LAND AND WATER REQUIREMENTS FOR SOYBEAN CULTIVATION IN BRAZIL: ENVIRONMENTAL CONSEQUENCES OF FOOD PRODUCTION AND TRADE

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Abstract

The increasing international demand of feed crops for livestock production has made Brazil one of the world´s leading soybean producers and exporters. This paper reviews the trends in water and land requirements needed to produce Brazilian soybean over the decade (2002-2008), and attempts to evaluate the main environmental impacts ascribed to its growing production and exportation. We applied the concepts of land and water footprints and we examined the statistical relationship between soybean expansion and the observed deforestation trends. During the period of investigation, Brazilian soybean production increased by 30% and exports grew by 22%, with the EU-27 and China accounting for 80% of the total exports. Today, 33% of the Brazil's total agricultural land is allocated to the cultivation of this oilseed, and this share will most likely increase as the international demand continues rising. The largest expansion has occurred in the Central-Western states. This regional specialization has contributed to create a more efficient production system by reducing the soybean water and land footprints. However, this regional trend has become the largest driver of current deforestation within the "cerrado" area. Contrary to those who argue that soya expansion is also an indirect driver of Amazon forest clearing, we did not find such relationship. Rather, the large increase in livestock production within Brazil explains Amazon deforestation. Therefore, global markets forces are to a large extent an important explanatory factor of modern deforestation across Brazil, but the increased national demand for meat products represents also a large risk.

Keywords: Water and Land Footprint, Deforestation, Agricultural trade

1. Introduction

Food consumption has increased dramatically worldwide over the last decades. This large demand has been driven by population growth and by the improvement of standard living conditions in many parts of the world (Molden, 2007). Because of the rising incomes, average calorie intake per capita has augmented almost 18% since the 70s from 2400 kcal/day to 2790 kcal/day (Alexandratos, 2006). As per capita income increases, consumers do not only increase their consumption of staple food, but also diversify their diets eating more meat, dairy products and vegetable oil products. This, in turn, amplifies the demand for grains and oilseeds (USDA, 2008). Meat and livestock products have been overall among the fastest growing components of the global agriculture and food industry over the last years (Nelleman et al., 2009; Westhoek et al., 2011). According to the latest UNEP's report on food crisis (Nelleman et al., 2009), just meat consumption is projected to increase worldwide an average of 25% by 2050 (from 37.4 kg/person/year to over 52 kg/person/year).

Future food demand is likely to continue rising, especially in emerging economies where the largest increases in population, urbanization and dietary shifts are expected in the next coming decades (Alexandratos, 2006; Godfray et al., 2010). This growing demand poses an important challenge from a natural resource use perspective. Different studies have provided accurate data on land and water needs required to meet world food demand (Molden, 2007; Rockström et al., 2009; de Faiture and Wilchelns, 2010). Most of them agree that globally there are sufficient land and water resources to meet future food demand, although their geographical availability is unevenly distributed and improvements in productivity are needed throughout the world. The trend over the last decade, however, evidenced that per capita grain consumption has grown faster than yields (*The Economist*, 2010). Options to improve yields still exist, especially in the African continent; however the global rate of yield increase has slowed down compared to previous decades (FAOSTAT, 2011).

In addition to yield improvements, economic globalization and agricultural trade may be part of the transformation to a promising prospect for feeding the world. In many countries where land and water are limiting factors for agricultural expansion, importing food is the only option to ensure adequate food supplies for their population (Falkenmark and Rockstrom, 2010). Recent data shows that world agricultural trade in 2010 grew by 12% (in euro terms) with respect to the pick trade achieved in 2008 (EC, 2011). After the US and EU-27, with roughly equal annual exports of €91-92 bill, Brazil is now third world exporter with €48 bill in 2010, tripling the average value of annual exports during 2000-2002. EU-27 is the largest food importer, €84 bill in 2010, of which 71% comes from developing countries. The EU-27 is importing now €12 bill from Brazil. A large fraction of this flow can be explained by expanding soybean imports, of which nearly 100% come from key the suppliers; Argentina and Brazil for soya cake and Brazil and the US for soybeans.

The rapid growth of the agricultural soybean market in countries like Brazil or Argentina is having a very positive impact in their national economies. However it also raises important concerns because of the environmental and social impacts that large scale agricultural trading could have in the producer countries; and because of the extreme concentration for feed production in just one crop produced in very confined areas. To gain insight into the environmental impacts of food production and trade, this study addresses the implications from a natural resource use perspective of large scale soybean production in Brazil and the trade progress over the last decade.

2. Motivation of the study

Brazilian soybean production increased in the 70s and 80s, but large scale production took off in the late 90s (Figure 1a). Between 2002 and 2008 soya production augmented by 16.5 mill tons (30%) and its national production in 2008 accounted for 26% of the world's production. Brazil is now the second largest producer after the US.

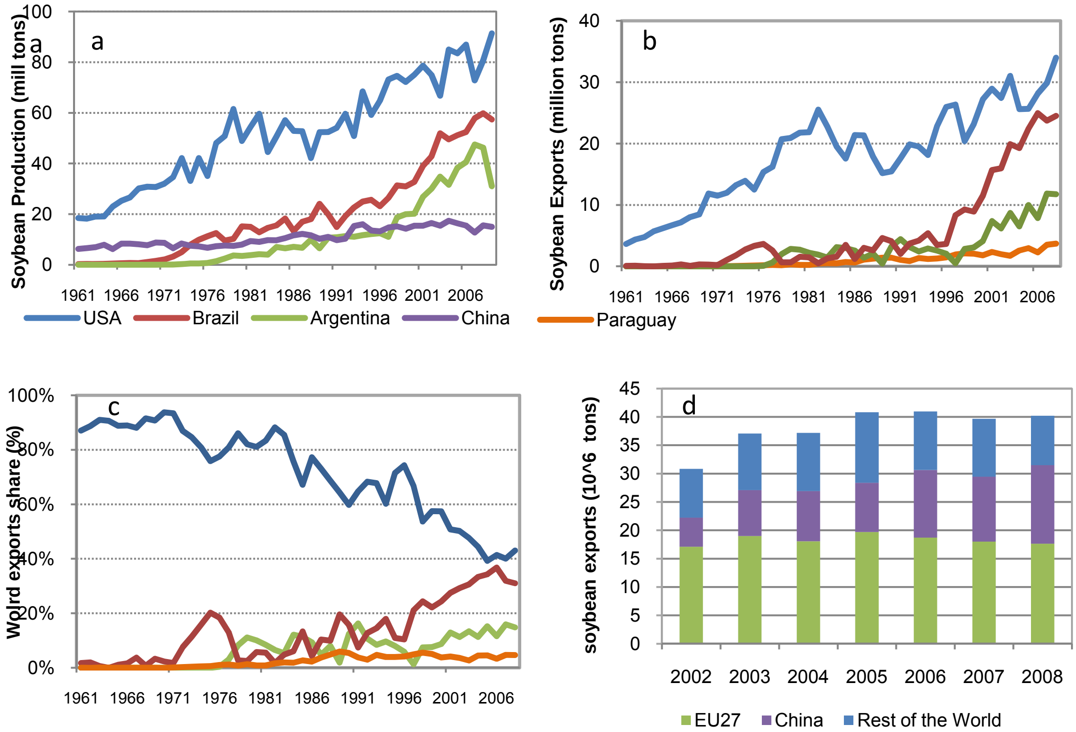

Figure 1 Trends in soybean production and exports in Brazil. *Source*: FAOSTAT (2011); IBGE (2011)

The increase in production went along with the growth of soybean exports (Figure 1b). Until 1996 the Brazilian share of world soybean exports was very small compared to the US, but ever since then it boomed and by 2008 Brazilian exports accounted for almost 66% of its total production. The relative importance of Brazil in world's soybean market is rapidly catching up with the historical market leader, the US (Figure 1c). Brazil's share of world's soybean exports represents now almost 21%.

The EU-27 is the main importer of Brazilian soybean products followed by China (Figure 1d). The rapid economic growth of China has almost tripled the imports of Brazilian soybean products in the last decade. Both China and the EU-27 import large quantities of soybeans because of their rich amino-acid content for animal feeding.

Across the country, the production of soybean is mainly concentrated in the Center-West states (Mato Grosso, Goias, Mato Grosso do Sul) and in the South (Paraná and Rio Grande do Sul) (Figure 2). The Southern states have been the historical production centers due to their better agronomic conditions. However since the 1990s, the production in the Center-West states increased substantially as a result of (The Economist, 2011; Weinhold et al., 2011): 1) the different national policies that have contributed to the development of large scale farm programs on available government land; and 2) the extraordinary technological development making soybean cultivation possible in soils that were originally unsuitable for the production process.

Over the last decade, soybean production has grown especially in Mato Grosso and to a lesser extent in Goias and Mato Grosso do Sul (Figure 2). Mato Grosso alone accounts for 30% of the observed increase between 2002 and 2008. The Southern states of Rio Grande do Sul and Paraná soybean has experienced also a slight increase. These five states account for 80% of the total national production in 2008 (IBGE, 2011).

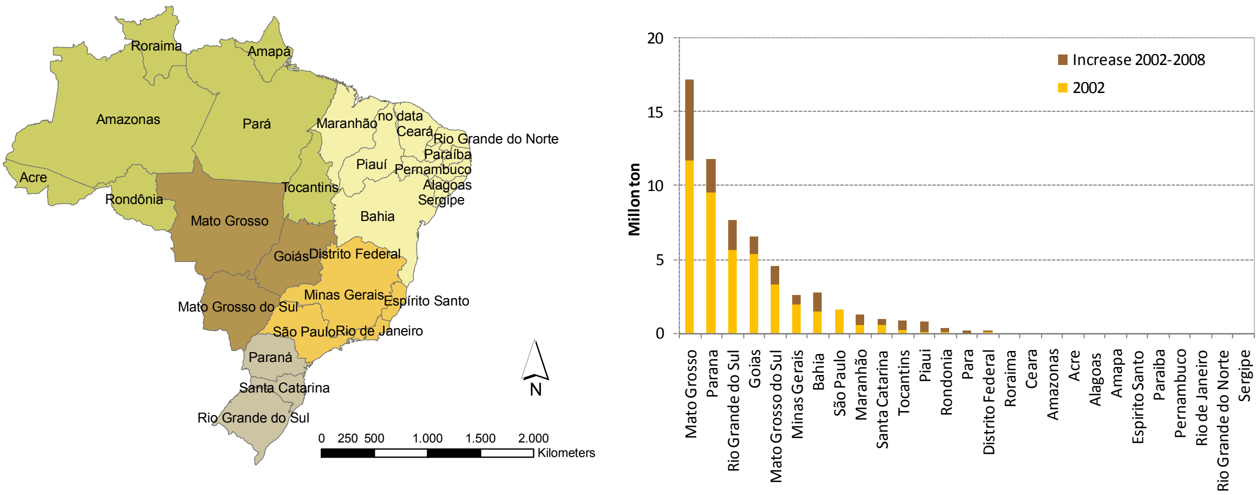

Figure 2. Major Brazilian soybean production areas and regional changes during the last decade (2002-2008). *Source:* IBGE (2011)

Even though Brazil has abundant water and land availabilities, large scale soybean production entails important environmental and social impacts that require a detailed assessment. Fearnside (2001) and Wienhold et al. (2011) have described the social inequalities soya expansion is causing in the major production centers. From an environmental perspective, there is a growing concern on the pressing effect that large scale soybean production is having on the Amazon deforestation (Foley et al., 2007; Nepstad et al., 2006). Some authors argue that much of the recent forest clearing observed in the Amazon region is related to the expanding soybean sector (Morton et al., 2006; Barona et al., 2010; Lapola et al., 2010), but others dispute this claim, arguing that soybeans are expanding into existing pasture land, and therefore not causing new deforestation (Mueller, 2003; Brandao et al., 2005). Most of these studies refer to data and trends observed until 2006, and since then little research has been done to see how soybean expansion has evolved in time. To this end, this paper aims to evaluate the implications soybean production has had in Brazil during the last decade (period 2002-2008) in terms of water and land resources use; how increased production links to the growing international demand; and if the increased production is linked to the deforestation rates observed.

3. Methods

3.1 Water and Land footprints

Annual water and land requirements allocated for soybeans cultivation between 2002 and 2008 were estimated using the water and land footprint indicators. The land footprint (LF) concept was originally introduced by Yang et al (2009) to quantify the amount of land required to produce a unit of biofuel. In the context of this study, the LF index represents the inverse of the agricultural yield, and it has been used to quantify the amount of land needed to produce a unit of product (m^2/ton). Likewise, we estimated the soybean LF of Brazil as the total amount of harvested land per year (km^2/year). Annual data on soya harvested land and production was obtained from the Brazilian National Institute of Geography and Statistics ("Instituto Brasileiro de Geografia e Estatística") (IBGE, 2011).

To estimate the water requirements, we used the water footprint (WF) index. The WF of a product is analogous to the concept of Virtual Water developed by Allan (1998) and quantifies the total amount of freshwater used to produce a good or a service (Hoekstra et al., 2011). Three different water sources of freshwater are considered when quantifying the WF: green water (soil moisture from rainfall); blue water (water from irrigation) and grey water (amount of water polluted by the use of fertilizers).

Accordingly, the WF of Brazilian soybeans refers to the total amount of water embedded in its annual production (hm^3/year). We used Mekonnen et al. (2010) calculations of green, blue and grey WF per unit of soybeans produced (m^3/ton) across the different regions in Brazil to quantify the annual WF of Brazilian soybean production.

3.2 The relationship between soybean production and trade

We examined the interdependencies between Brazilian soybean exports and the agricultural market of the leading importers of soybeans and derived products coming from Brazil. To this end, we first quantified the "external" WF and LF ascribed to the major Brazilian soybean importers. The external footprint refers to the "amount of water and land needed to produce a good that is consumed by the importing country" (after Hoekstra et al. 2011).This approach allowed us to quantify the amount of Brazilian land and water that is being used to satisfy the demand of major importing nations.

We also conducted a simple regression analysis to assess whether livestock production and biofuel production in Europe influenced EU-27 imports of Brazilian soybeans. The relationship between meat consumption in China with Brazilian soya exports was also assessed.

Data on the dynamics of trade from Brazil to the rest of the world were available until 2008 and were obtained from FAOSTAT (2011). Data on European´s biofuel production was provided by Eurostat (2011).

3.3 Environmental impacts of soybean expansion

The environmental implications of soybean expansion in Brazil were assessed by looking at the relationship between the increase in cultivated land for soyabean and the deforestation rates observed within the different producer states. A simple linear regression analysis was performed to quantify this relationship. Since information on deforestation rates was available for the different types of Brazilian biomes (Amazon Forest, Cerrado, Caatinga, Mata Atlantica, Pantanal and Pampa), we conducted a regression analysis for each type of biome to assess the impacts of soyabean expansion separately. Data on deforestation rates per states and type of biome was obtained from "Projeto do Desmatamento dos Biomas Brasileiros por Satélite (PMDBBS)" (MMA, 2009).

4. Results

4.1 National and Regional Footprints

The national soybean LF has increased 41,900 km^2 between 2002 and 2008 (Table 1). This augment means that Brazil is nowadays using 33% of its total agricultural land to grow soybeans. Currently, soybean crops hold the largest share of the total Brazilian agricultural land (IBGE, 2011). The large amount of allocated land together with the increase of the LF indicates Brazil's tendency towards an agricultural specialization.

Table 1. National Land Footprint (LF) of soybean production, period 2002-2008. *Source*: IBGE (2011)

LF	2002	2008
Soybean area (km^2)	163,654	210,573
% Brazil's Agricultural Land	30	33

Figure 3 describes the changes in soybean LF across states. In 2002 the largest agricultural areas devoted to the cultivation of soybeans were located in the Center West states of Mato Grosso and Goias and the Southern states of Rio Grande do Sul and Paraná. The cultivation in the Northern states adjacent to the Amazon region was very small. In 2008 the Center West states (Mato Grosso and Mato Grosso do Sul) have increased their LF (between 5,000 – 20,000 km^2), accounting for almost 50% of the national LF increase. The Amazon bordering states have augmented their LF, so increasing the pressure on the Northern regions.

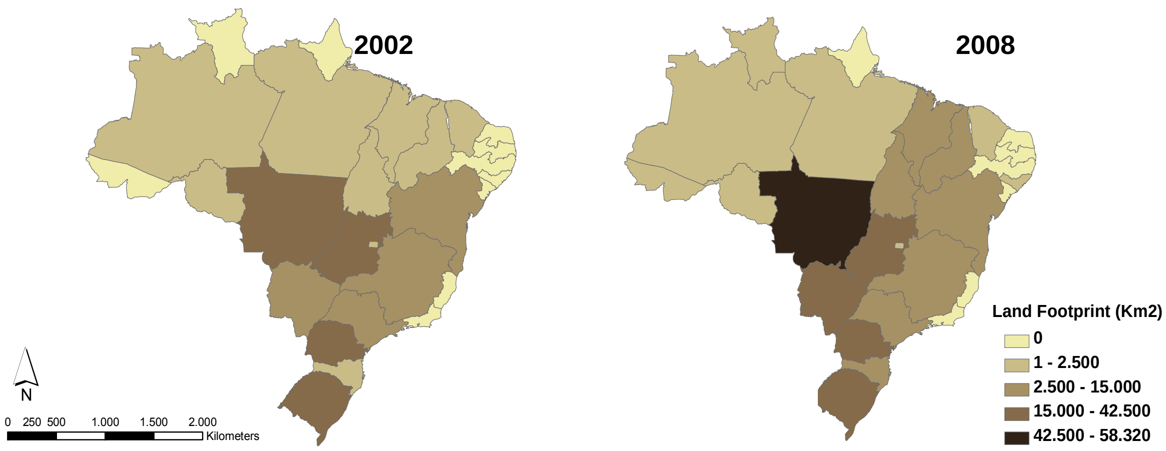

Figure 3. Regional Land Footprint (LF) of soybean production, period 2002-2008. *Source*: IBGE (2011)

The increase in land allocated for soybean cultivation obviously entails a greater consumption of water resources (Table 2). During the period of the study, the national WF of soybean has increased around 35,600 hm^3 (Δ +28%). The largest fraction of the WF in both years is green (± 99%), since soya is mostly cultivated under rain fed conditions. Blue water represents an extremely low fraction (< 1%). Good climatic conditions favor the non-irrigation of this crop, even though in some states small scale irrigation programs have been developed. The grey water footprint also accounts for a very small fraction of the total WF (<1%), although Brazil´s soybean cultivation is highly intensified in terms of herbicide's use. The average amount of water polluted per crop was obtained from Mekonnen et al (2010) and only accounts for the impacts of fertilizers on the water quality, disregarding the effects of herbicides. Since soybeans are legumes with the capacity to fix nitrogen, the amount of fertilizers added are low and so is the overall grey WF.

Table 2. Water Footprint of Brazilian soybean, period 2002-2008. *Source*: Mekonnen et al (2010), IBGE (2011).

WF (hm^3)	2002	2008	%
Green	91,021	126,390	99,3
Blue	40	54	< 1
Grey	632	855	< 1
TOTAL	**91,693**	**127,329**	

Regionally, important differences in WF can be found across states (Figure 4). Green WF represents the largest fraction of the total WF in all states. Blue water is barely used and only Rio do Sul, Paraná, Santa Catarina and Bahia in the eastern coast seem to have developed some small irrigation schemes. The grey water fraction represents less than 1% of the total WF in all states, however these figures probably would have been higher if we had taken into account the impacts of herbicides. According to Fearnside (2001) in states like Mato Grosso soyabean production is highly intensive in terms of herbicide use, causing important impacts on the local biodiversity and streams.

Between 2002 and 2008 the largest increases in soybean WF occurred in the Center-West states of Mato Grosso, Mato Grosso do Sul and Goias. Only Mato Grosso accounts for 30% of the national increase (Δ+12,133 hm^3). The WF in the Southern states has also increased although moderately. The largest augment occurred in Rio Grande do Sul and Paraná. In Sao Paulo the soya WF decreased somewhat (-300 hm^3). The bordering states in the Northern region (Tocatins, Maranhao, Pará and Rondonia) have also experienced a small increase in their WFs (< 1000 hm^3), but are irrelevant compared to the Center-West states. The remaining states along the Western coast have not experienced important changes in their soya WF, since their agricultural activity is mainly oriented towards the production of sugarcane and maize.

The former results indicate that soybean production in Brazil is moving towards a regional specialization from the Southern to the Center West states. From a natural resource use perspective, this specialization is efficient (Table 3). The water and land footprints in the major production areas (Center West) are smaller compared to the other states, even the Southern ones. Likewise, the LF over time has improved in most regions, and particularly the major production centers like Mato Grosso and its nearby states. Compared to the US or Argentina, LF of the Center West states are already highly efficient.

Table 3. Mean Water and Land Footprint for soybean production in the main production states. Source: Mekonnen et al (2010); IBGE (2011)

Region	States	WF (m^3/ton)	LF 2003-2005 (m^2/ton)	LF 2006-2008 (m^2/ton)
Center West	Mato Grosso	1938	3432	3249
	Goias	1938	3739	3451
	Mato Grosso do Sul	2562	4194	3852
	Distrito Federal	1924	3672	3336
	sub-total	2091	3759	3472
South	Paraná	2385	3570	3690
	Rio Grande do Sul	2463	5595	4544
	São Paulo	2385	3887	3729
	Santa Catarina	2463	4347	3764
	sub-total	2424	4350	3932
South East	Minas Gerais	2033	3851	3470
	sub-total	2033	3851	3470
North East	Bahia	1872	4800	3793
	Maranhão	1642	4059	3623
	Piaui	1739	5765	3945
	Ceará	1642	3764	3074
	sub-total	1724	4597	3609
North	Tocantins	1642	4111	3815
	Rondonia	1938	3401	3246
	Para	1726	3532	3485
	Roraima	1895	0	3530
	Amazonas	1895	4426	3337
	sub-total	1819	3868	3559
US			**3941**	**3562**
Argentina			**3891**	**3633**

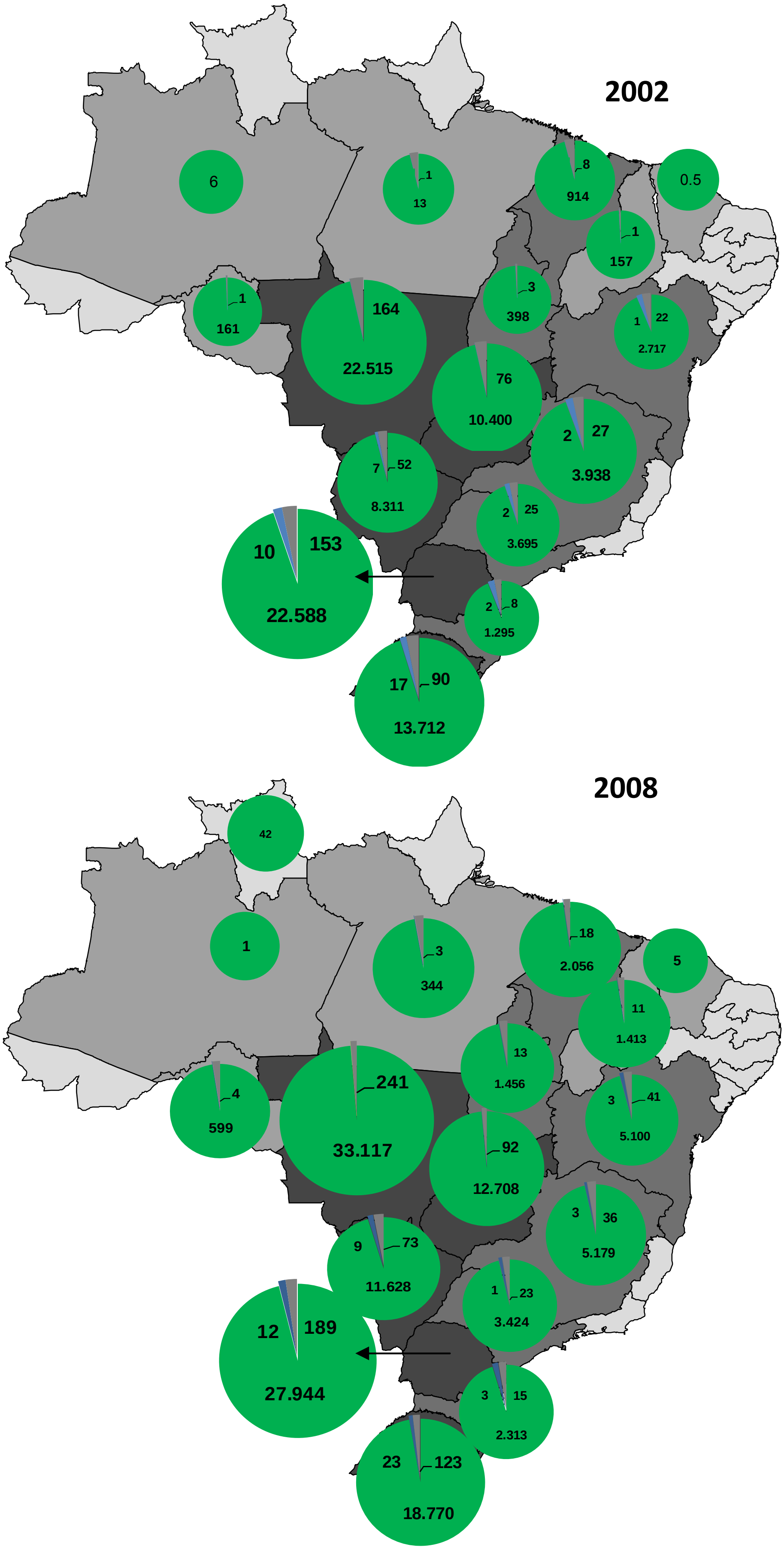

Figure 4. Regional Water Footprint (hm^3) of soybean production 2002-2008.

4.2 Relationship between soybean production and trade

The trends in production and trade of Brazilian soybeans between 2002 and 2008 are described in Figure 5. The drivers of the observed increase (from 42 to 59 mill tons) are twofold: 1) the augment of the international demand, especially of soybeans (exports increased by Δ +8.5 mill tons); and 2) the growth of the national demand (Δ +7.6 mill tons). Exports of soya-derived products like soya oil have also increased slightly (Δ +1 mill tons), although soya cake exports remained stable (Δ -180,000 tons).

Because of the growing national demand, the share of soyabean exports has decreased over time (Figure 5). In 2002 Brazil's exports accounted for 73% of the total production but in 2008 this fraction decreased to 68%. The national consumption has therefore increased during the period of study by 5%.

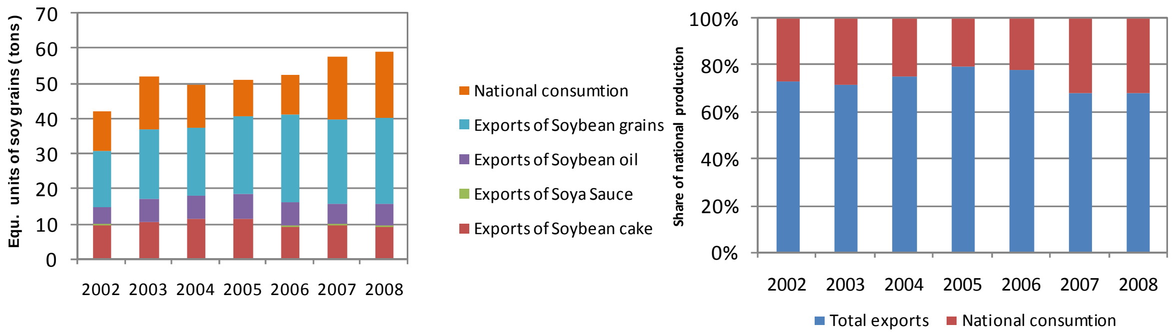

Figure 5. Trends in exports and national consumption of soybean products. Source FAOSTAT(2011)

The increased amount of exports between 2002 and 2008 has been accompanied by a greater allocation of land and water resources for soybean production. In absolute terms, the amount of harvested land used to grow this oilseed for exports grew by 23%, from 130,000 km^2 to 170,000 km^2 (Figure 6). Most of the cultivated land "for exports" satisfies the demand of EU-27 and China, and only a small fraction is exported to the rest of the world (RoW). The external LF of the EU-27 has remained more or less constant during the study period. Between 72,000 and 74,000 km^2 of Brazilian soybean land is used annually to grow soybeans for the EU-27 market. However it is noteworthy that China's external LF has almost tripled between 2002 and 2008 (from 21,000 to 58,000 km^2), indicating its growing importance. The external LF of RoW has remained relatively stable over time (± 36,000 km^2).

Regarding the freshwater use, water allocation for soya exports has increased by 23% (from 61,400 to 80,000 hm^3) (Figure 6). China´s external WF has experienced the largest augment (from 10,200 to 27,600 hm^3). The external WF of the EU27 remained constant (from 34,000 to 35,000 hm^3) as well as the external WF of all the other importing countries.

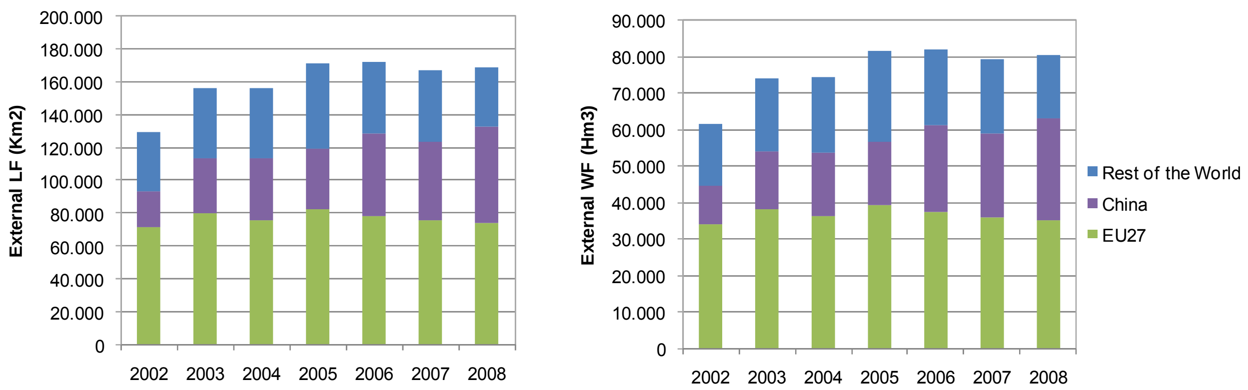

Figure 6. Brazilian water and land exports through soybean trade, period 2002-2008. Source: FAOSTAT (2011)

The above results evidence that most cultivated soybean land in Brazil in 2008 (80%) has been used to satisfy international demand. Consequently, international market forces are currently driving most of the Brazilian soybean production. From the total share of exports, 35% is imported by the EU-27 and 28% to China. The RoW imports the remaining 17%.

The large demand for soybean imports by the EU27 and China is closely related with the increased average intake of calories among other factors. Today, the average annual per-capita EU consumption of meat and dairy products has doubled respect to fifty years ago, although in the last decade consumption has stabilized (Westhoek et al., 2011). Europe is almost self-sufficient in its meat production sector. As meat consumption increased over time, so did the production, which overall resulted in a higher demand for animal feed, partially accommodated by a rapid development and implementation of new agricultural production techniques. However, a clear trend of increasing fodder and feed imports, especially from Latin America, were necessary to meet the European demand. Because of their rich vegetal protein content, soybeans are very suitable for raising animal in confined operations, and this is why they became the most important animal feed import by the EU over the last decades (Westhoek et al., 2011). Although soybean and soya cake imports in the EU27 have stabilized in the last years, imports of soybean oil (used for human consumption and biofuel production) have almost doubled (Figure 7).

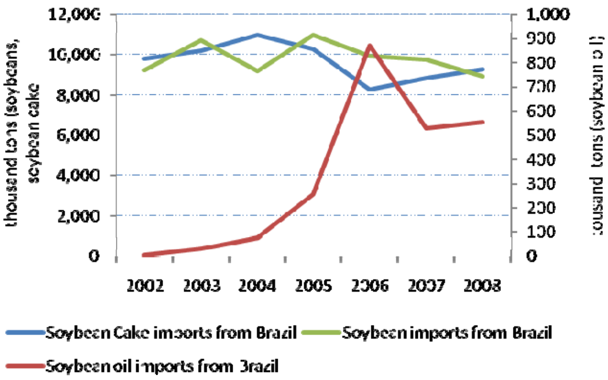

Figure 7. Trends in European soybean (product) imports from Brazil (2002-2008). *Source:* FAO (2011)

There is an ongoing debate over the links between increasing soybean exports and the EU strong demand. As EU trade barriers for soya are almost negligible, the post-2013 CAP is not expected to have a strong impact on the market in terms of improved market access (Bardají et al. 2011). However, the interdependencies can be explained by different influence factors which are discussed below.

(1) European tariff escalation of other import products hampered the demand for more value-added Brazilian products, which in turn boosts soybean demand. This could be one reason for the strong focus on the soybean production for the export market in Brazil. A potential free trade agreement (FTA) between the EU and the Mercosur in the future may affect this condition and shift imports and thus Brazilian production away from soybeans to more profitable products (Dufey et al., 2006).

(2) Brazil has benefited from EU restrictions on genetically modified organisms (GMO) soy imports (especially from US and Argentina), further expanding its market share (Nepstad et al., 2006), supplying 45% of the EU soybean imports in 2002 and even 54% in 2008 (FAOSTAT, 2010).

(3) As EU soya imports are used for domestic animal feed, changes in the EU meat market is also relevant. For our period of investigation the European meat production had stabilized on a very high level. However the European Union’s demand for soybeans as animal feed experienced an upward trend partly due to Europe’s widespread BSE outbreaks at that time. The EU imposed a ban on the feeding of animal-protein-based ration to all livestock in 2001. The resulting shortage of protein for animal ration has been filled primarily by soybean meal (Nepstad et al., 2006). Future EU demand for soya related to the meat market will also be affected by the CAP reform on beef and pigmeat, whose results are likely to differ. On the one hand, beef is a highly protected market and thus the CAP reform is likely to heavily reduce internal production (Bardaji et al. 2011). On the other hand, the EU pigmeat industry is much more market-oriented, and the EU is expected to increase its future

pigmeat production and exports. This in turn is likely to have demand effects for South American soybeans, of which Brazil will probably be the main winner (Dufey et al., 2006).

(4) European energy policy has also influenced the soybean demand in Europe because of the growing importance of the production of crops for bio-energy which was virtually non-existent in the EU some 20 years ago (von Witzke, 2010). It has grown significantly since then and constitutes a significant portion of farming activities in Europe. The amount of biofuel in 2008 is tenfold the amount of 2002 binding agricultural production areas formerly used for feed production (Eurostat, 2011). Thus, the lack of animal feed production can be compensated by soybean imports from Brazil.

When assessing the relationship between meat production in the EU-27 and Brazilian soybean imports between 2002 and 2008, no significant correlation was found (Figure 8a). Meat production has clearly stabilized while soybean imports have fluctuated more over time. However, soy oil imports between 2002 and 2008 are positively correlated with EU-27 biofuel production (Figure 8b). Since Brazilian soy oil is a substitute for European vegetable oil used for bio fuel production, the increase in imports could be explained by lower prices of Brazilian products during the period of the analysis. Indeed, European energy policies might drive future soybean imports, with a high chance of Brazil becoming even more relevant.

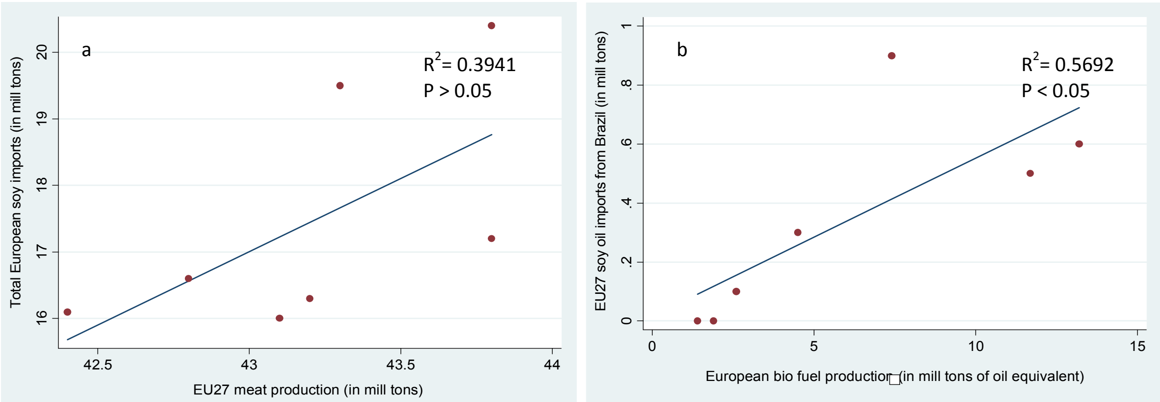

Figure 8. Relationship between EU27 meat production and soybean imports (a) and European bio fuel production and soy oil imports (b), period 2002-2008. *Source:* own elaboration, data: FAO (2011), Eurostat (2011)

In China, however, we found a strong correlation between meat consumption and imports of Brazilian soybeans between 2002 and 2008 (R^2 = 0.866; p < 0.005). The large increase of soybean imports along this period in China is similar to the trend observed within EU before 2005. China´s demand for meat (especially chicken and pork) is the underlying driver of this increase in soybean imports, and it is likely to continue growing in the mid-term.

4.3 Environmental impacts of soybean expansion

Figure 9 shows the deforestation rates registered across Brazil between 2002 and 2008. Overall, 256,000 km^2 of natural land has been cleared. The biome that have mostly been affected are the Amazon forest (-145,000 km^2), especially in the Northern region; and the subtropical savannah forest “Cerrados” (- 85, 000 km^2), particularly of the Center West and Northeast. The remaining biomes have suffered less pressure.

The extent to which agriculture and in particular soybean expansion is responsible for this large natural land clearing is surrounded by controversy. Morton et al (2006) found that forest clearing in the Southern Amazon due to cropland expansion was on average twice the clearing area of pasture land between 2001 and 2004. However, recent studies (Baron et al., 2010; Lapola et al., 2010) have concluded that deforestation in the Amazon region is significantly correlated with the increase in pastures but not with the expansion of soybeans.

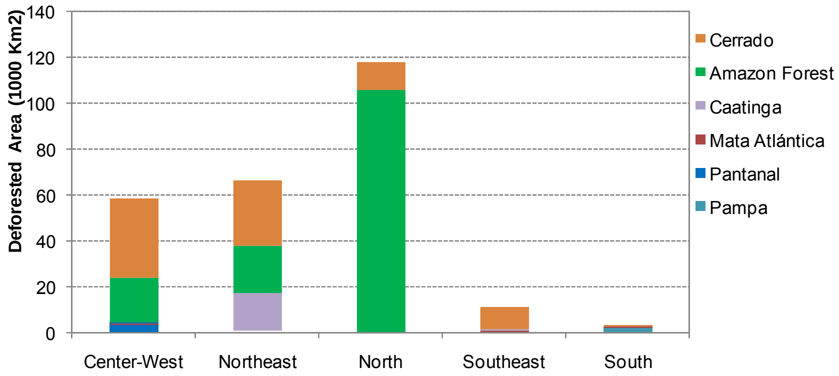

Figure 9. Deforestation rates of the different biome types across Brazilian regions, period 2002-2008. *Source*: MMA (2009).

According to our results, soybean expansion between 2002 and 2008 has significantly contributed to the clearing of the cerrado (Figure 10). Approximately 30% of the new soybean land expanded at the expenses of this natural savannah-type ecosystem. Land cleared in the remaining biomes can't be explained by the increase of soybean land, at least directly.

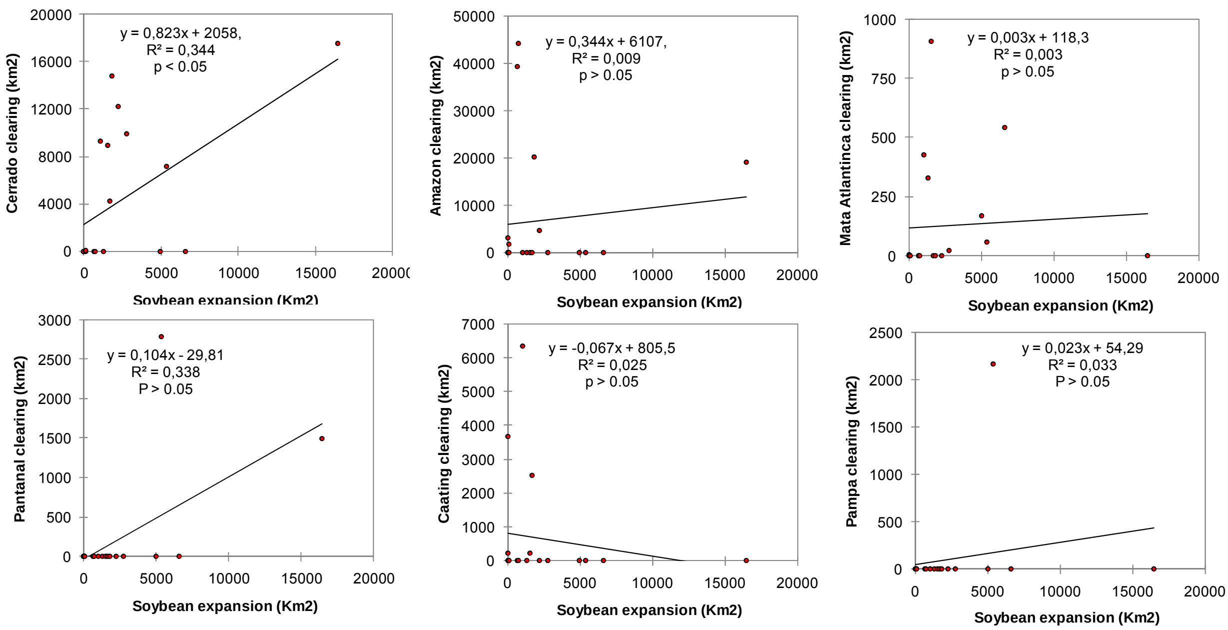

Figure 10. Relationship between soybean expansion and deforestation rates in the different production states (n=20), period 2002-2008. *Source*: IBGE (2011), MMA (2009).

Between 2002 and 2008 Brazil's agricultural land has increased around 112,000 km^2. Compared to the observed deforestation trends, it is clear that besides agricultural expansion other factors are contributing to Brazil´s forest clearing. Several authors have stated that livestock is a major driver of Amazon deforestation through pasture expansion (Barona et al., 2010; Lapola et al., 2010). During the period of our investigation we found a strong relationship between livestock expansion and deforestation rates (Table 4). Bovine is the most important cattle herd in Brazil and it has experienced an important increase between 2002 and 2008 of almost 17 mill heads. Livestock heads have especially increase in the Northern halve of Brazil but also the Center West states, most likely leading to a substantial expansion of cultivated pastures lands at the expenses of native forests. Less than 1% of the annual production is exported (FAOSTAT, 2011), indicating that most livestock in Brazil produced to satisfy the national demand for meat and derived products.

Table 4 Correlation between changes in livestock and deforestation rates across states (n=27) between 2002 and 2008.

Biomes cleared	Bovine Increase
Cerrado	0.380
Amazon Forest	0.782 *
Mata Atlantica	0.030
Pantanal	0.038
Caatinga	-0.005
Pampa	-0.129

*** p < 0.0001**

When quantifying the join effect livestock increase and soybean expansion have had on the overall deforestation observed in Brazil, we found that livestock increase and particularly bovine has been the largest driver of forest loss across the country, above soybean expansion (Table 5).

Table 5 Results of the multiple regression of deforestation against soybean expansion and livestock increases. (R^2 = 0.702; $p < 0.001$; n=27)

Coefficient	Estimate	STd error	t value	Pr > |t|
(Intercept)	371522.321	172552.498	2.153	0,042
Soybean expansion	0.513	0.463	1.107	0,279
Bovine increase	0.777	0.117	6.625	< 0,0001

According to Nepstad et al (2006) the increase of livestock in the Amazon region is indirectly caused by the expansion of soybean in the Center West states, and therefore soybean is an indirect driver of Amazon deforestation. This author argues that high demand for soybeans in the major production centers like Mato Grosso has multiplied land prices by a factor between 5 and 10. This circumstance apparently has stimulated ranchers to sale their valuable land, purchase new land further north and expand their herds into it. However, we did not found an inverse relationship between bovine heads and soybean expansion in the Center West States but a strong positive correlation (Pearson correlation coefficient= 0.94; p< 0.05; n=4). Accordingly, soybean and livestock are both direct drivers of deforestation; soybean generates its larger impact in the cerrado area, while livestock in the Amazon region.

The expansion of the soybean and beef business provides important revenues (soybean around 23,000 mill US$ and beef industry 91,600 mill US$ in 2008) and abundant food at a fair prices nationally and internationally (IBGE 2011). However, it involves large ecosystem service trade-offs with important social and environmental consequences (Foley et al., 2007). The clearing of the cerrado and the Amazon forest is currently the major driver of biodiversity loss in Brazil (Carvalho, 1999). The disappearance of these ecosystems involves the loss of many species but also of its rich genetic pool. Furthermore, tropical and subtropical forest clearing is an important driver of climate change. Since these ecosystems hold a large carbon pool, the loss of their forest cover is currently the major source of GHG emissions in Brazil (Santilli et al., 2005). This effect also leads to soil erosion and the impoverishment of watersheds (Nepstad et al., 2006); alters the regional climate pattern (Gordon et al., 2005); and increases the risk of fire and extreme events (Nepstad et al., 2001).

The underpinning reasons for much of this natural capital loss are closely related with the small opportunity cost currently ascribed to these natural ecosystems. Compared to the direct revenues obtained through soybean cultivation, there are almost no economic incentives to promote forest conservation and sustainable practices in most tropical regions like Brazil. According to Viglizzo and Frank (2006), the shadow price of the cerrado conversion is 30 times higher than the annual revenues obtained from cultivation on these areas. These high economic values highlight the need to find a balance between policies promoting large scale land conversion programs for farming and those who pursue the development of conservation strategies. One example of a policy mechanism aiming at reducing deforestation, while providing an economic incentive to land owners and governments, is the Reduced Emissions from Avoided Deforestation and Degradation (REDD), developed by the United Nations Framework Convention on Climate Change. Since avoiding deforestation is now recognized as the most cost-effective way for mitigating climate change (Canadell and Raupach, 2008), REDD might become a realistic reduction strategy during the next commitment stage. Such instrument could be an interesting incentive for exporting countries, especially in areas of high ecological importance, to promote forest conservation. Measures like REDD would need to be complemented with other policies aiming at increasing agricultural yields on existing land under cultivation.

Lastly, policies aiming at preventing further deforestation would need to take into account the big challenges of globalization, expressed through agricultural trade. In the case of Brazil the largest share of the national soybean production is exported, evidencing the driving force of trade on deforestation in these regions. Therefore, successful future policies aiming at reducing deforestation within countries will not only need to take into account national drivers but also the international market (DeFries et al., 2010).

Conclusions and outlook

In the last decade Brazil has become a major world producer of soybean and a key player in the international agricultural market. The largest fraction of Brazilian soybean is exported to the EU27, although China's imports are growing faster. The national demand has also increased, which overall implies that soybean expansion is expected to continue in the near future.

Brazil allocates now one third of its total agricultural land for cultivating soybean. Since it is mainly grown under rain fed conditions, the largest impacts in terms of natural resource use are related with the land conversions needed for its cultivation. The regional specialization of Brazilian soybean cultivation in the Center West states made more efficient the production system, but it has also contributed to the massive deforestation of the “cerrado” land. Although some studies found that soybean expansion is also an indirect driver of Amazon deforestation because it displaces cattle ranching further into the North, we did not find such a relationship during our period of investigation. Livestock is overall increasing in the North but also in the Center West states, and constitutes the most important driver of Amazon deforestation by itself. Therefore, global markets forces are to a large extent an important driver of modern deforestation across Brazil, but the increased demand for meat products within Brazil represents a larger risk.

As long as the demand for soybean continues increasing it seems difficult to reverse the negative environmental impacts ascribed to this profitable agro-business. Under the current circumstances, it is the capacity of global markets to absorb additional production the most likely limit to soybean current expansion in Brazil (Fearnside, 2001). One way of reducing the current trends of natural capital loss caused by the expansion of soybean is to advance in the understanding and assessment of the opportunity costs ascribed to the conversion of ecological valuable lands such as the cerrado; and the development of economic incentives to promote forest conservation policies. By doing so, there might be opportunities to conciliate economic and environmental objectives.

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