Global Environmental Change 28 (2014) 84–97

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil

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ARTICLE INFO

Article history:
Received 12 April 2013
Received in revised form 29 May 2014
Accepted 1 June 2014
Available online

Keywords:
Pasturelands
Increasing demand
Agriculture
Sustainable intensification
Land sparing

ABSTRACT

Providing food and other products to a growing human population while safeguarding natural ecosystems and the provision of their services is a significant scientific, social and political challenge. With food demand likely to double over the next four decades, anthropization is already driving climate change and is the principal force behind species extinction, among other environmental impacts. The sustainable intensification of production on current agricultural lands has been suggested as a key solution to the competition for land between agriculture and natural ecosystems. However, few investigations have shown the extent to which these lands can meet projected demands while considering biophysical constraints. Here we investigate the improved use of existing agricultural lands and present insights into avoiding future competition for land. We focus on Brazil, a country projected to experience the largest increase in agricultural production over the next four decades and the richest nation in terrestrial carbon and biodiversity. Using various models and climatic datasets, we produced the first estimate of the carrying capacity of Brazil's 115 million hectares of cultivated pasturelands. We then investigated if the improved use of cultivated pasturelands would free enough land for the expansion of meat, crops, wood and biofuel, respecting biophysical constraints (i.e., terrain, climate) and including climate change impacts. We found that the current productivity of Brazilian cultivated pasturelands is 32–34% of its potential and that increasing productivity to 49–52% of the potential would suffice to meet demands for meat, crops, wood products and biofuels until at least 2040, without further conversion of natural ecosystems. As a result up to 14.3 Gt CO_2 Eq could be mitigated. The fact that the country poised to undergo the largest expansion of agricultural production over the coming decades can do so without further conversion of natural habitats provokes the question whether the same can be true in other regional contexts and, ultimately, at the global scale.

1. Introduction

Driven by the global population increase and the concomitant per capita rise in consumption (Godfray et al., 2010), the global demand for agricultural products is projected to rise over the next decades (Alexandratos and Bruinsma, 2012), likely entailing further competition for land (Smith et al., 2010). Competition for land is transboundary (Lambin and Meyfroidt, 2011; Strassburg

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http://dx.doi.org/10.1016/j.gloenvcha.2014.06.001

et al., 2014) and although demand increase occurs in one part of the world, pressure to provide commodities may be shifted elsewhere. Lambin and Meyfroidt (2011) show that such displacement, amplified by economic globalization, is driving land conversion in developing countries. Indeed, in the 1980s and 1990s, tropical forests were primary sources of new agricultural land (Gibbs et al., 2010). According to projections from the Food and Agriculture Organization of the United Nations (FAO), land under crop cultivation in developing countries may increase by some 110 million hectares by 2050 (FAO, 2006a,b) while others forecast that as much as one billion additional tropical hectares could be converted into cultivated land by 2050 (Tilman et al., 2001). Moreover, land use and land-use change may contribute to 32% of anthropogenic greenhouse gas emissions (IPCC, 2007) and represent the main driving force behind the extinction of species (Baillie et al., 2004).

Currently, nowhere this conflict over land has the magnitude observed in Brazil. Brazil is the world's second-largest agricultural producer, with the largest forecasted increases in output over the next four decades of any country worldwide (FAO, 2006a). At the same time, Brazil is the first deforesting country (55 million hectares over 1990–2010, versus 24 million hectares in second-place Indonesia) (FAO, 2010), the nation richest in forest carbon (63 billion tonnes, versus 33 billion tonnes in Russia) (FAO, 2010) and the most biodiverse country on the planet (56,000 known plant species, versus 29,375 in Indonesia) (UNEP-WCMC, 2010). Brazilian society is currently discussing its plans for forestry and agriculture, and the government has laid out ambitious plans to reduce deforestation and land-use emissions while simultaneously increasing agricultural output (BMA, 2010). However, there are doubts whether recent reductions in Amazon deforestation can be sustained in the future without further plans that include projected demand (Nepstad et al., 2009; Lapola et al., 2014). In addition, there is evidence of increased pressure elsewhere in Brazil through production displacement, especially the Cerrado savanna (Mesquita, 2009). Cerrado is a global biodiversity hotspot, which over the last 15 years has lost 20% of its area (Mesquita, 2009).

Worldwide, sustainably increasing production on current agricultural lands has been proposed as a solution to the conflict between expanding agricultural production and conserving natural ecosystems (Godfray et al., 2010; Herrero et al., 2010; Phalan et al., 2011, 2013; Foresight, 2011; Mueller et al., 2012; Latawiec et al., 2014). It has been shown (Herrero et al., 2010; Lapola et al., 2010; Tilman et al., 2002; Burney et al., 2010) that it is possible to increase agricultural efficiency and mitigate greenhouse gases through resource conservation and improvements in land management.

In this paper, we hypothesise that Brazil existing agricultural lands are enough to sustain production at levels expected to meet future demand (including both internal consumption and exports) for meat, crops, wood and biofuels until 2040 without further conversion of natural habitats. Increasing productivity of pasturelands has been suggested as a promising resource in reconciling agricultural expansion with the reduction of the environmental impacts of agriculture in Brazil (Arima et al., 2011; Bowman et al., 2012; Bustamante et al., 2012). On account of their low productivity and total area (170 million hectares, versus 60 million hectares for crops) pasturelands indeed present an opportunity for sustainable intensification (producing more food from the same area while reducing the environmental impacts; Royal Society of and London, 2009; Godfray et al., 2010). A recent study estimates that the livestock sector holds the largest mitigation potential in Brazil because the emissions from this sector account for approximately half of all Brazilian GHG emissions (Bustamante et al., 2012).

The extent to which sustainable intensification of current pasturelands in Brazil could contribute to meeting future demands for agricultural products (including for exports) while respecting biophysical constraints has not been tested. Here we, first, show the spatial description of current pasture stocking rates (number of animals per unit of area) for Brazil. Second, we estimated the potential productivity of pasturelands expressed as their potential carrying capacity (the stocking rate at the optimum grazing pressure (Mott, 1960) which is consistent with maintaining the pasture productivity) for two climatic datasets and for Brazil's main types of fodder grass, given edaphoclimatic conditions. Third, we allocated future land uses in order to meet demands until 2040. We finally calculated greenhouse gases mitigation potential from avoided deforestation and from improved livestock management. The results presented here are not only relevant in the Brazilian context, but may also have wider implications for land-use decision-making, especially in the developing world. The analysis presented here may also be repeated at other scales to investigate whether the hypothesis tested here is true globally.

2. Materials and methods

2.1. Current productivity of Brazilian cultivated pasturelands

We used spatial data on current cultivated pasturelands from PROBIO land-use classification project (remote sensing data from TM Sensor onboard Landsat, 30-m resolution) (PROBIO, 2009) for the year 2002. We compiled only the polygons classed as 'Ap', or cultivated pasturelands, which totalled 219,122 polygons with a median area of 13 ha. PROBIO polygons are based on visual identification by experts of blocks of the same land-use category and are therefore of varying size and shapes. This totalled to 115.6 million hectares (Supplementary Material, Fig. S1). We did not include 55 million hectares of additional natural pasturelands, which are not mapped (and the topic of intensification in natural pasturelands may be more technically and ethically complex). We combined this information with census data on total cattle heads per municipality to generate a estimate of the current stocking rates in animal units (AU = 454 kg of animal live weight; The Forage and Grazing Terminology Committee, 1991) per hectare to represent the current productivity of Brazilian pasturelands (Fig. 1a) per municipality (so that all "cultivated pasturelands" polygons in the same municipality had the same value). Current productivity was estimated for all 3308 municipalities where PROBIO identified cultivated pasturelands (PROBIO, 2009).

2.2. Sustainable carrying capacity of cultivated pasturelands

A scientific assessment of our hypothesis that Brazil already has enough land under production to meet future demands includes a 'cap' for the number of animals that can be supported without degrading the pasture or requiring supplementary feed (i.e., a sustainable carrying capacity for extensive systems). This type of estimate has not yet been developed for Brazil.

We produced three independent estimates for sustainable carrying capacity, based on estimates for fodder grass herbage accumulation. Fodder accumulation values for Estimates 1 and 2 were based on Tonato et al. (2010) model (with two extra steps added in order to refine it – explained below), whereas Estimate 3 used fodder accumulation data from the Global Agro-Ecological Zones 2009 project (FAO/IIASA, 2010).

2.2.1. Estimate 1

The Tonato et al. (2010) model estimates the Climatic Potential monthly forage (fodder grass) accumulation rates (kg/ha). It was parameterised using data from five field trials performed in the