ha)										
Rice	0.30	0.11	0.58	0.14	48.2	1.14	0.19	1.55	0.21	26.4
Maize	1.14	0.27	1.24	0.27	8.0	1.05	0.17	1.53	0.22	31.3
Bean	0.46	0.14	0.62	0.20	25.8	0.40	0.08	0.40	0.08	0
Cassava	0.38	0.11	0.58	0.18	34.4	0.72	0.12	1.20	0.24	40.0
Production (kg)										
Rice	220.80	104.76	363.60	146.39	39.2	688.88	147.77	835.55	139.72	17.5
Maize	1022.00	251.59	1185.33	288.39	13.7	742.61	117.79	1125.03	141.20	33.9
Bean	50.66	19.84	61.33	21.33	17.4	9.56	2.50	9.56	2.50	0
Cassava	157.06	79.78	299.06	170.55	41.7	607.90	172.92	970.86	225.37	37.3

Notes:
SE = standard error of the mean.
Scenario A = current production after the land use change due to adoption of oil seeds activity.
Scenario B = potential production if the oil seeds activity was not adopted and therefore there was no land use change.

REDD plus projects be fostered in the region in question as an instrument for native forest preservation, while concurrently providing an alternative source of income to small-scale farmers.

In addition, the oil seed activity in both sub-study areas diminishes local food production, which might increase food insecurity of families. Roughly 56% of families in the RC group responded positively to food deficits during the year, and at the same time produce 25% less feedstock after adopting the oil seed activity. These outcomes address an important topic for policy and decision makers. Local food production and, therefore, food security should be supported and not harmed with the implementation of a new project.

This study is unprecedented in the region and the results are extremely important in obtaining an appropriate method of regional and national government subsidy for clean energy activity without harming the local environment or food production, therefore, achieving regional sustainable development. Small-scale oil seed production in the Brazilian savannah (Cerrado) can now be better gauged in other parts of the Brazilian Legal Amazon Region because our study highlights one of the most discussed topics in bioenergy debate: oil seed production taking precedence over the preservation of native forests and local food security.

As the present study focuses only at family level in a specific region, we suggest that the study should be continued with larger sample and in the same or in other areas to get a more representative result. In addition, other studies should be carried out considering the biodiesel production at regional and national levels with the aim of attaining a broader idea of the biodiesel production in Brazil.

Acknowledgments

We would like to thank the DAAD (German Academic Exchange Service) for the financial support and Dr. Gautam Dutt and an anonymous referee for much appreciated suggestions on the paper. Any remaining errors are the responsibility of the authors.

References

FAO (Food and Agriculture Organization of the United Nations). 2008a. Bioenergy, food security and sustainability — towards an international framework. Rome, Italy. Available at http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-3-E.pdf (verified 26 October 2009).

FAO (Food and Agriculture Organization of the United Nations). 2008b. Climate change, bioenergy and food security: civil society and private sector perspectives. Rome, Italy. Available at http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-6-E.pdf (verified 26 October 2009).

FAO (Food and Agriculture Organization of the United Nations). 2008c. Climate change, bioenergy and food security: options for decision makers identified by expert meetings. Rome, Italy. Available at http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-5-E.pdf (verified 26 October 2009).

FAO (Food and Agriculture Organization of the United Nations). 2008d. Bioenergy: policy, markets and trade and food security. Rome, Italy. Available at ftp://ftp.fao.org/docrep/fao/meeting/013/ai788e.pdf (verified 26 October 2009).

FAO (Food and Agriculture Organization of the United Nations)/ UNDP/ UNEP. 2009. UN Collaborative Programme on reducing emissions from deforestation and forest degradation in developing countries (UN-REDD). Available at http://www.un-redd.org/ (verified 26 October 2009).

Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Sci Express Rep 2008. doi:10.1126/science.1152747.

Fearnside PM. Desmatamento na Amazônia: dinâmica, impactos e controle. Acta Amazonica 2006;36:395–400.

Fearnside PM, Barbosa RI. Avoided deforestation in Amazonia as a global warming mitigation measure: the case of Mato Grosso. World Resource Rev 2003;15: 352–61.

Finco MVA, Rodrigues W, Rodrigues I. A Amazônia Legal Brasileira e o mercado de créditos de carbono: perspectivas para o Estado do Tocantins. Amazônia: Ciência e Desenvolvimento; 2006. p. 7-24.

Frondel M, Peters J. Biodiesel: a new Oildorado? Energy Policy 2007;35:1675–84.

INPE (Instituto Nacional de Pesquisas Espaciais). Projeto PRODES. 2009. http://www.obt.inpe.br/prodes/. Brazil.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change: synthesis report. Genova.

Jürgens I, Best G, Lipper L. Bioenergy projects for climate change mitigations: eligibility, additionality and baselines. 2nd Conference on biomass for energy, industry and climate protection; 2004. 10–14 May. Rome, Italy.

Merlin, S.; Rezende, D. 2003. Social Carbon. Adding value to sustainable development. Ed. Peiropolis, Brazil.

Nepstad D, et al. The costs and benefits of reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon. Falmouth, USA: The Woods Hole Research Center; 2007.

Rajagopal, D.; Zilberman, D. 2007. Review of environmental, economic and policy aspects of biofuels. Policy research working paper 4341, The World Bank. Available at http://www.wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2007/09/04/000158349_20070904162607/Rendered/PDF/wps4341.pdf (verified 26 October 2009).

Rezende, D. 2000. Seqüestro de carbono: uma experiência concreta. Estudos iniciais do projeto de seqüestro de carbono da Ilha do Bananal e seu entorno. Ecológica Planejamento e Desenvolvimento Ambiental, Canguçu, Centro de Pesquisa, Educação Ambiental e Ecoturismo, FIETO/SESI/SENAI/IEL. Brasil.

Schlamadinger B, Ciccarese L, Dutschke M, Fearnside PM, Brown S, Murdiyarso D. 2004. Should we include avoidance of deforestation in the international response to climate change? Available at http://www.joanneum.at/carboinvent/post2012_/Bird/Schlamadinger_et_al_2004.pdf (verified 26 October 2009).

Schlamadinger B, et al. 14th European biomass conference; 2005. 17–21 October 2005. Paris, France.

Searchinger T, et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land use change. Sci Express Rep 2008;319: 1238–40.

UNFCCC (United Nations Framework Convention on Climate Change). 2009. Reducing Emission from Deforestation and Forest Degradation (REDD). Available at http://www.unfccc.int/methods_science/redd/items/4531.php, and http://www.unfccc.int/documentation/documents/advanced_search/items/3594.php?such=j&symbol="FCCC/AWGLCA/2008/16/Rev.1"#beg (verified 26 December 2009).

Verchot, L.V.; Petkova, E. 2009. The state of REDD negotiations: consensus points, options for moving forward and research needs to support the process. Available at http://www.cifor.cgiar.org/publications/pdf_files/Papers/PVerchot0901.pdf (verified 11 January 2010).