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The expansion of Brazilian agriculture: Soil erosion scenarios

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Abstract

During the next 10 years Brazil's agricultural area will expand to meet increased domestic and worldwide demand for food, fuel, and fiber. Present choices regarding land use will determine to what degree this expansion will have adverse effects that include soil erosion, reservoir siltation, water quality problems, loss of biodiversity and social conflict, especially around indigenous reservations. This paper presents an up-to-date inventory of soil erosion in Brazil caused by crop and livestock activities and provides estimates based on three different hypothetical land-use scenarios to accommodate the expansion of Brazilian agricultural activity by 2020: Scenario 1 – expansion of cropping into areas of natural vegetation, without adoption of conservation practices; Scenario 2 – expansion of cropping into areas of degraded pasture, without adoption of conservation practices; Scenario 3 – expansion of cropping into areas of degraded pasture, together with conservation practices in 100% of the expanded area. The worst-case scenario involves expansion of agriculture into areas of native vegetation in the Brazilian Savannah (Cerrado) and Brazilian rainforest (Amazon) biomes, and could increase total soil erosion in Brazil (currently about 800 million metric tons a year) by as much as 20%. In the best-case scenario, crop expansion under a conservation agriculture model would utilize currently degraded pasture, especially in the Savannah (*circa* 40 million hectares), reducing soil erosion in Brazil by around 20%. For this to occur, however, a national soil and water conservation policy needs to be implemented in Brazil to support a sustainable model of agriculture in which the environment can be preserved as much as possible.

Key Words: Land use, Conservation agriculture, Degraded pasture, Soil and water conservation policy

1 Introduction

The world-wide need for increased food and biofuel production has pointed to a scenario in which the use of natural resources must be greatly increased over coming years (Godfray et al., 2010). Against this backdrop, one of the expected consequences is increased soil erosion and sediment yield, with consequent reduction in the productive capacity of soils, changes to aquatic ecosystems (Allin et al., 2002) and problems involving sediment deposition in reservoirs used for hydropower generation (Campagnoli, 2005). In Brazil, the area under grain cultivation increased by 80% between 1996 and 2006, particularly in areas such as the Cerrado (Brazilian Savannah). On the other hand, there was a decrease in cattle grazing area in almost all Brazilian states except for Amazon, where it increased by 34% (Merten et al., 2010). Amongst the various causes of increased cattle production, the most im-

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portant is the displacement of beef cattle from the Cerrado to the Amazon since pasture areas in the Cerrado can be easily converted to cultivated fields to accommodate soybean expansion (Barona et al. ,2010; Brandão et al. , 2005).

Although the expansion of agri-business has brought many economic benefits to Brazil, there is an environmental cost to be considered if economic growth is to be environmentally and socially sustainable. Large-scale agricultural activity is generally accompanied by changes in the hydrological regime (Chaves et al. , 2008; Costa et al. ,2003), loss of biodiversity (Klink & Machado, 2005), and problems with water quality and soil erosion.

The rate of water erosion in Brazil has been estimated to be between 600 and 800 million t yr^{-1} (Bahia et al. , 1992; Hernani et al. ,2002), but the contributions from different agricultural activities that add up to this enormous amount are not well-understood. The lack of quantitative information about what each activity contributes makes it difficult to define effective polices for erosion control. For example, of the 237 million hectares of Brazil used for agriculture, 60% is under cultivated pasture or natural rangeland, but little attention has been given to erosion problems in pasture areas since there is a general belief among members of the Brazilian scientific community that pasture areas have low rates of erosion (Sparovek et al. ,2007). It is also recognized, however, that Brazil has large areas where pasture is degraded, especially in the Cerrado region.

Although there is no consensus about the size and location of such degraded pastures, values of about 36 million ha (Klink & Machado, 2005; Costa et al. ,2006) have been suggested. Pastures are considered degraded when soil fertility has been exhausted, so that grazing is reduced and invasive plants of low nutritional quality appear (Carvalho et al. ,1990). These areas, especially when found on sandy soils, show clear evidence of erosion channels and gullies linked to the river channel. Restoring degraded pasture to a state of productivity or grain cultivation would contribute not only to reducing the expansion of cattle-ranching into Amazonia but would also allow expansion of national grain production (Freitas & Manzatto, 2002) without the need to convert areas currently under native vegetation. But for this to happen, a model for sustainable agriculture needs to be adopted in Brazil: a model that should not only meet short-term economic goals but which would also take into account social interests, environmental preservation (biodiversity and water resources), and maintain national security (provision of hydropower and food) in the medium and long term. The purpose of this paper is to analyze the dynamics of land use and settlement in agricultural areas of Brazil through an inventory of the contributions of different farming activities to erosion, with consideration of different expansion scenarios in agricultural activity expected over the next ten years. Based on this survey, some suggestions are put forth for the introduction of public policy for sustainable agricultural development.

2 Research methodology

Estimates of water erosion were obtained by using the average values of erosion rates per crop given in Table 1, together with agriculture land use data provided by the Brazilian Geographical and Statistical Institute IBGE (2009). In the case of cotton, sugar-cane, cassava and degraded pasture (Table 2), data on erosion rates were derived from experimental studies outside Brazil, since no other information was available for these crops. Such information was sought, however, for regions with climate and soil similar condition to those of Brazil. For degraded pasture, a value of 12 t ha^{-1} yr^{-1} was based on information shown in Table 2. It can be seen from this table that rates of soil loss from degraded pasture are 30 times greater than those from non-degraded pastures. Thus the erosion rate from degraded pasture was taken to be thirty times greater than the 0. 4 t ha − 1 yr^{-1} found experimentally in Brazil.

The estimated expansion of cultivated area by the year 2020 was based on projections of planned needs for grain and bio-fuel given by Schlesinger (2008). To define land use and soil management in 2020, three scenarios were considered, as well as the present situation:

Table 1 Areas under cultivation in Brazil in 2009, and areas estimated for the year 2020, with erosion rates under cropping systems and soil management, and sources of reference for rates of water erosion

Crop	Cultivated area in 2009 (ha)	Projected cultivated area in 2020 (ha)	Estimated soil erosion using conventional tillage ($t\ ha^{-1}$)	Estimated soil erosion using no-till ($t\ ha^{-1}$)	Source
Soybean[1]	21, 750, 468	35, 750, 468	6. 0	0. 6	Hernani et al. (1999)
Corn	13, 659, 776	14, 000, 000	7. 0	0. 7	Castro et al. (1986)
Beans	4, 099, 991	4, 099, 991	9. 7		Lal (1990)
Rice[2]	1, 436, 018	1, 436, 018	8. 0		Dedecek et al. (1986)
Wheat	2, 430, 253	2, 430, 253	6. 0	0. 6	Hernani et al. (1999)
Sugar cane[3]	8, 514, 365	12, 200, 000	13. 0		El-Swaify & Cooley (1980)
Coffee	2 ,430, 088	2 ,430, 088	4. 0		Prochnow et al. (2005)
Manioc	1, 760, 578	1, 760, 578	8. 5		Lal (1990)
Cultivated forest	5, 560, 203	5, 560, 203	1. 4		Martins (2003)
Pasture	136, 570, 658	136, 570, 658	0. 4		Bertoni & Lombardi (1990)
Degraded pasture[4, 5]	35, 762, 415	15, 406, 556	12. 0		Several authors (see Table 2)
Cotton	811, 686	3, 141, 686	6. 2	3. 0	Lal (1990); Rebich & Knigth (2001)
Tobacco	443, 239	443, 239	17. 2		Merten et al. (2010)
Others	1, 625, 154	1, 625, 154	15. 0		Hernani et al. (2002)

[1] Cultivated area in 2009 given by IBGE (2009) and area in 2020 as estimated by Schlesinger (2008).

[2] Cultivated area of rain-fed rice.

[3] Cultivated area in 2009 given by IBGE (2009) and expansion as given by Schlesinger (2008).

[4] Área of degraded pasture in 2009 estimated by Klink and Machado (2005) and by Costa (2006) for the Amazonian region.

[5] Degraded pastures from 2009 to 2020 are expected to be reduced to accommodate expansion of soybeans, corn, sugar-cane and cotton (FIESP, 2012).

Table 2 Rates of measured soil loss in areas of degraded (D) and non-degraded (ND) pasture in different countries of the world

Place	Biome	Pasture management	Erosion plot size or method	Soil loss ($t\ ha^{-1}$)	Reference
Madagascar	Humid Tropic	ND	watershed	0. 03	Fournier (1967)
Kenya	Savannah	D	watershed	53. 3	Barber (1983)
Kenya	Savannah	ND	watershed	1. 1	Barber (1983)
Texas	Prairie	ND	watershed	0. 012	Bennett et al. (1954)
Wisconsin	Prairie	ND	watershed	0. 22	Bennett et al. (1954)
Nepal	Prairie	D	watershed	35	Fleming (1983)
South Africa	Prairie	D	plots	6. 5	Dlamini et al. (2011)
Zambia	Savannah	ND	Cesio 137	2. 5	Collins et al. (2001)
Kenya	Savannah	ND	watershed	1	Dune (1979)
Brasil	Savannah	ND	plots	0. 1	Dedeseck et al. (1986)
Brasil	Atlantic Forest	ND	plots	0. 4	Bertoni & Lombardi (1990)

D = degraded; ND = non degraded.

a) Scenario 1 – expansion of cropping into areas of natural vegetation, without adoption of conservation practices;

b) Scenario 2 – expansion of cropping into areas of degraded pasture, without adoption of conservation practices;

c) Scenario 3 – expansion of cropping into areas of degraded pasture, together with conservation practices in 100% of the expanded area.

Here, conservation practices are taken to mean a system of soil management based on no-till contour planting, with crop residues of at least 4 t ha^{-1} dry matter preserved, combined with control of surface runoff (Bernardi et al., 2003). In such conditions, expected soil loss is less than 1 t ha^{-1} yr^{-1}.

3 Results and conclusions

3.1 *Total erosion*

The estimated erosion from different crops listed in Tables 1 and 2, and summarized in Table 3, shows that present-day total erosion from cultivated areas of Brazil is approximately 847×10^6 t yr^{-1} (Fig. 1). This Fig. is of the same order of magnitude as that given by authors of other research reports Bahia et al. (1992) and Hernani et al. (2002). However these authors assumed a single rate for all crops (15 t ha^{-1}) and a single rate for all pasture areas (0.4 t ha^{-1}).

Fig. 1 Highly eroded fields in southern Brazil cultivated with no-till, where soil erosion is caused by low residue density, compacted soils and absence of terraces
Source: EMATER-PARANA.

3.2 *Erosion per crop type*

Erosion estimates for each type of crop are given separately in Table 3. It is important to emphasize that the area of degraded pasture (Fig. 2) contributes 50% of total water erosion caused by agricultural activity in Brazil, followed by sugar-cane (13%), soy (8.5%), maize, corn (6%) and non-degraded pasture (6.5%). These results indicate that development of any soil-erosion policy in Brazil requires the inclusion of degraded pasture in any program for research and extension, since it is of fundamental importance if a national program for erosion control and sediment production is to be defined Sparovek et al. (2007).

Sugar cane contributes significantly to the enormous total soil loss (Fig. 3), the main factor in this case being the high rate of erosion (13 t ha^{-1}), rather than the area planted (7×10^6 ha). Soybean has the largest of any crop-

Fig. 2 Termite mounds populate degraded pasture in the Brazilian Savanna
Source: EMBRAPA.

ping areas (21×10^6 ha) but makes only a minor contribution to Brazil's total soil loss. There are two explanations for the smaller contribution from soybean: erosion rates are smaller (6 t ha^{-1}) and no-till planting is used in about 50% of the area planted to soybean and maize, leading to erosion rates lower than 1 t ha^{-1}. It must be emphasized that this value of 1 t ha^{-1} can be expected only if no-till planting is performed according to the recommended practice of planting across the slope, with previous crop residues greater than 4 t ha^{-1} of dry matter maintained in place to control surface runoff. Another important issue to be emphasized is the relative importance of erosion by different crops in different regions. The figures given in Table 3 show the relative importance between crops for Brazil as a whole. It is recognized, however, that the values for each crop may vary from region to region because of differences in soil, topography, climate and systems of soil management. On the other hand, this does not invalidate the proposition advanced in this paper, which is to draw attention to the relative magnitudes of erosion associated with different agricultural activities. The lack of information about erosion rates and sediment yield for the main agricultural cropping systems in Brazil suggests the need to establish a study network in different Brazilian biomes to monitor soil and water loses at different spatial scales. As well as providing information on these erosion rates, such studies would be useful for calibrating and validating mathematical models for estimating soil loss and sediment yield.

3.3 *Erosion by scenario*

The expansion in areas under cropping and livestock production in Brazil is expected to reach 20×10^6 ha in the year 2020, with particular increases for soybean (14×10^6 ha), sugar cane (4×10^6 ha) and cotton (2×10^6 ha). Amongst the possible scenarios, the worst would be the planting of crops on land that has not yet been brought into cultivation, in particular land under original vegetation in the Brazilian savannah (Cerrado). If this were to happen, total erosion in Brazil would increase by about 20%, with adverse effects on natural resources and loss of biodiversity, hydrological change, reduced water quality, and increased release of greenhouse gases from vegetation burned during clearance.

Fig. 3 Severe soil erosion in Mato Grosso do Sul state caused by intense precipitation (120 mm in 40 minutes) in a sugar cane field cultivated using conventional tillage, in which sugar cane residue is totally incorporated into soil
Source: Denizart Bolonhezi.

In Scenario 2, the expansion of agriculture would occur in areas of degraded pasture. The area used for agriculture would remain the same (236×10^6 ha) and total erosion in Brazil would be reduced by 11%, without the need to bring under cultivation any areas presently under natural vegetation.

Scenario 3 would be similar to Scenario 2, but with soil conservation practices used throughout 100% of the areas. Total erosion in Brazil would be reduced by 20%, there would be no additional environmental damage, and no need to clear new areas for cultivation.

The figures given in Table 3 show that it would be possible for Brazilian agriculture to meet projected demands for grain, fiber and bio-fuel by 2020 without expanding agricultural activities into fragile areas such as the Cerrado and Amazon biomes (Scenarios 2 and 3). Furthermore, the different scenarios indicate that it would be possible to actually reduce soil erosion by converting degraded pasture into grain production. It should also be pointed out that this would not require changes to the Brazilian Forest Code BFC Brasil (2013) which have been proposed by some sectors of Brazilian society who argue that this Code needs to be changed to accommodate the expansion of agribusiness in Brazil. The BFC is one of the most advanced pieces of environmental legislation in Brazil. Under it, riparian vegetation is protected by Federal law and cannot be converted to agricultural use. BFC rules also require that all agricultural properties exclude at least 20% of their area from annual crops, or 80% in the northern region. The BFC is important for preserving the nation's rivers, since riparian vegetation increases the resistance of river banks to erosion processes and also reduces the transfer of sediment and pollutants to river channels (McInnis & McIver, 2009) as shown in Fig. 4. The obligation to maintain part of each property free from intensive cultivation allows areas that are most susceptible to erosion to be conserved.

Agriculture occupies 25% of Brazil, and with growing demand for agricultural products in the international

Fig. 4 Riparian vegetation separates a river in Parana state from agricultural fields under conservation management
Source: Gustavo Merten.

market this percentage is expected to be stable in coming years (FIESP, 2012). It has been suggested that extending agricultural activity to more than 20% of areas under natural vegetation could bring about irreversible and adverse environmental changes (Rockstrom et al., 2009) such as, for example, alterations to nitrogen and phosphorus cycles, carbon, and pesticides. Besides the environmental consequences that accompany the expansion of areas producing crops for export, social stresses to the local population are also generated by land use conflict. This happens, for example, when Brazilian agribusiness encroaches on indigenous reserves where Indians have claimed that agricultural activities are polluting the water and destroying the health of stream habitats (Hoffman & Grigera, 2013).

Impacts on water resources arising from agricultural activity in the Cerrado must also be taken into account, since the headwaters of important rivers draining both to the Amazon basin and to the Pantanal region lie within it. In the Pantanal biome, especially, the impacts of agriculture in the Cerrado biome have already been observed, with increased suspended sediment and the presence of agricultural chemicals in Pantanal Rivers (Bordas, 1966). On the map of sediment yield within Brazil the areas with greatest susceptibility to sediment yield lie within the Cerrado. Increased sediment yield in Cerrado Rivers will provoke serious problems of sedimentation in important hydropower plants, both currently in operation and still under construction, in the drainage basins of the rivers Tapajos, Xingu and Tocantins.

Brazil needs to reconcile economic growth with the preservation of natural resources. If this objective is to be attained, it will be necessary to adopt a public policy of conservationist planning for the use of natural resources. Within the context of developing sustainable agriculture in Brazil, the passage of legislation for soil conservation should be considered, along the lines that are now appearing in some Brazilian States such as Paraná and São Paulo, where agricultural activities that lead to soil degradation may be punishable by law. Together with conservationist legislation, the creation of a permanent conservation program for natural resources is needed, to provide technical and financial resources to support of conservationist actions. In the case of agricultural activities, a conservationist agricultural model should be based on the premise that each agricultural holding should have access to a conservation plan approved and overseen by a competent authority. This conservation plan should include demarcation of areas that meet BFC requirements (preservation of riparian environments and of areas most susceptible to erosion), and submission of a conservation plan for cultivated areas. This plan should be based on three fundamental principles: increasing soil cover [by minimizing cultivation (Figs. 5, 6 and 7), use of crops which cover the soil, maintaining forest and pasture], control of surface runoff (by terracing and grass waterways where is necessary); diminished use of agro-chemicals through integrated practices for the control of insects, diseases and invading plants; and control of effluents produced by animal production. To maintain such a program, it will be necessary to create a national budget for the preservation of natural resources, with the power to draw its funding through a tax on a percentage of exported agricultural products (at present, Brazilian law exempts some exported items from payment of tax). Co-ordination of the program should involve the official rural extension service of each Brazilian State. The motivation for farmers to take part in the soil conservation program could be through payments to them, or to watershed associations that would administer environmental services such as maintaining water quality, preservation of water bodies, and reduction of carbon emissions, along the lines of the program "Farming and Water Yields (Agricultor Produtor de Água)" (PAPA, 2013) and "Low-Carbon Agriculture-ABC" (PABC, 2013).

Fig. 5 Soybean planting in the Brazilian Savanna using no-till with millet straw
Source: Eloy Panachuki.

Brazil must be regarded as an important producer of foodstuffs both for its own domestic needs and for the world market as well establishing a national bio-fuels program in order to diversify its energy framework. However, depending on how agricultural expansion occurs, an increase in soil erosion (currently 800 million t yr^{-1}) is expected, with degraded pasture, sugarcane and soybeans (in order of importance) representing the main contributors. The worst-case scenario involves expansion of agriculture into areas of native vegetation in the Brazilian Savannah (Cerrado) and rainforest (Amazon) biomes and could increase total soil erosion in Brazil by as much as

Fig. 6 Soybean plants in Sao Paulo state cultivated with no-till with sugar cane straw
Source: Denizart Bolonhezi.

20% . Under the best-case scenario, crop expansion under a conservation agriculture model would utilize currently degraded pasture, especially in the Savannah (*circa* 40 million hectares), reducing soil erosion in Brazil by around 20% . In this last scenario, in addition to positive benefits in controlling soil erosion, other important environment problems such as deforestation in the Amazon to accommodate beef cattle expansion and destruction of the Savannah to accommodate soy expansion could be averted. For this to occur, however, a national soil and water conservation policy needs be implemented in Brazil to support a sustainable model of agriculture in which the environment can be preserved as much as possible.

Table 3 Estimated erosion from cultivated areas in 2009 and for Scenarios 1 (S1), 2 (S2) and 3 (S3)

Cultures	Soil erosion ($\times 10^6$ t yr^{-1})			
	2009	Scenario 1	Scenario 2	Scenario 3
Soybeans	72	156	150	80
Corn	53	55	55	53
Beans	40	40	40	40
Rice	11	11	11	11
Wheat	8	8	8	8
Sugar cane	111	159	159	159
Coffee	10	13	13	13
Cassava	15	15	15	15
Cultivated forest	8	10	10	10
Pasture	55	55	55	55
Degradated pasture	429	429	185	185
Cotton	5	19	19	12
Tobacco	8	8	8	8
Others	24	24	24	24
Total	848	1,002	752	673

Fig. 7 Sugar cane plants in Sao Paulo state cultivated with no-till using *Crotalaria juncea* as cover crop Source: Denizart Bolonhezi.

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