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Converting Brazil's pastures to cropland: An alternative way to meet sugarcane demand and to spare forestlands

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ABSTRACT

Brazil seeks to rapidly increase its agricultural production to meet future demands, especially for sugarcane, which is an agricultural commodity and a biofuel source. In this paper, we explore how to achieve this increase without compromising existing forestlands. We propose that it is possible to substantially expand sugarcane production in Brazil while avoiding further environmental losses and the indirect land use changes often associated with them, such as deforestation. This task could be accomplished by converting existing pasturelands with agricultural potential into cropland. A great deal of pastureland exists in Brazil. Thus, we addressed the following questions in this study: (1) where are the most suitable pasturelands for sugarcane located geographically and (2) what potential do these pasturelands have for sugarcane production regarding their physical suitability and other significant factors, such as infrastructure availability and socioeconomic factors. We conducted a land suitability analysis using a spatial location model based on multicriteria decision-making and geographic information systems (GIS) to identify the cultivated pasturelands most suitable for conversion to sugarcane production in Brazil. "What if" scenarios were built to determine how changes in the subjectively derived weights of the priority criteria would modify the spatial distribution of the suitability classes relative to the MCDA model and demonstrate the robustness of the crop suitability assessment. The most suitable pastureland areas for conversion to sugarcane production were predominantly located in Minas Gerais, São Paulo, Paraná, Goiás, Mato Grosso do Sul, Mato Grosso and Pará. These zones have large contiguous areas of pasture with moderate and high agricultural potentials for sugarcane production. The total estimated area of cultivated pasturelands with moderate or high suitability for sugarcane production was 50 million hectares, which is much larger than the area currently used for sugarcane production in Brazil.

Introduction

Sugarcane production has been part of Brazil's farming culture since the colonial period and continues to play an important role in Brazilian agriculture. Pioneer ethanol fuel programs were implemented by the government to protect Brazil from global oil crises. Consequently, Brazil has become a major producer of ethanol biofuels from sugarcane. The first attempt to use ethanol as a fuel was made in the 1920s and resulted in little success. However, between the 1930s and the early 1970s, most available petroleum products contained an average of 7.5% ethanol. In the 1970s, the Proálcool program was used to regulate ethanol and petroleum mixtures and increased the average proportion of ethanol to 25%. Although this program was successful, ethanol use began to decrease during the early 1990s. However, after 2003, a second increase in sugarcane production occurred that was strongly related with the insertion of flex fuel cars that use either gasoline or pure ethanol into the national market (Martines-Filho, Burnquist, & Vian, 2006; Rudorff et al., 2010).

Nevertheless, the rebound in sugarcane expansion during the early 2000s was interrupted in 2009 by a decrease in economic activity. This interruption reflected the global financial crisis of 2008, which directly affected sugarcane production and caused the sugarcane industry to rethink their investments. Despite the crisis faced by the sugarcane industry, ethanol production in Brazil is expected to represent 28% of global production by 2021 (OECD-

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FAO, 2012). This trend resulted from the growing demands of renewable energy sources, and Brazil is considered one of the few countries with the potential to produce enough sugarcane to meet both domestic and external biofuel demands (OECD-FAO, 2010). According to agricultural projections for Brazil, the area of sugarcane croplands is expected to increase by approximately 5.6 million hectares (Mha) by 2030 (Lima et al., 2012), primarily in response to increasing demands for ethanol. In addition, the profitability of the sugarcane industry will improve due to technological advances in this sector and economic recovery (Goes, Marra, & Silva, 2008).

However, agricultural growth in Brazil and the substantial potential for agriculture expansion are of concern due to land use practices (FAS, 2003; Fearnside, 2005; Klink & Machado, 2005; Martinelli & Filoso, 2008; Morton et al., 2006; Nepstad et al., 2009; Pardini, De Arruda Bueno, Gardner, Prado, & Metzger, 2010; Peres et al., 2010), which can contribute to further environmental degradation (Carvalho, De Marco Júnior, & Ferreira, 2009; Foley et al., 2007; Schlesinger, Ortiz, Moreno, Bermann, & Teixeira Assis, 2008) and increase the amount of CO_2 emitted into the atmosphere (Fargione, Hill, Tilman, Polasky, & Hawthorne, 2008; Fujisaka et al., 1998; Metzger et al., 2010; Tilman et al., 2009). Therefore, while the outlook for increasing agricultural production in Brazil is improving (BRASIL, 2012; FIESP-ICONE, 2012), Brazil still faces the dual challenge of increasing production and developing agricultural while lowering environmental impacts and not compromising sustainability (Ferreira et al., 2012). Sustainability initiatives are a new theme in agricultural development and have already decreased the rate of deforestation observed in Brazil (INPE, 2012; Nepstad et al., 2014).

Among biofuels, ethanol production has been focused on due to its significant advantages over gasoline (Macedo, Seabra, & Silva, 2008), including lower air pollution due to its more complete combustion relative to petroleum products and reductions in greenhouse gas (GHG) emissions (Goldemberg, 2007, 2008; Goldemberg, Coelho, & Guardabassi, 2008). In addition, a substantial portion of the carbon dioxide produced during ethanol production and consumption is retained in the sugarcane biomass (De Carvalho Macedo, 1992; Seabra, Tao, Chum, & Macedo, 2010). Unfortunately, despite the environmental benefits of using ethanol as a substitute for petroleum derivatives, the use of land for its production could result in greater GHG emissions into the atmosphere rather than reductions due to the emissions that result from land use change (including deforestation) (Cohn et al., 2014; Fargione et al., 2008; Searchinger et al., 2008). In response to this problem, several studies have noted that sustainably produced biofuels in pasturelands can play important roles in reducing GHG emissions by decreasing the demand for forestland (Cohn et al., 2014; FIESP-ICONE, 2012; Lima et al., 2012). Other authors have also mentioned the possibility of expanding sustainable agriculture in Brazil by directing it towards pasturelands with higher agricultural potentials (Sparovek, Barretto, Klug, Papp, & Lino, 2011).

The advantages of producing ethanol as a substitute for petroleum could be maximized further by identifying cultivated pasturelands with the highest potentials for sugarcane production in Brazil, which would prevent the conversion of large areas of forestland to croplands. (1) The need for large and continuous areas of suitable lands for extended mechanization, (2) the proximity of areas to modes of transportation and other types of infrastructure and (3) access to qualified and skilled laborers are all strategic factors that support productivity and farmland growth. Therefore, it is important to investigate where such areas are located geographically and to determine the potentials of the located areas for sugarcane production in Brazil. Thus, the objective of this study is to identify and map the currently cultivated pasturelands that are most suitable for conversion to sugarcane. This objective was achieved using a multicriteria framework combined with GIS to consider the physical suitability of the land and other important factors, such as available infrastructure and socioeconomic criteria, in the modeling process.

Methods

Spatial modeling was based on public data from different information sources for the national territory of Brazil. Soils, climate, topography, land use and biome data were added to a database using ESRI ArcGIS 10 ModelBuilder as a starting point for a multicriteria decision analysis (MCDA) model. Next, other data processing and analysis operations were linked to define the infrastructure accessibility and socioeconomic factors that completed the MCDA model. All original ESRI format map shapefiles were converted to a gridded raster format to conduct map algebra operations. The workflow that the model followed is presented in Fig. 1.

Primary data processing

In this stage, vector map data from government sources were converted to raster data and projected to the South America Lambert Conformal Conic Projection so that all layers had a common geographic map projection and scale in kilometers. A cell size of 90 m × 90 m was used for all layers, making the unit for analysis 0.81 ha. Each grid cell was submitted to a different type of data processing and reclassified to a common scale with values ranging from 1 (unsuitable) to 5 (highly suitable). Soil, climate, topography, biome and land use data were used as input data layers to create the physical land suitability model.

Physical land suitability evaluation

Soil. The soil map of Brazil at a scale of 1:5,000,000 (IBGE, 2001) was interpreted using a qualitative methodology, starting with the general characteristics of the map units based on the combined opinions of experts, which were obtained using surveys. A soil suitability analysis for sugarcane was conducted by a group of experts using a range of values from 0 (maximum restriction) to 9 (highly suitable) that were based on the soil attributes (drainage, fertility and rooting conditions) directly associated with their agricultural suitability (Fig. 2). The soil information enclosed in the map legend classes was ranked based on the soil's capacity for providing nutrients for sugarcane growth and phenology. The geometric mean drainage, fertility and rooting conditions were used as a proxy for determining the attainable yields.

Climate. Precipitation data were obtained from weather station databases to achieve dense coverage of Brazil (ANA, 2005; FAOCLIM, 2001). The National Water Agency (ANA) collects temperature information at irregularly distributed weather stations. Temperature data were interpolated from the meteorological station data to the same grid used in the climate suitability analysis and were corrected for the latitude, longitude and altitude of the stations using linear regression equations (Barretto, 2013).

Precipitation and temperature data points were interpolated using a Voronoi algorithm to predict values at locations that lacked sampling points. This interpolation created a continuous surface for further map analysis. Climatic conditions are a major determinant of crop production and indicate the necessity of irrigation for reducing risks of harvest loss. To evaluate the suitability of climates for sugarcane, the climate components of precipitation and temperature were grouped into zones ranging from 1 (conditionally suitable) to 6 (highly suitable), which represented different aspects of the climate relative to the crop yield. Precipitation and temperature data were reclassified into four classes (from 1 to 4) of suitability for sugarcane production (Table 1).